Westinghouse ENGINEER July 1967

Pure water from brine is the product of experiments with reverse osmosis being conducted at the Westinghouse Research Laboratories. Water molecules pass through a semipermeable membrane in this process, but the salt is left behind. The development work is aimed primarily at purification of water of relatively low salt content—"brackish" water.

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Cover design: A thyristor—the basic element in a solid-state dc power supply—and a dc motor are the symbols combined by artist Tom Ruddy in this month's cover. The relationships between these two useful devices are discussed in the article that follows.

The DC Motor and the Thyristor Power Supply

V. E. Vrana

The dc power output of the thyristor power supply has significant differences from that of the dc generator. But when these differences are properly accommodated in a drive system, the result is a variable-speed dc-motor system that is efficient and trouble-free and has a number of advantages over systems employing generators.

The dc motor has been powered by the dc generator so successfully and so long—nearly a century—that the relationships between the two are well understood and are allowed for in motor application. Now, however, a completely different source of dc power, the thyristor power supply, is being used to eliminate the disadvantages of generators in many applications, and so a new set of relationships applies between motor and power supply.

The basic difference between the two dc power supplies is the amount of voltage and current ripple in the output. The thyristor power supply (TPS) has more output ripple than the dc generator (although the amount varies greatly with the type of TPS and how it is applied). Consequently, the motor needs to be designed and applied properly with the TPS to prevent possible problems with motor commutation and excessive motor heating. Application is simple once the principles are understood. Before outlining the principles, though, it is necessary to understand why the TPS is so attractive for many uses, what the different types of TPS are, how the outputs of these types differ, and how output affects motor application.

TPS Versus DC Generator

The essential advantages of the TPS over the dc generator are: less maintenance requirements; higher efficiency and therefore lower power costs; small size, less weight, and lower installation cost; and faster response, permitting system response time to be limited only by the motor commutating ability and the inertia of the drive. The lower maintenance requirements stem mainly from static operation. Although the modern dc generator is a rugged and dependable power supply, its bearings require maintenance, its commutator is subject to wear and flashover and requires careful handling and maintenance, its brushes need to be replaced periodically, its armature is vulnerable to insulation breakdown, and commutation can be a problem.

The TPS also has some disadvantages, of course. The main one is the higher ripple content of its output (especially with some types), which contributes to motor heating and commutation problems. Also, power factor is not as good as that of an m-g set. The advantage of power-factor correction of the synchronous-drive m-g set is lost, as well as the inherent ability of any m-g set to regenerate. Overload capability of a TPS is not as great as that of a dc generator. Moreover, distortion of the input ac supply is an inevitable property of rectifiers and therefore of the TPS, even if the dc current ripple content is very small. As the gating angle is increased, distortion becomes worse; it can cause false firing in other power supplies connected to the same line, as well as heating in ac motors connected to the line.

However, most of these difficulties can be overcome by properly applying and designing power supplies and motors, and a very satisfactory drive system then results. Power supply and motor must be matched, an isolation transformer may be required, and smoothing inductance may be required in series with the motor supply lines. The advantages outweigh the disadvantages in so many applications that more and more TPS capacity will be installed in place of m-g sets as power sources for dc-motor drive systems.

Basic TPS Types

Many types and application methods have been developed in both single-phase and three-phase systems, so it is not possible to generalize broadly. However, the basic types are briefly described here, with their wave shapes and typical uses.

Single-Phase Half-Wave TPS—This is the simplest TPS (Fig. 1). It is used for the most part in fractional-horsepower variable-voltage drives where operation below base speed is desired; examples are precise moving and positioning drives for various industrial processes, and special feed drives for lathes and boring mills.

The isolation transformer shown in the figure permits matching the power supply input voltage with that of the dc motor, and it adds some inductance to the circuit that helps with commutation in the motor. It also limits rate of current change during commutation (current transfer) within the converter, improving the dc wave form. The isolation transformer is omitted in some of the less expensive drives or replaced with an autotransformer.

Gating angle (α) is the instantaneous point in the ac cycle at which the thyristor is turned on. As gating angle is increased, the output voltage of the TPS is decreased because, as can be seen, the area under the sine wave is being reduced. Gating angle is adjustable in a TPS to make an adjustable-voltage power supply and, thereby, a variable-speed drive through motor armature voltage control.

A "free-wheeling diode" is connected in parallel with the load. It carries current from the load, bypassing the power supply, whenever the direct voltage of the TPS falls to zero. This current flow occurs only at the higher values of gating

1—Single-phase half-wave thyristor power supply (TPS) is the simplest type. It rectifies the input ac power and, because the point at which the thyristor is turned on is controllable, output voltage is controllable. The resulting adjustable-voltage power gives the connected dc motor variable-speed capability. Form factor of the output voltage wave is poor (that is, it contains much voltage and current ripple), which tends to cause motor heating and commutation problems. Practical application of this TPS is restricted to fractional-horsepower motors.

2—Single-phase bridge semiconverter TPS provides a voltage wave with twice the area of that from a single-phase half-wave TPS. Form factor is consequently much better.

3—Three-phase bridge semiconverter provides still better form factor because its output is made of a number of pieces of three input ac line voltages.

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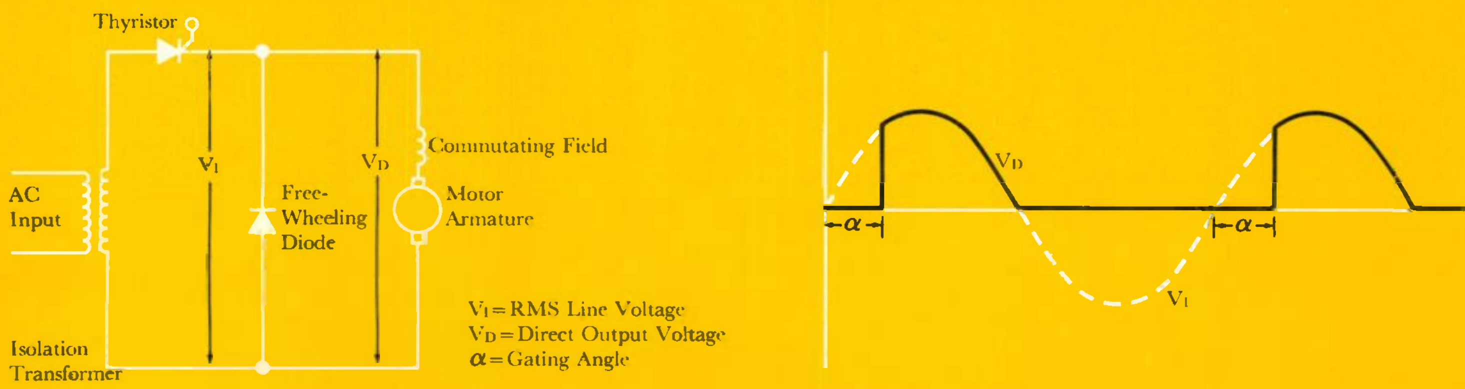
Thyristor
Commutating Field
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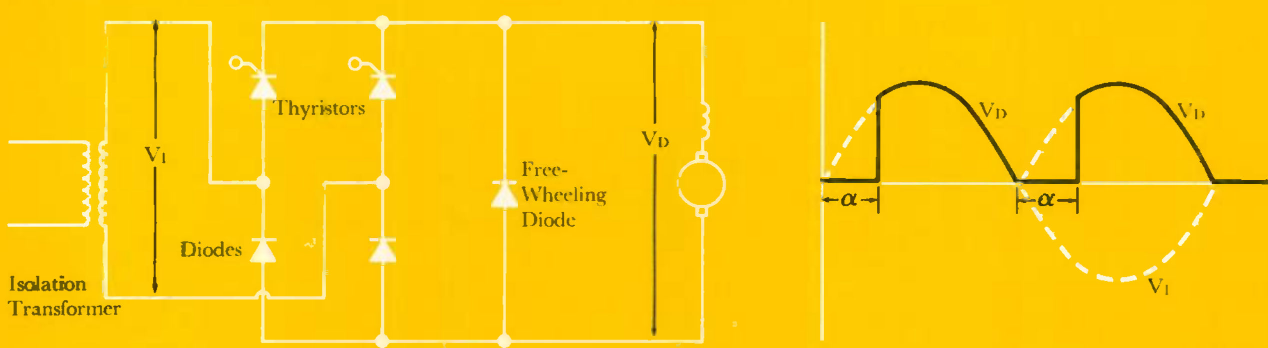
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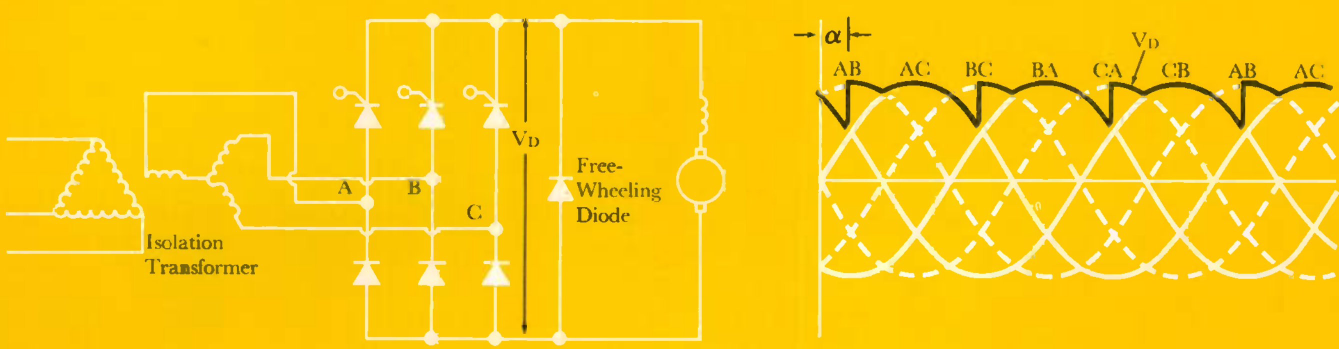
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angle and is due to the inductive effect of the motor armature circuit and any other external inductance that may be used. The inductance continues the current flow in the original direction, and this flow would normally be against the negative electromotive force of the line. Because the free-wheeling diode is able to carry the load current with very low voltage drop, the current takes this path through the diode rather than the path through the thyristor. This occurs whenever the dc voltage wave goes to zero because at this point the polarity of the free-wheeling diode is reversed by the action of the circuit inductance, forcing it to conduct. The current is conducted through the free-wheeling diode until the next pulse of direct voltage, if the current is continuous, or it is at least prolonged if the current is discontinuous. This next voltage pulse occurs the next time the thyristor is gated in a single-phase half-wave power supply or when the next thyristor is gated in a single-phase or three-phase bridge semiconverter.

The form factor of the dc output of a single-phase half-wave TPS is the poorest of the power supplies considered here. Form factor is defined as the ratio of the effective or rms voltage (or current) to the average value of voltage (or current). For the voltage wave, form factor is a function of gating angle and load current. For the current wave, form factor is governed by the voltage wave form, the inductance of the circuit, and the load current; it varies from motor to motor. A high form factor, with its high peak-to-peak ripple, results in motor heating and commutation problems, and these factors restrict economic use of the half-wave power supply to fractional-horsepower motors because larger motors would have to be greatly oversized or derated for reasons explained later.

Single-Phase Bridge Semiconverter—Bridge circuits reduce the voltage stress applied to the thyristors to just half the voltage applied in center-tap circuits for the same output dc voltage. Thus, they permit use of thyristors of lower voltage rating than would otherwise be needed. They are the preferred choice in TPS design for that reason and because their wave forms are better. All of the following circuits are bridge types, and it is the type assumed in the rest of this article.

The single-phase bridge TPS provides a voltage wave with just twice the area of the wave from the corresponding half-wave power supply for the same gating angle (Fig. 2). This characteristic improves the form factor.

The single-phase bridge TPS is used in the range of one to four horsepower wherever an adjustable-voltage source of dc power is required. Examples are table drives for metallurgical furnaces and feed drives for planer-miller machines.

Three-Phase Bridge Semiconverter—This TPS consists of a rectifier bridge with three thyristors on one side of the line and three diodes on the other side, with a free-wheeling diode across the output (Fig. 3). Its dc output voltage is made up of a number of "pieces" of the three-phase ac line voltages. In the example illustrated, which is for a gating angle of $\alpha = 30$ degrees, the dc output is made up of six pieces of voltage wave per cycle. This is the pattern up to $\alpha = 60$ degrees, after which the first hump of the dc wave vanishes and only the second part remains. From that point on, this pattern gives the three pulses or pieces per cycle that is characteristic of the three-phase bridge semiconverter.

Gating angle, or phase-back angle as it is also called, is arbitrarily referred to the earliest possible thyristor turn-on point in the three-phase full-wave bridge output wave form. The form factor of the dc current in the load is a function of the gating angle and the inductance of the load circuit. As the gating angle is increased, the voltage output of the power supply is decreased and the form factor gets poorer until a maximum form factor is reached at $\alpha = 90$ degrees.

The semiconverter TPS is widely used in small to medium-power industrial drives such as the Westinghouse Mod-U-Pak drive. Typical applications are in machine tools, such paper-converting equipment as corrugators and box-board machines, and textile mill applications including slasher and range drives.

Three-Phase Bridge Full Converter—This is the finest of the power supply designs discussed here, and it is the one used in the Westinghouse M-4 and M-5 power supplies.[1] It is used for more demanding and higher-power applications than the semiconverter.

The circuit is similar to that of the semiconverter except that all six devices are thyristors and no free-wheeling diode is used (Fig. 4). Its direct output voltage is made up of six pulses per cycle; the wave pictured is for a gating angle of $\alpha = 30$ degrees.

The current wave from the full converter is better than that from the semiconverter (Fig. 5). It is smoother in that ripple content is less, so it more nearly approaches straight direct current. (The term "straight direct current" in this article means the type of current produced by a conventional dc generator.) It is for this reason that the dc motor prefers the output of the full converter to that of the semiconverter.

Three-phase bridge full converters are used as drive power supplies in many process lines such as steel galvanizing, shearing, and pickling lines. They are also used to power main drives for such machinery as metal rolling mills, paper machines, and supercalenders.

Which Voltage?

No standards have been defined as yet for motor terminal voltages to use when the motor is applied to a TPS. Voltages being used or proposed for the three-phase power supplies are 240, 480, 500, 520,

[1]Stringer, L. F., and Tresino, L. R., "Thyristor-Power DC Drive Systems," *Westinghouse ENGINEER*, September 1966, pp. 154-160.

4—Three-phase bridge full converter has still smoother output. All six rectifier devices are thyristors, so the output voltage is made up of six pulses per cycle. This type is used for the more demanding and higher-power applications.

5—Comparison of actual voltage and current wave forms of a three-phase bridge semiconverter and a full converter illustrates the relative smoothness of the latter. The oscillograms were made with each TPS providing 360 amperes and 200 volts to the same motor at the same load. Frequency and magnitude of ripple in a TPS output are functions of the bridge connection used (semiconverter or full converter) and the phase angle at which the ac input is switched on.

and 550 volts; it appears that NEMA may standardize on 240 and 500 volts. Power supply manufacturers prefer the higher voltages because higher-voltage power supplies are less expensive to manufacture and are smaller than the higher-current ratings that would be required at lower voltage for the same horsepower. The reason is that as the current rating goes up the thyristors have to be paralleled, which complicates the gating circuits and adds to the cost. On the other hand, motor designers prefer the lower voltages, especially 240 volts. Use of 240-volt motors offers two basic advantages.

First, the voltage is already standard, and many present 240-volt motors can be applied to the TPS even though the rating may have to be reduced as will be explained later.

Second, and even more important, commutation is made easier. Using higher voltages forces the bar-turn combination of the armature upward. (Bar-turn combination is the product of the number of commutator bars and the turns per coil in the armature divided by half the number of paths or circuits through the armature.) For some ratings, bars cannot be added, so higher voltage requires the use of wave-wound armatures instead of lap-wound, two-turn armature coils instead of one-turn, three turns instead of two turns, and so on in the development of a line of armatures. Armatures having commutators with an abnormally high number of bars are more expensive than standard armatures. For ratings not requiring high-bar commutators, cost is not much greater than that of standard motors because, while the two- or three-turn coil is more expensive than the one-turn, the wave-wound armature is less expensive than the lap-wound.

The higher bar-turn armature combinations make commutation more difficult, which limits the weak-field speed range. Commutating ability of a motor is based on the reactance voltage developed in the armature coil undergoing commutation, and this voltage is equal to a constant multiplied by the product of armature current and speed. For example, compare the reactance voltage of a 240- and a 480-volt motor. Armature current of the 480-volt motor is half that of the 240-volt motor, but the constant increases directly as the product of the number of commutator bars and the square of the armature turns per coil and inversely as

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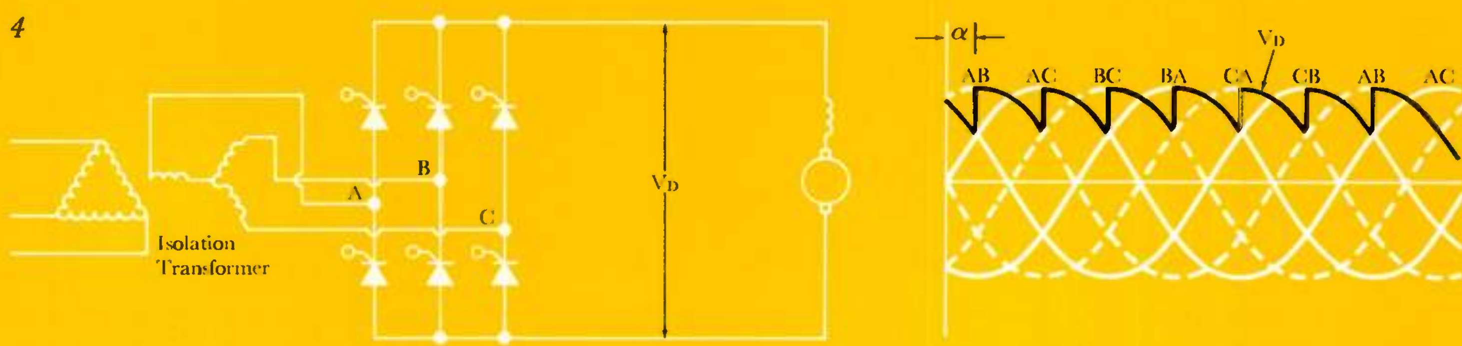

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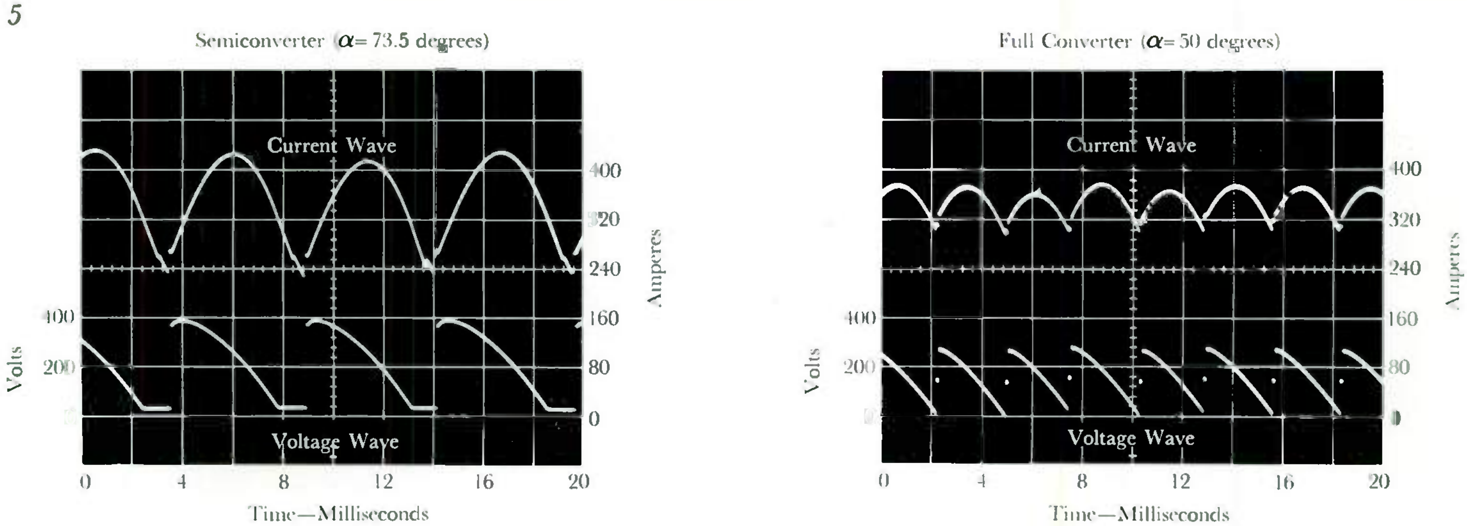


the square of the number of circuits through the armature:

$$E_c \sim \frac{BT^2}{a^2} I_a n$$

where E_c is reactance voltage, B is number of commutator bars, T is number of armature turns per coil, a is number of circuits through the armature (i.e., four for a four-pole lap-wound armature and two for a wave-wound armature), I_a is armature current, and n is speed in rpm.

There are two possibilities, assuming that both the 240-volt and the 480-volt motor would be built on a wave-wound armature (as they would at about 100 horsepower and below). If it is physically possible to double the number of commutator bars, that is the thing to do because then the reactance voltage remains constant since half armature current is being multiplied by twice the number of commutator bars, the turns remaining constant. For instance, a standard motor may have an armature with a bar-turn combination of 93 bars and two turns per coil, with the result that it may have a reactance voltage too high for acceptable commutation. Redesigning the armature with 185 bars and one turn per coil gives a much better design.

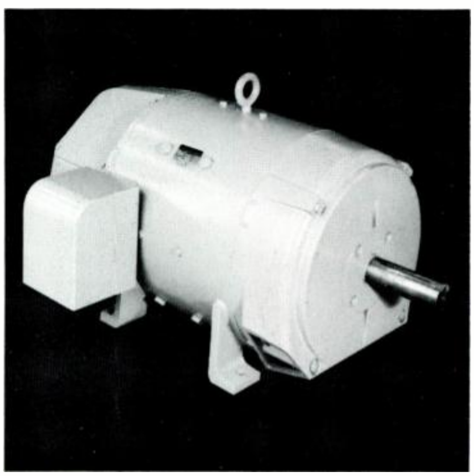
However, it seldom is physically possible to double the number of commutator bars, so the number of turns must be doubled. Since the turns are squared in the above proportionality, half armature current is being multiplied by two squared, doubling the reactance voltage.

Reactance voltage of the 480-volt armature would then be twice that of the 240-volt armature for a motor of the same horsepower and speed. This means that the weak-field speed of the 480-volt motor would be limited to half the weak-field speed of the 240-volt motor if the reactance voltage is to be held to the same limit.

In some medium-size motors where fractional-turn armatures are possible, the number of commutator bars can be increased to the maximum obtainable on the commutator and the turns increased by the required amount so as to maintain the desired bar-turn combination on the armature. These armatures produce a reactance voltage somewhere between the two cases discussed above, depending on the relative increase of commutator bars to armature coil turns. Many combinations are possible.

Maintaining weak-field speed capability requires the use of oversize frames. For example, a 25-horsepower 240-volt 850-rpm motor operating on either straight direct current or a full-converter TPS has a weak-field speed range to 2400 rpm and is normally built on frame 404A. With a semiconverter power supply, at 480 volts it is built on frame 405A and at 550 volts on frame 444A, and its weak-field speed is only 1700 rpm. In this example, then, use of the higher voltages with a semiconverter power supply forces frame size up one and two frames respectively but, even so, weak-field speed capability is considerably lessened.

When a transformer is not used in applying a semiconverter TPS to a dc motor, great care must be taken to match the power supply and motor properly. It is generally not proper to merely apply the TPS to, for example, a 550-volt motor and then, by phasing it back, use it also for a 500-volt, 480 volt, or 240-volt motor as well. Severe commutation difficulties may result due to the high rate of change of armature current that occurs. (This effect is explained later.) Thus, there must be mutual understanding and coordination between motor and power-supply designers.



Typical dc motor for use with thyristor power supplies. Machines of all sizes and speeds are being supplied daily by the Motor and Gearing Division for use with both semiconverters and full converters. Voltage ratings supplied are 240, 480, 500, and 550.

More About Commutation

Without doubt, the most important consideration in designing motors for use with a TPS is commutation. Commutation is more critical when operating from a TPS than from straight direct current, especially when the TPS is a semiconverter and no isolation transformer nor line inductance is used. The reason is the larger value of $L\frac{di}{dt}$, voltage of self induction due to current rate of change. (See *Effects of Voltage Ripple on Motor Operation* at right.)

The value of $L\frac{di}{dt}$, can be reduced in two ways:

1) Pick the voltage rating of the motor as high as possible, approaching a value of about 1.3 times nominal ac line voltage. At this point, the power supply would be operating at a near-maximum conduction angle and minimum gating angle. An example of this approach is the use of a 550-volt motor for operation from a 460-volt line.

2) Reduce the ac voltage supplied to the power supply, maintaining a relationship similar to that just specified. This can be done by using a transformer for the power supply input. The Westinghouse Mod-U-Pak, for example, uses 400 volts ac for a 480-volt dc motor.

The reason a large $L\frac{di}{dt}$ is detrimental to good commutation is that it invariably results in very high $\frac{di}{dt}$ change in armature current. This current change takes place in the armature circuit but, because of the induced eddy currents in the iron parts of the commutating pole magnetic circuit, which oppose the change of the commutating pole flux, the commutating pole flux cannot follow the current change. The result is that ideal compensation for commutation does not take place. The commutating pole is undercompensated on current rise and overcompensated on current decay. For that reason, the spark observed is not as harmful to brushes and commutator as a corresponding spark when the motor is operated on straight dc. This is because, at some point between under and over compensation, the amount of uncompensated reactance voltage is zero and no spark results, although the observer's persistence of vision makes him think he sees a spark. Only prolonged operation will show whether or not a given spark deteriorates the commutator.

Because the value of current rate of change can be reduced by increasing inductance in the armature circuit, a logical request might be to "build a highly inductive motor." Unfortunately, that is not as easily accomplished as it sounds and, moreover, high inductance in the motor itself is detrimental to its performance. Inductances of motors of the same rating (horsepower, voltage, speed) do not vary much regardless of manufacturer or designer. Even if a deliberate attempt were made to increase inductance, there would not be much change. Any attempt to increase inductance brings a sacrifice in commutating ability. For instance, inductance can be increased by designing a narrow deep armature slot, but the reactance voltage of commutation would be increased with the result that the motor would not commutate satisfactorily even on straight direct current. (Conversely, a shallow wide slot reduces inductance of the armature circuit and at the same time produces a motor of superior commutating ability.)

Thus, where rate of change of current is too high and increased inductance is necessary, it must be supplied externally to the motor. It can be either a series inductance in the armature circuit or a transformer with high leakage reactance for the TPS input.

To summarize, then, a dc motor for use with a TPS must be the best sort of motor —that is, one with superior commutating ability. This is especially true when a semiconverter TPS without an isolation transformer is used. However, for such power supplies as the Westinghouse M4 and M5, which are full converters with isolation transformers, and the Mod-U-Pak, which is a semiconverter with an autotransformer, coordination reviews indicate that near-standard dc motors are frequently satisfactory.

Superior commutating ability can be achieved by using more bars in the commutator and thereby reducing armature turns per coil. If it is physically impossible to put enough bars in the commutator, then the frame size has to be increased to reduce reactance voltage. Special brush grades, or special brushes with several wafers of carbon in two different brush grades, may be required to obtain acceptable commutation. Each of these modifications adds to the cost of the motor.

Effects of Voltage Ripple on Motor Operation

The basic voltage equation for a dc motor is

$$V_D = L\frac{di}{dt} + E + I_a(R_a + R_c + R_s) + 2 \quad (1)$$

where V_D is instantaneous value of motor dc terminal voltage; L is inductance of armature circuit in henries; $\frac{di}{dt}$ is current rate of change in amperes per second; $L\frac{di}{dt}$ is voltage of self induction due to current rate of change; E is motor counter emf; I_a is armature current; R_a, R_c, R_s are armature, commutating-field, and series-field resistances respectively; and 2 is normal two-volt brush drop.

When the motor is put on a conventional dc power supply such as a generator, $\bar{V}_D$ (average value of dc terminal voltage) equals V_D. There is no appreciable $\frac{di}{dt}$, so the term $L\frac{di}{dt}$ becomes zero. The equation then reduces to

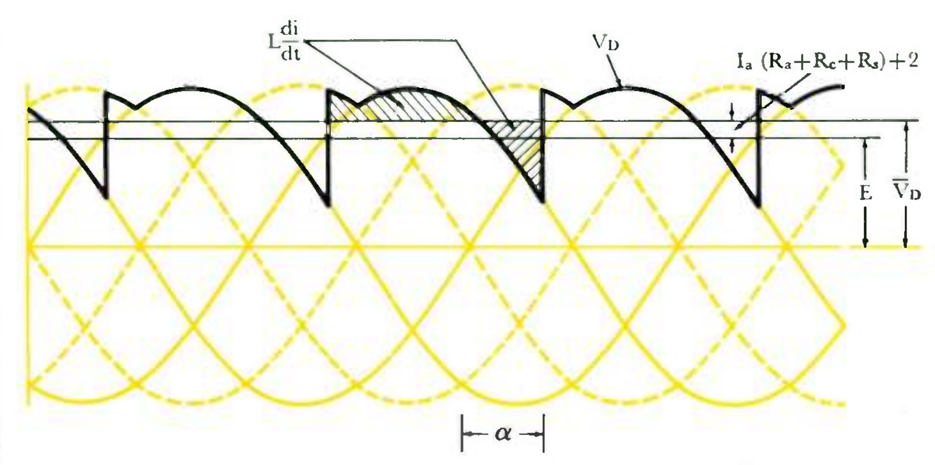
$$\bar{V}_D = E + I_a(R_a + R_c + R_s) + 2 \quad (2)$$

Under conditions of constant speed and load, E is almost as large as $\bar{V}_D$ and is constant since E is proportional to the product of speed and flux.

When the motor is put on a TPS, however, the term $L\frac{di}{dt}$ is not zero except instantaneously, and it is not constant either in magnitude or polarity as it must make up the instantaneous values of voltage that exist between E and V_D except for the relatively small IR drop. This is illustrated in the figure. Since speed and flux are constant (as they cannot change values readily due to the inertia of the armature and load and the inductance of the field), E and $\bar{V}_D$ remain constant and $L\frac{di}{dt}$ must change rather drastically. The shaded areas in the figure show the action of $L\frac{di}{dt}$. In the shaded area above $\bar{V}_D$, $L\frac{di}{dt}$ takes a positive value in equation (1); it takes a negative value in the portion below $\bar{V}_D$.

The figure also illustrates that $L\frac{di}{dt}$ increases in value as the TPS is phased back to reduce dc voltage, and it reduces in value if the amount of phase-back or the magnitude of the ac input is reduced. To look at it another way, the maximum height above $\bar{V}_D$ between $\bar{V}_D$ and the maximum point on the V_D curve increases as E is reduced due to phasing back the power supply.

The maximum output voltage at no load of a three-phase power supply is $\frac{3\sqrt{2}}{\pi} V_{L\text{-}L} = 1.35\, V_{L\text{-}L}$, where $V_{L\text{-}L}$ is the rms value of the line-to-line input voltage. (This is with zero phase-back angle.) This peak ac voltage that the dc motor sees is really $V_{ac\ max}$, being equal to $\sqrt{2}$ times rms ac voltage.



Heating Effect of Current Ripple

Heating is a problem to some extent in all electrical machinery, but it is aggravated by the ripple content of a TPS current wave. Since copper losses in the armature circuit vary as the square of the armature current, any ripple results in an appreciably higher copper loss. The ripple current also is reflected in increased iron losses in the armature core and in the nonlaminated iron parts of the commutating pole magnetic circuit because of the cross-magnetizing component of armature reaction. Flux density under the magnetized pole tip is higher than that with straight direct current, and this increases core and tooth loss as well. Stray load loss is also increased. As a result of these higher losses, any motor runs at a higher temperature when applied to a TPS. For this reason, it probably is rated at 70 degrees C rise with 1.0 service factor instead of 60 degrees C rise with a 1.15 service factor as it is when applied to straight direct current.

The amount of temperature rise depends on the form factor of the current wave: a poorer form factor produces a correspondingly higher motor temperature. This, then, is another reason why motor manufacturers prefer the full converter with its superior form factor.

Average results of motor temperature tests with straight direct current and a semiconverter TPS having no transformer nor external inductance are illustrated in Fig. 6. Three motors were used, rated at 250, 75, and 25 horsepower; the two larger ones had a base speed of 1750 rpm, and the smallest one 1150 rpm. Shutdown temperatures were measured by the rise by resistance method, with the temperature held at 90 degrees C rise. Each motor was run in a cradle dynamometer at a specific torque, speed, and field current, since it is not possible to meter input power to the motor accurately when a TPS is used. In this way, the horsepower output was known with both types of power supply.

The curves in Fig. 6 show, first, how much the motor load must be reduced when supplied with a semiconverter power supply without transformer and external inductance, as compared with straight direct current, to maintain the same temperature at a given speed. Second, they show how torque must be reduced to maintain constant temperature as speed is reduced below base speed. Although the dc motor is commonly thought of as a constant-torque motor when operating below base speed on adjustable voltage, that is not thermally correct (unless the motor is force ventilated) because reduced speed diminishes the motor's ability to ventilate itself.

With a full converter, or a semiconverter with transformer and series inductance, performance is better than that shown in Fig. 6 for the TPS. It much more nearly approaches the data obtained with straight direct current.

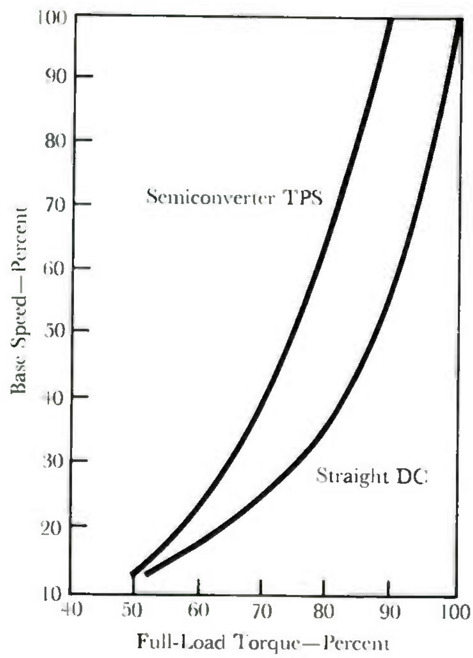
Industry Standards

The whole subject of dc motors and thyristor power supplies is now being studied by NEMA. Its study will resolve many of the problems and standardize many parameters.

Also, the AISE Research Committee has recommended a revision of its AISE Standard No. 1 (which covers dc mill motors) to the board of directors. The proposed standard applies to the new 800 line of dc mill motors now being developed for the steel industry by the several motor manufacturers. The committee recommends that the motor be suitable for operation to 460 volts on a TPS that is three-phase and 60 cycle, has six controlled legs (full converter), and has a maximum of 370 volts ac (rms line-to-line) applied to it.

If this standard is adopted, virtually any dc mill motor or industrial motor will operate satisfactorily on the power supply. Not only does the use of 370 volts require a transformer but, since 370×1.3 is only 480 volts and $370\sqrt{2}$ is 521 volts peak, the TPS will be phased back only slightly and the value of $L\frac{di}{dt}$ will be very low. These conditions result in a better wave form with a reasonable value of current rate of change, which gives good commutating performance along with a minimum of heating.

The most important consideration is that the power supply be matched to the required dc voltage. If the semiconverter power supply were used without transformer and with no attempt to match the ac input to the power supply, severe commutating difficulties might result with the indiscriminant application of existing dc motors.



6—When a motor is operated below base speed by control of armature voltage, load must be reduced to maintain constant temperature at a given speed, and torque must be reduced to maintain constant temperature as speed is reduced. Both reductions are appreciably greater when the power source is a semiconverter TPS than they are with straight direct current; however, a full converter TPS would provide a curve close to that of the straight direct current. Dripproof motors of three sizes were used for this test, with their temperatures held at 90 degrees C rise. Data was averaged to obtain the curves.

Conclusion

As time passes, more and more TPS capacity will be installed in place of m-g sets as power sources in dc-motor drive systems. The motors used, especially when a semiconverter TPS is applied without an isolation transformer, must be the best that can be made in order to prevent problems with commutation and heating. However, when the full converter is used, its superior performance characteristics often make near-standard motors satisfactory.

Electrical Machines Improved Through a Decade of Design Progress with Computers

H. M. Chen
F. R. Karr
F. A. List

Motors and generators keep getting better, and delivery times shorter. The reason, in large measure, is the routine use of digital computers for making the calculations that fit the machines to their applications in the most economical manner.

The design of a rotating electrical machine determines to a great degree its cost, capability, delivery time, physical size, and reliability. Consequently, both the user and the manufacturer of the machine have a large stake in its design and, therefore, in the *approach* used to achieve that design.

The outstanding advance in the design approach in recent years has been the use of the digital computer. By making practical much more detailed computations than could be justified previously, computer programs have been among the main factors in greatly increasing machine capability for a given physical size (Fig. 1). They have also helped increase reliability, reduce delivery time, and produce more nearly optimum economic designs.

At the same time, the computer has changed the design engineer's work from much routine calculation to more creative work: it has given him more time to think, to analyze, and to decide and act in areas where original thought is required. Such areas include basic design analysis, development of new apparatus, better definition of customers' applications, and, in short, all those efforts requiring the creativity and judgment possessed only by intelligent technically trained humans.

Evolution of Computer Design

By the early 1950's many simple and limited digital computers were being used successfully for accounting, and some motor design engineers saw potential advantages to using them for their calculations. (Those calculations predict efficiency, heat dissipating ability, torque capability, and other performance characteristics related to watts loss at various horsepower loads; they are used to properly design a machine to suit a customer's application.) Even with the difficulty of programming those early computers, and the limited scope of the problems they could handle, the success of the first programs was dramatic in comparison with previous design methods.

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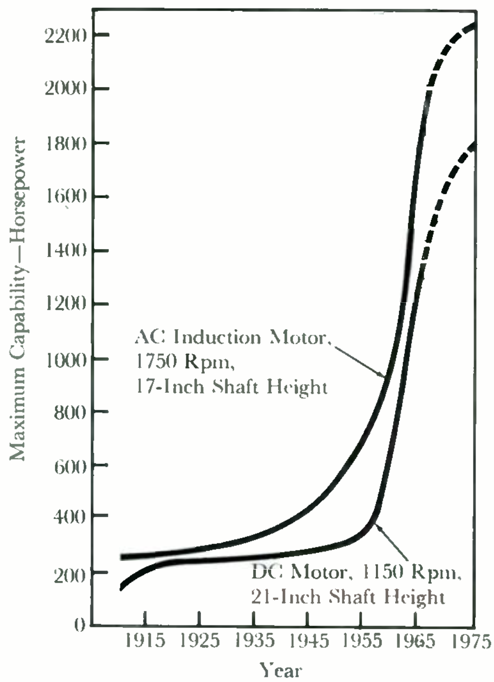
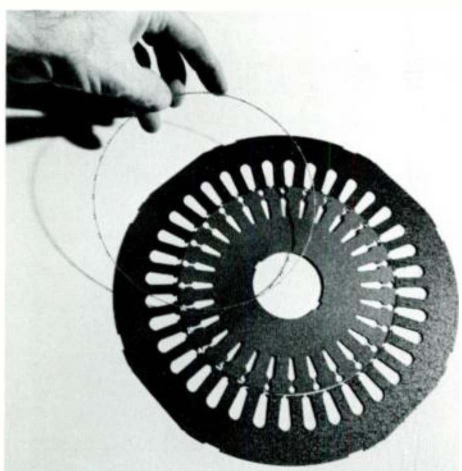


1—Better design calculation, materials, and manufacturing techniques have greatly improved performance of rotating electrical machines. The most dramatic improvement dates from the introduction of computers as design tools in the 1950's.



Motor components, as well as entire motors, are designed with computers for optimum performance. This stator and rotor lamination for the NEMA 250 frame diameter were made by a high-speed precision press that even punches out the air gap, saving the time and expense of machining material away later.

Those previous methods for designing a machine for a particular application involved guessing a set of parts, estimating their performance, building a model, testing the model, comparing the test results with desired performance, and repeating the process as necessary until the design was satisfactory. Reasonable reliability and delivery time could be assured only by over-conservative design, and that tended to increase cost and physical size. Much better calculation systems were evolved in time but, although they improved designs, they also raised the new problem of how to perform them at reasonable cost and in a reasonable time.

By 1957, more than 20,000 new electrical designs were being required in a year for the ever-increasing variety of standard and special motors that customers needed for their particular applications. (In 1967, it is more than 50,000 a year!) Between 2 and 16 hours were required per design for manual calculation, so the tendency was to use a combination approach—abbreviated calculations combined with a build, test, and modify procedure.

Fortunately, as the requirements for new designs began to overtake our ability to calculate them, general-purpose digital computers were arriving on the scene. The first calculations at the Motor and Gearing Division with a major general-purpose computer were made in late 1957. Every working day since then, calculations have been produced at least twice daily, and the computers used have become faster, capable of handling larger programs, and easier to use. For example, a 16-hour manual calculation was reduced to three minutes in 1957, to one minute in 1963, and to less than 30 seconds in 1967. And during this same period, the considerations to be calculated for the same design have been increased by approximately 20 times to obtain a more accurate and optimum solution!

As soon as engineers were trained in the art of programming, they began to computerize the manual design calculation of the squirrel-cage induction motor. The initial approach involved trying to duplicate the manual calculations the individual designers were making with slide rule and desk calculator. That procedure involved a series of approximations (iterations) that approached the exact answer more and more closely until the designer decided agreement with specifications was sufficiently good. Individual designers frequently introduced personal "adjustment factors" of their own, which often caused redesigning on the test floor and thus added cost and delayed shipment.

Since only the calculated results were usually recorded (and not the method of obtaining them), it was impossible for one design engineer to use another's calculations without some degree of risk. Quite often the engineer was pressed for time and gambled that previously calculated values for the longer calculations (such as AC locked-rotor current and temperature rise) were correct. Too often he lost, causing the need for redesigning on the test floor.

Calculation errors and various "adjustment factors" were eliminated when the computer program was first prepared; only the best known calculation methods were used. Correlations of test data to calculated data on a statistical basis then began to point out that the test procedures must be improved and that calculation methods must be modified. Continuing modifications and correlations have resulted in improved test and calculation methods that give close correlation between test values and calculated values.

The first computer program written handles only the use of parts and assemblies that the engineer specifies completely. (This initial program has been continuously improved and is often used for more than a hundred design calculations a day.) However, the engineer does have the option of not telling the computer what winding he wishes to use. When he does not specify the winding, the program arrives at a suitable winding to provide the maximum torque the user requires. A case where the winding has been completely specified in the "Input" is illustrated by the typical computer-printed output sheet in Fig. 2. When the winding is not specified by the engineer, it appears only in "Winding Data."

The next step was to move from the calculation of known and specified sets of parts to the design and optimization of major components, such as the laminations used to build up stator and rotor core assemblies. Lamination design involves dimensions measured in thousandths of an inch to obtain maximum performance from a given amount of material, and a nearly infinite variety of slot shapes can be used to provide the several industry-standard design types and countless special designs that users request. Again, the design process is set up in such a manner that iteration is directed to arrive at the dimensions that give optimum performance. This type of program produces designs limited only by conformance to our manufacturing techniques and present-day materials and processes.

Selector and Designer Program

As experience grew, the engineers saw that they could develop computer programs that required very little data describing a design; the rest of the information could be assumed to be standard unless the user or the engineer took exception to the standards for the particular design in question. Detailed industry standards were already established for motors up through the 440 frame diameter in ratings through 200 horsepower, 4 pole; they cover such parameters as maximum torque, starting torque, locked-rotor current, frame size for a given horsepower and speed, temperature rise for various enclosures, and mechanical dimensions for standard frame sizes.

A special type of computer program was conceived, to make use of all the known advances in calculation techniques for induction motors. We call it a selector and designer program. It operates with a file of standard high-volume components and assemblies especially selected to meet most standard and special customer design requirements. Use of high-volume components and assemblies helps assure quick delivery and minimum cost.

The minimum amount of information necessary to inform the selector and designer program about a customer's order is horsepower, number of poles, industry design type, frame size, mechanical enclosure type, and Westinghouse design type. If no other information is specified, the computer program assumes that all other variables agree with industry or Westinghouse standards. If the customer requires an exception to the standards, the engineer who is requesting the calculation from the computer includes it in his request; he can take exception to more than 30 different items to establish the exact specifications for the particular customer's design.

The program, using an approach guided by good design logic, explores all the reasonable possibilities of countless combinations of winding turns and connections, rotor and stator laminations, rotor cage material, and core length to meet the special performance requirements by using standard high-volume components and assemblies. If a design meeting the customer's specifications can be made (it usually can), the computer prints out information that the engineer can send to the factory to have the design manufactured.

2 *(Top)*—Initial computer design program requires the engineer to specify parts and assemblies in his input. The computer then calculates and prints out the detailed design data and the performance of a standard motor built to that design. The engineer uses this printout to write engineering specifications for manufacturing.

3 *(Bottom)*—A later computer design program, called the selector and designer program, requires less input. The engineer enters the basic design specifications on this form, and the computer assumes that the rest are standard unless the engineer enters exceptions to meet special customer requirements as he has done in this example. The coded exceptions used here are: 001, 380 volts; 003, 50 cycles; 005, series connection; 010, dual voltage (380/220) with star-delta connection; 026, minimum efficiency of 80.0; 028, service factor of 1.00; 029, overvoltage of 1.00 (no overvoltage); 030, ambient temperature of 35 degrees C; 034, altitude requirement of 6600 feet above sea level.

```
***PROGRAM    ME7113    IDENT    FRK01

   TYPE     FRAME        HP     POLFS      FREQ      ENCL      RISE      TIME   POT/FLT    DESIGN       INS      S.O.
    LLT      184T      5.00        4.       60.      DRPR      80.C     24.00       0.0         B         B

              LINE    NUMBER               PHASE                                  CORE    STATOR     ROTOR    SINGLE
  PHASF      VOLTS     VOLTS     THROW     BELTS      CONN       PAR       TPC    LENGTH      I.D.      O.D.   AIR-GAP
     3.       440.        2.        8.       60.         Y        1.       20.     3.500     4.631     4.601    0.0150

   WIRE      COND    WEIGHT   (FF)MAX    WIRE-1     NUM-1    WIRE-2     NUM-2  MAX.REEL      IRON     THICK    E-SPEC
     82     0.977     1.024      0.80        20        2.        21        0.       10.    9197-2     0.025    000000

   DATE   STATOR PCHG     ROTOR PCHG      (UPPER)DIE-MOULD(LOWER)     ALLOY      SKEW     SHAFT  (F&W)NL    M-SPEC
 670202   418A421H01      675A094H01     H1797C170        H1797C170     0.500     0.377         M      30.    000000

     S1        S2     NOISE   LOCKING   (+)CUSP   (-)CUSP
    36.       45.

  LB-CU      F.F.     THROW   BALANCE      CONN       PAR       TPC    WIRE-1     NUM-1    WIRE-2     NUM-2       MCL
   6.52  0.81(0.50)      8.       YES         Y        1.       20.        20        2.        21        0.     8.336

(25.C)RTT( 75.C)     (I)NL     (W)NL       *XM     *CORE     (B)AG     (B)T1     (B)T2     (B)CI     (B)C2
 3.5309   4.2113     2.815      293.   1.68420   0.05698     52.29    107.60    113.75    107.63     57.03

                      SLIP       RPM       EFF      P.F.   (HP)OUT    (T)OUT     INPUT    LOSSES      (I)L    CU1/LB
 LOCKED ROTOR       100.00        0.       0.0      62.4       0.0     33.55    20093.    20093.    42.230   1728.68
 BREAK   DOWN        24.65     1356.      54.0      78.8     10.83     41.95    14978.     6966.    24.945    603.19
 1-1/4   LOAD         5.13     1708.      82.6      88.4      6.23     19.16     5628.     1006.     8.355     67.66
 FULL    LOAD         3.88     1730.      83.9      86.3      4.99     15.16     4442.      737.     6.753     44.20
 3/4     LOAD         2.80     1750.      84.1      81.8      3.77     11.31     3343.      547.     5.362     27.87
 1/2     LOAD         1.81     1767.      82.3      72.1      2.52      7.50     2288.      415.     4.165     16.82

                       *R1       *R2       *X1       *X2  *(HP)OUT   *(T)OUT    *INPUT   *LOSSES     *(I)L   O/O SAT
 LOCKED ROTOR      0.04057   0.03284   0.04712   0.04471   0.0       2.30010   5.38698   5.38698   8.62824      70.6
 BREAK   DOWN      0.04057   0.03014   0.05281   0.06441   2.16652   2.87544   4.01559   1.86749   5.09674      90.2
 1-1/4   LOAD      0.04057   0.02996   0.05529   0.07401   1.24610   1.31350   1.50890   0.26965   1.70704      99.4
 FULL    LOAD      0.04057   0.02996   0.05529   0.07415   0.99852   1.03885   1.19080   0.19766   1.37968      99.6
 3/4     LOAD      0.04057   0.02996   0.05529   0.07429   0.75344   0.77513   0.89613   0.14670   1.09555      99.7
 1/2     LOAD      0.04057   0.02996   0.05529   0.07441   0.50497   0.51427   0.61351   0.11125   0.85108      99.8

                                          CORE     (CU)1     (CU)2       F&W      S.L.     TOTAL
 FULL-LOAD LOSSES (IN WATTS)              213.      288.      152.       27.       59.      737.
                  (PER UNIT)           0.05698   0.07722   0.04062   0.00714   0.01569   0.19766

                                        CU1/LB    (C/S)I    CUR/LB    (C/S)R    CUB/LB    (C/S)B
 LOCKED ROTOR                          1728.68     10.42   6135.27     14.61   4277.64     10.18

* INDICATES THE PER UNIT VALUE                  (REVISION DATE 66-10-05)                  L-SPEC    799875
```

Computer Input — Winding Data — Test Limits — Actual Output — Per-Unit Output

Program ME7437T AC Squirrel Cage Motor Calculation
Selector for Standard LLT Electrical Parts (Frame Diameters 140 Through 445)

FRKO1 — Identification (all cards) (columns 1–5)

9 for Last Card

Card	S.O. (col. 9)	G.O. (col. 25)	Date (col. 41)	Engr. (col. 57–80)
01	EXAMPLE	BUFFALO N.Y.	670202	J. ERLANDSON

Card	Hp. (col. 9)	Poles (col. 21)	Frame (col. 33)	Motor Type (col. 45)	NEMA Des. (col. 57)	Enclosure (col. 69–80)
02	4.00	04.	184T (AXXXAA)		B	DP

Exceptions

Card	Last	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description
03		001	380.	003	50.	005	1.	010	3.	026	80.0	028	1.00	029	100.
04	9	030	35.0	034	6600.										
05															

The computer program logic permits great freedom in designing the stator winding and somewhat less freedom in arriving at other components. The stator winding logic permits changes in throw, turns per coil, wire sizes, number of parallel wires, number of parallel paths, and connection type, depending on the customer specifications; the logic for other components forces use of certain limited combinations of parts.

If the computer program cannot find a design using standard high-volume parts, it indicates the design that comes closest to meeting the specifications and indicates the difficulty. With this information, the design engineer can use other programs that consider less standard parts.

Computer input covering the customer's special requirements is prepared by the engineer on a simple form (Fig. 3). It consists of the basic specifications of horsepower, poles, frame size, Westinghouse type, NEMA (industry) design type, and mechanical enclosure type (dripproof), plus the exceptions to industry and Westinghouse standards that the design engineer wishes to take. The logic used by the computer program in arriving at the optimum design is illustrated in Fig. 4.

The computer prints out the basic specifications and the exceptions, as shown in the upper part of Fig. 5. The rest of the printout shows the performance of the special design arrived at; it uses standard high-volume components identical to those of the standard 5-hp, 4-pole, 60-cycle motor specified in Fig. 2. Especially significant for the designer is the tabulation of *PERFORMANCE*, where the *Specified* and *Calculated* values of *POT/FLT* (maximum torque), *S*(*FL*) (full-load slip), (*EFF*)*FL* (full-load efficiency), (*PF*)*FL* (full-load power factor), *TS/FLT* (starting torque), *IS* (locked-rotor current), and *RISE* (temperature rise) are compared. With these values, the engineer can decide if the design completely fulfills the customer's requirements.

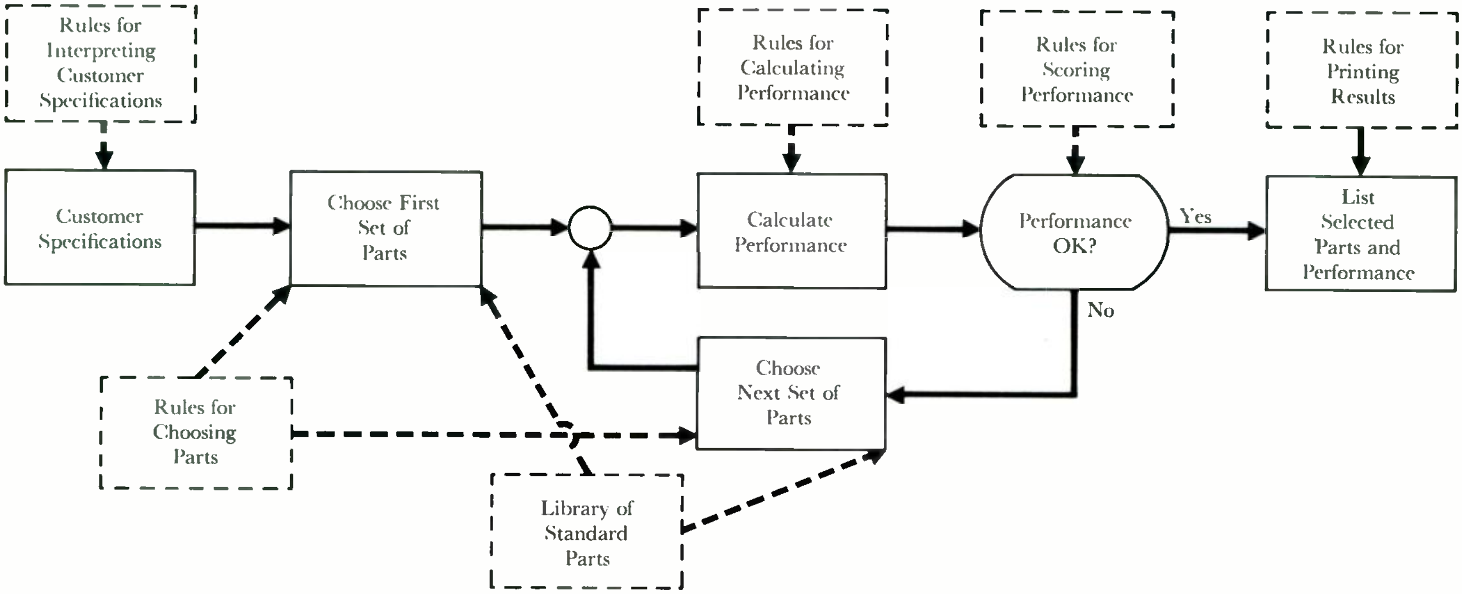
Broadening Applications

The original use of computers for design was in ac squirrel-cage induction motors in frame sizes 140 through 440. Because of the early success in satisfying customer needs on those initial sizes, the effort was broadened to include the machines shown in the table on page 110.

Since many dc motors are now being operated from an ac power source through a thyristor power converter, a need has arisen for rapid design and selection of motors that give satisfactory performance with them. This need has led to development of a special selector and designer program that operates with a file of standard components and assemblies previously selected because of their good performance with a dc power supply having an output with relatively high voltage ripple content. It explores all reasonable possibilities of countless combinations of armature bar-turns, shunt field turns and wire sizes, series field turns and wire sizes, pole face types, and air gaps to arrive at the best combinations.

The minimum amount of information needed to inform this program about a customer's order consists of two parts: first, motor horsepower, rated dc armature voltage, base speed, design specification, and enclosure; second, power-supply ac line voltage, ac line frequency, and number of controlled elements in the bridge circuit. Other characteristics and specifications such as rated field voltage, speed regulation at various rated speeds, commutation ability at various loads and speeds, stability at various rated speeds, load capacity at various rated speeds, and frame size are considered to be Westing-

4—Selector and designer program operates with a file of standard high-volume components and assemblies. Using the design logic illustrated, it explores the many possible combinations and determines the one that meets the requirements most economically.



PROGRAM ME7437T   IDENT FRK01   S.O.EXAMPLE   G.O.BUFFALO N.Y.DATE-670202   ENGR-J ERLANDSON

BASIC SPECIFICATIONS

HORSEPOWER	=	4.00
POLES	=	4.
FRAME	=	184T
TYPE	=	T
NEMA DESIGN	=	B
ENCLOSURE	=	DP

EXCEPTIONS

(001) VOLTS*	(002) PHASE	(003) FREQ1*	(004) FREQ2	(005) CONN*	(006) PARLL	(007) TPC	(008) THROW	(009) SI	(010) N VOLT*
380.0	3.	50.	0.	1.	0.	0.	0.	0.	3.

(014) F.P.M.	(021) POT/FLT	(022) (I)S	(023) TS/FLT	(024) SLIP MN	(025) SLIP MX	(026) EFF MN*	(027) P.F. MN	(028) SR FACT*	(029) O.VOLT*
0.	2.36	48.6	1.85	0.0	5.0	80.0	85.0	1.00	100.

(030) AMBIENT*	(031) INS	(032) TIME	(033) RISE*	(034) ALT*	(035) STATOR	(036) ROTOR	(037) DIE MOULD	(038) L1 MN	(039) L1 MX
35.0	2.	24.00	75.0	6600.	0.	0.	0.	3.	4.

(040) COND.	(041) ST ID	(042) ROT OD	(043) FE MAX	(044) SHAFT	(045) BORE	(046) RES TEMP	(048) IRON	(049) BLOWER	(050) ENCL
0.0	0.0	0.0	0.0	0.	0.	1.	0.	0.	0.0

* EXCEPTION TAKEN

Input and Potential Exceptions

PROGRAM ME7437   IDENT FRK01   S.O.EXAMPLE   G.O.BUFFALO N.Y.DATE-670202   ENGR-J ERLANDSON

HP	POLES	LINE	FRAME	DESIGN	ENCL	INS	RISE	TIME	PHASE	FREQ	SERVICE
4.00	4.	T	184T	B	DP	B	75.C	24.00	3.	50.	1.00

LINE VOLTS	NUMBER VOLTS	PHASE BELTS	CONN	WIRE	COND	WEIGHT	(FE)MAX	THROW	STATOR I.D.	ROTOR O.D.	SINGLE AIR-GAP
380./220.	1.	60.	Y/D	B2	0.891	1.122	0.77	8.	4.631	4.601	0.0150

CORE LENGTH	STATOR PUNCHING	ROTOR PUNCHING	(UPPER)DIE-MOULD(LOWER)	STATOR CORE	ROTOR CORE
3.500(4.)	418A421H01(1.)	675A094H01(1.)	H1797C170 (1.) H1797C170	797C158G16	797C170G04

S1	S2	NOISE	LOCKING	(+)CUSP	(-)CUSP	ALLOY	SKEW	SHAFT	(F&W)NL	IRON	THICK
36.	45.					0.500	0.404	M	17.	9197-2	0.025

LB-CU	F.F.	THROW	BALANCE	CONN	PAR	TPC	WIRE-1	NUM-1	WIRE-2	NUM-2	MCL
6.41	0.73(0.45)	8.	YES	Y	1.	20.	20	1.	21	1.	9.356

(25.C)RTT	(100.C)	(I)NL	(W)NL	*XM	(B)AG	(B)T1	(B)T2	(B)C1	(B)C2	(I)NL-220V60C	(W)NL
4.3185	5.5667	3.105	291.	1.41145	54.09	111.30	117.66	111.32	58.99	3.583	209.

		CORE	(CU)1	(CU)2	F&W	S.L.	TOTAL		
1.15 LOAD LOSSES (IN WATTS)		194.	476.	209.	14.	55.	948.		
FULL-LOAD LOSSES (IN WATTS)		194.	369.	151.	15.	47.	775.		
		CU1/LB	(C/S)1	CUR/LB	(C/S)R	CUB/LB	(C/S)B		
LOCKED ROTOR		1694.28	9.99	4786.97	11.40	3203.20	7.63		
		POT/FLT	(S)FL	(EFF)FL	(PF)FL	TS/FLT	IS	SCORE	RISE
PERFORMANCE	(SPECIFIED)	2.36	0.0- 5.0	80.0	85.0	1.85	48.6		75.
	(CALCULATED)	2.52	4.8	80.0	85.4	2.09	36.1	0	73.

* INDICATES THE PER UNIT VALUE   (REVISION DATE 67-02-16)

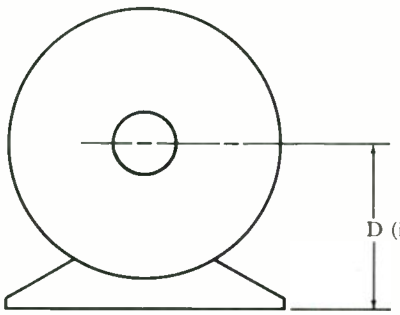
IHC217I

5—Printout from the selector and designer program includes the basic design specifications and exceptions taken (Fig. 3), the latter indicated with asterisks from among the possible exceptions. The printout then shows the performance of the motor built to this design. Although of special design, the motor will be built of standard high-volume components for quick delivery and minimum cost.

Rotating Machines Being Designed by Computer

Machine Type	*Frame Diameters*
AC Squirrel-Cage Induction Motors	140 through 440 5000 through 6800
AC Wound-Rotor Motors	210 through 6800
DC Industrial Motors	180 through 8400
DC Industrial Generators	180 through 8400
DC Motors for Thyristor Power Supplies	180 through 8400
DC Mill Motors	802 through 820
RectiFlow Drives	180 through 8400
AC Synchronous Machines	320 through 6800

Shaft height, the principal frame size dimension, is tabulated below.



DC Mill Motors		*AC Squirrel Cage Motors* *AC Wound-Rotor Motors* *AC Synchronous Machines* *DC Industrial Motors* *DC Industrial Generators* *DC Motors for Thyristor Power Supplies* *RectiFlow Drives*	
Frame Size	*D*	*Frame Diameter*	*D*
802	7⅝	140	3½
803	8½	180	4½
804	9	210	5¼
805	10	250	6¼
808	11¼	280	7
810	12¼	320	8
812	13⅜	360	9
814	14¾	400	10
816	16	440	11
818	17¾	5000	12½
820	20⅞	5800	14½
		6800	17
		8400	21

house standards unless the engineer takes exceptions to establish exact customer requirements.

The computer program prints out the total motor specifications, design details, and performance. It also prints out the external inductance (if any) required to give satisfactory performance of the combination of motor and power supply.

Many other types of computer program are employed to insure the manufacture of reliable high-quality products. One of these calculates current fluctuations in compressor drive motors to establish that the motor will operate satisfactorily with a pulsating load. Another analyzes test results to determine the accuracy of data and to assure that the results conform to customer specifications. Other programs involve calculation of critical speeds and maximum speeds of rotating systems (rotor, armature, commutator, and overhung loads) to assure safe, long, and trouble-free life. Others include calculation and reduction of noise and vibration, resulting in quieter and longer-running motors. Still others are for predicting and eliminating cusps, dead points, and other undesirable or abnormal performance during speed changes.

The use of these various computer programs has freed engineers who were previously involved with routine calculations to develop new lines of improved apparatus, such as the rerated Life-Line T motors and the dc mill motors designed to meet the new 800-frame AISE tentative standard. Others are now working to develop new specifications on the definition and application of our industry standard motors (with or without modification) to special customer requirements.

Moreover, successful application of general-purpose digital computers in design led to use of computers for other functions, including order inquiry negotiations, order entry, production scheduling, manufacturing information, production tracking, shipment, invoicing, and historical records. This trend to better control of the entire manufacturing process results in better apparatus and more accurate and timely information to customers regarding orders.

Automating the Design and Manufacture of Surface Condensers

E. J. Barsness
J. McLean
A. R. Geesaman

A digital computer program now designs the condenser tube layout and generates the tape for controlling the manufacturing operation.

Steam surface condensers are a product in which any significant degree of standardization is impractical because of the great variety of sizes and configurations needed to satisfy specific requirements of each power generating station. In this respect, the surface condenser is typical of large equipments that have traditionally been custom designed and built.

Yet condensers being built today at the Westinghouse Heat Transfer Division are designed by computer, and major component parts are manufactured by automated machine. Even more significant is the fact that the engineering and manufacturing functions have been joined so that the computerized engineering designs are completely compatible with the requirements of automated manufacture. Customer specifications are fed to the computer, which is programmed to design the key components and develop the punched tapes for controlling the machining of these component parts. With this automated design-manufacturing approach, the overall lead time required for surface condensers has been reduced by 30 percent.

A typical surface condenser is composed of a vacuum-containing shell, water boxes, tube sheets, tube supports, and tubes. In the plant steam cycle, steam from the turbine exhaust condenses on the cool tube surfaces and is returned to the boiler. Condenser tube surfaces are kept cold by cooling water flowing through the tubes. Depending on the condensing capacity required, the number of tubes in a given condenser shell may vary from a few thousand to more than 40 thousand.

The thermodynamic performance of a surface condenser is largely determined by the physical arrangement of the tubes. Therefore, the design of the tube-hole pattern and the drilling of tube sheets and tube support plates to these hole patterns are a substantial part of the engineering and manufacturing cost of a surface condenser. Because of the variety in number of tubes and the variations in tube-hole patterns, any attempt to automate the design and manufacture of surface condensers must have flexibility.

The automated design-manufacturing technique now in use has this required flexibility, and it has evolved through a

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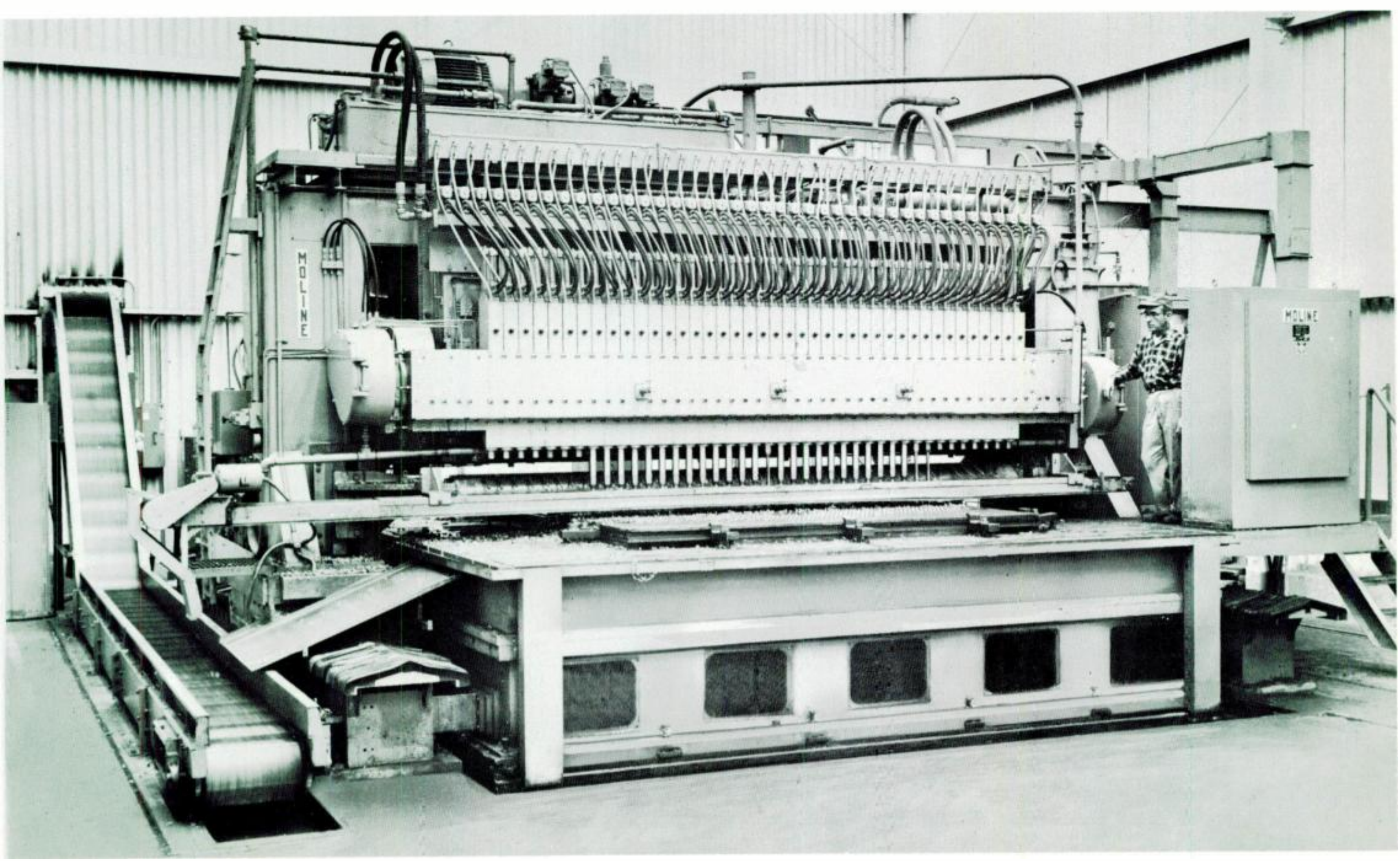


Multiple-spindle gantry drill has 41 spindle heads, positioned over the workpiece by tape control.

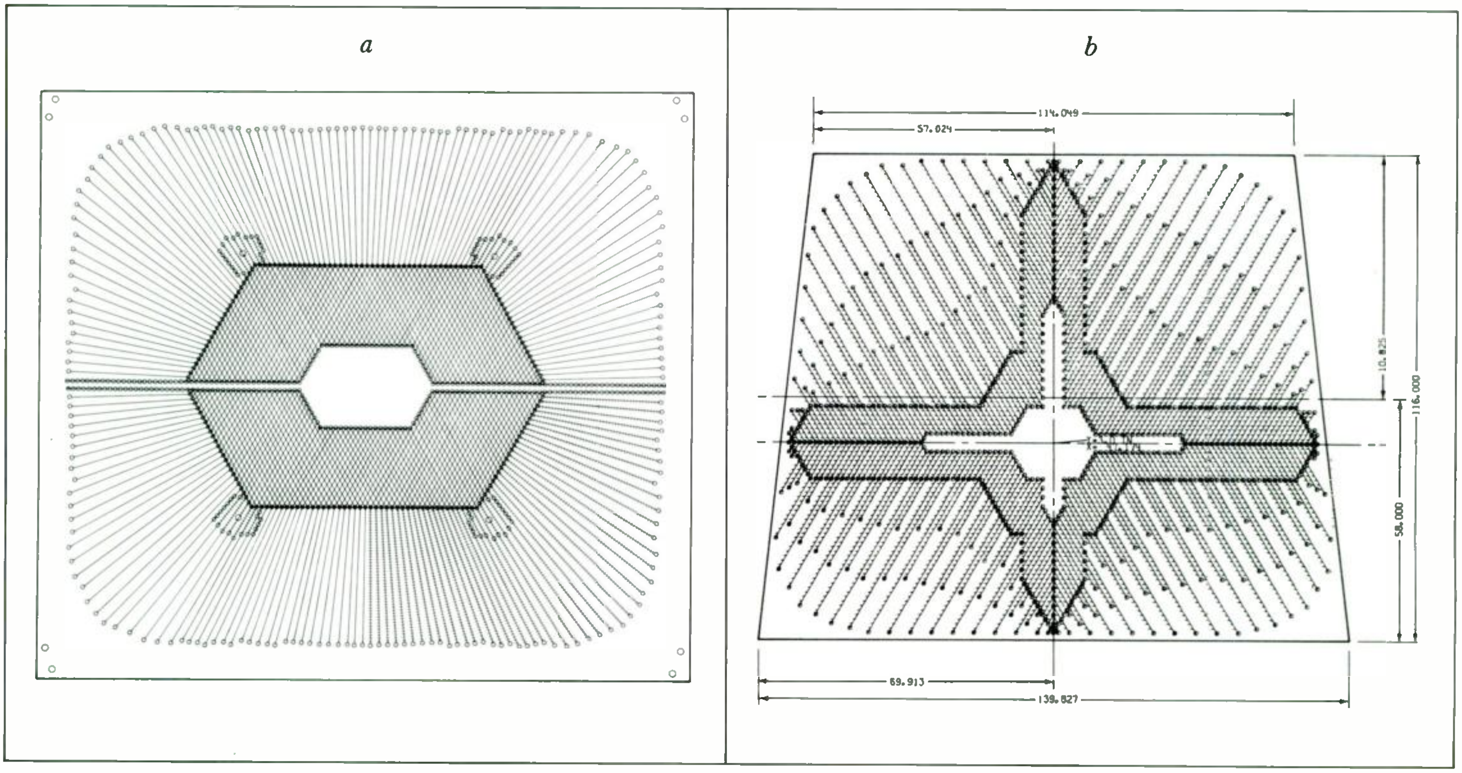
number of steps that began with the introduction of high-powered computer technology in the early 1950's. Prior to this, tube-hole patterns were designed by trial-and-error graphical techniques. Tubes were located in the water-box area according to rules determined from previous experience with similar units. Although the process was time consuming, this procedure worked reasonably well with small surface condensers. Tube-sheet manufacture consisted of manually laying out and center punching each tube-hole location. The inlet and outlet tube sheets were placed back to back and holes were drilled one at a time with a conventional radial drill press. The drilled tube plates were then used as jig plates to permit parallel drilling of stacks of support plates.

As turbine sizes increased, condensers required correspondingly greater tube surface, usually without a proportional increase in available space for the condenser. It became more and more difficult to predict performance by extrapolation from previous designs, so more accurate analytical techniques were needed to evaluate the detailed thermodynamic characteristics of the condenser. Using a digital computer, designers developed a thermodynamic analysis that used an iterative procedure to determine the interrelated three-dimensional heat-transfer and fluid-flow characteristics in and around the tube bundle.[1] The approximations and assumptions that were required for this technique were derived from field tests on operating condensers.

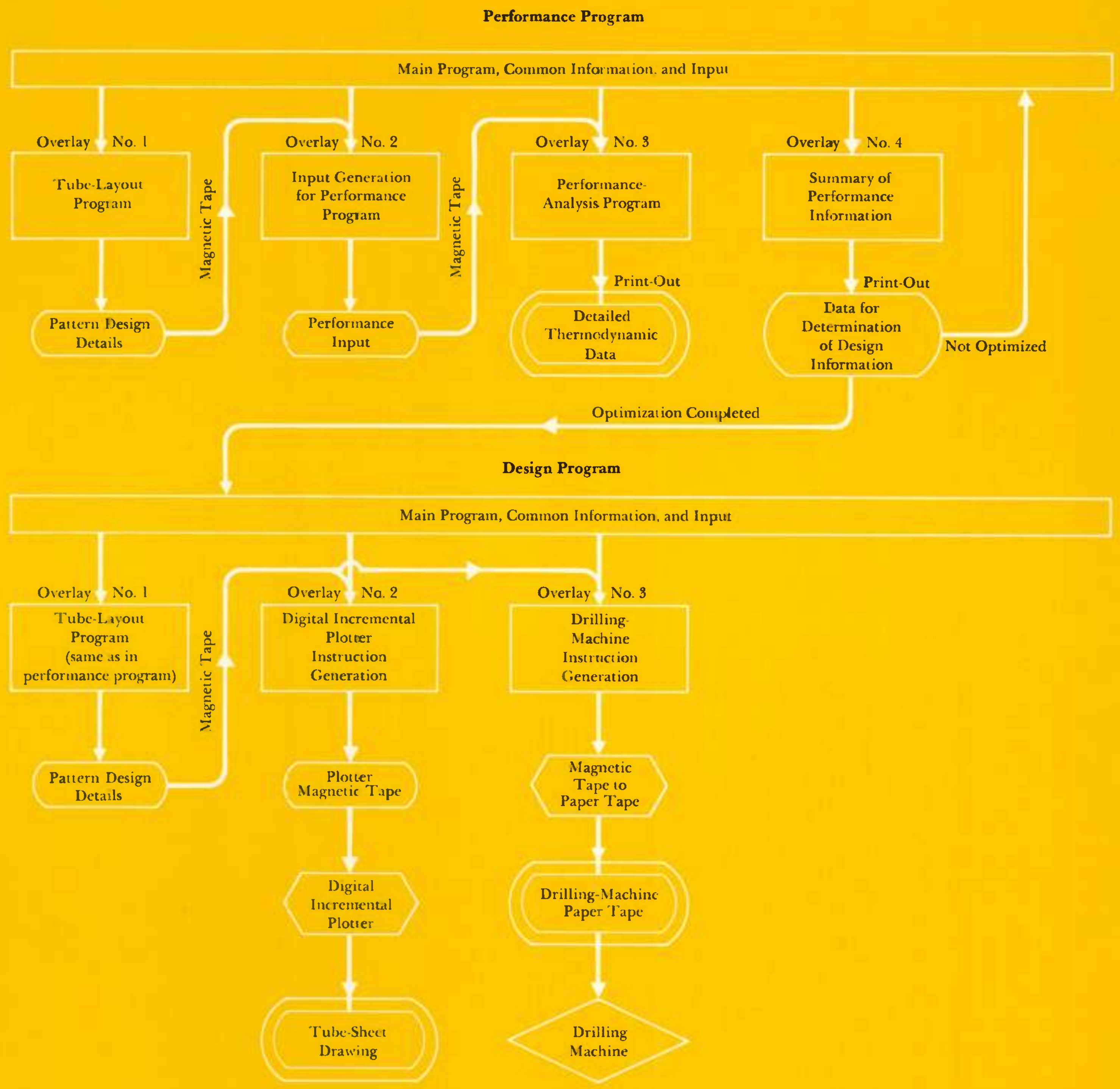
The results of this analysis pointed out a need for changes in tube patterns and for the addition of an orificed core-pipe venting system in large surface condensers. These improvements reduced bundle pressure loss and improved noncondensible removal.

The thermodynamic analysis also emphasized the difficulties of obtaining input information, which limited the number of condensers that could be analyzed in a reasonable time. For example, the substantial amount of geometrical input information required for the analysis had to be measured from scale layouts that were still being done graphically. Thus, the next step was to develop an additional computer program that could generate the geometrical input data from a few key dimensions that specified the general features of the tube pattern. This latter program then led to the development of an iterative computer program to replace completely the trial-and-error graphical design procedure that had been performed by draftsmen. Condenser designs could now be generated directly from performance specifications, and the computed results tabulated and used to plot tube-sheet layouts with a point-to-point data plotter, thereby eliminating the drafting effort for tube-sheet layout.

Although the computer design system as developed to this point solved the problems of engineering design, it did not



1—*(a)* Original tube pattern has provided the desirable radial-flow characteristics for many years, but was not adaptable to multiple-spindle drilling. *(b)* New pattern developed for surface condenser retains desirable characteristics of the radial-flow design and satisfies requirements of multiple-spindle drilling.

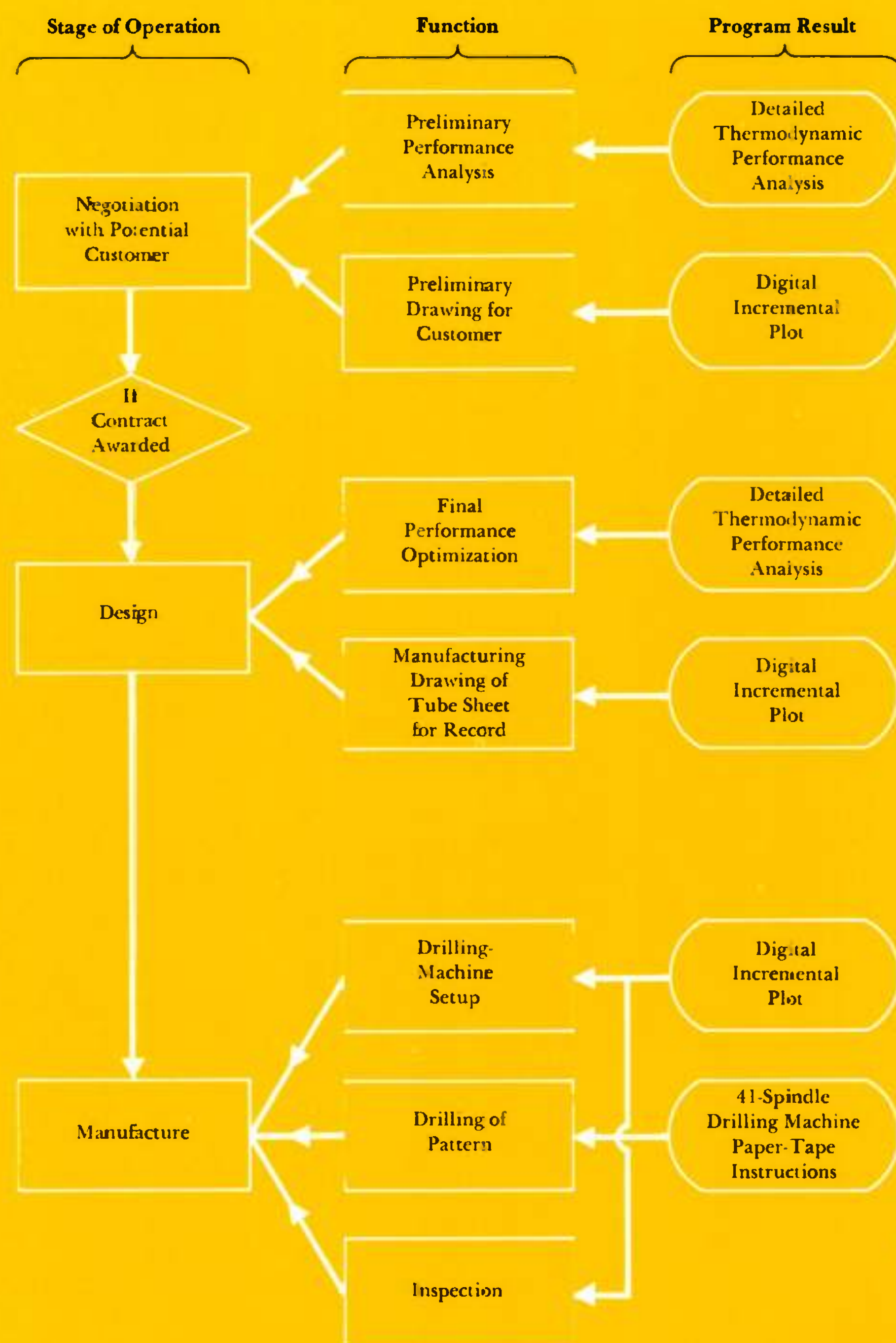


2—The computer system consists of two programs: the performance program designs the tube layout and summarizes performance; the design program develops the tube sheet drawing and generates the control tape for the multiple-spindle drilling machine.

improve the process of manufacturing the tube patterns. The fundamental problem came from the nature of the tube pattern (Fig. 1a), which was composed of a core area and a peripheral area; the core area was developed on a fixed triangular pitch pattern, but the peripheral area was a pattern of radial lines in which the horizontal and vertical pitch changed for each line of holes. Since the peripheral area of the tube pattern usually contained a greater number of holes than the core area, multiple-spindle machines were not practical for drilling the combined pattern. Although attempts were made to use an automated single-spindle drilling machine with point-to-point positioning controls, both design and manufacturing engineers soon recognized that some form of multiple-spindle drilling was required to achieve any real improvement in the drilling operation.

The tool selected as most economic for the drilling operation was the numerically controlled, gantry-type drilling machine. A gantry drill has many adjustable-center spindle heads (41 for the machine selected) positioned over a stationary table. The major limitation of the gantry drill is that all spindles must move together, both laterally and longitudinally; and the distance between spindles, although manually adjustable with spacer blocks, must remain fixed for each set of tube-hole patterns. Flexibility in drilling is provided since any combination of spindle heads can be retracted during any drilling cycle. Gantry position over the workpiece and individual spindle-head retractions can be completely tape controlled once the machine is initially oriented over the workpiece. Obviously, for most efficient use of a multiple-spindle machine, the tube pattern must allow maximum use of drills during each drilling cycle.

From a thermodynamic standpoint, designers wanted to retain the low pressure-loss characteristics inherent in the radial-tube design. With this arrangement, steam flows around the periphery



3—Flow diagram illustrates the sequence of condenser manufacture and the use of the results of the program system.

of the tube bundle and radially toward its center, the lowest pressure area. The pressure drop through the tube bundle is kept to a minimum because steam velocities are kept low as possible with this concept. To obtain essentially constant steam flow velocity throughout the bundle, the area for steam flow inward from the bundle perimeter to the center is decreased to compensate for the decrease in volumetric flow as steam condenses on the tubes, again an inherent feature of the radial-flow arrangement. Thus, before a gantry drilling machine could be used economically, a tube pattern was required that would provide this desired radial-flow performance and at the same time satisfy the requirements of multiple-spindle drilling.

A typical pattern developed to satisfy both requirements is shown in Fig. 1b. Maximum drill usage per cycle is provided by having all tube holes located on a uniform triangular pitch throughout the entire tube pattern. Reduction in flow path area is accomplished by using tube rays of a single row at the outer portions of the pattern, and increasing bundle density by making double and triple rows until the area around the venting system is reached, where uniform triangular pitch is utilized. This pattern provides a general flow path that is 30 degrees from vertical in each quadrant of the pattern and thereby retains most of the advantages of the original radial-flow concept. The core venting plenum provides a tube void area for the vent orifice pipe, which is positioned along the length of the condenser. The core void area is shaped to give equal pressure drop from any part of the tube bundle periphery to the orifice core pipe by adjusting the length of the four narrow tube voids and by raising or lowering the entire core system.

With a tube pattern that was compatible with both performance and manufacturing requirements, computer programs were developed to design the pattern and provide manufacturing information and instructions. This computer system consists of two separate programs, which is desirable because it allows performance information to be reviewed (and adjusted) before manufacturing instructions are generated. A schematic diagram of the two-program system is shown in Fig. 2.

The *performance program* is composed of four overlays, each with a specific function. The overlaid program arrangement was required because of computer memory limitations. The first overlay determines the location of each tube in the pattern according to a specific design criterion. The second overlay generates geometric input data to be used in the detailed performance analysis, which is the third overlay. The fourth overlay summarizes and prints out a summary of performance information. If performance is not acceptable, design details such as the location and shape of the air core void can be changed in the first overlay and the analysis repeated.

The *design program* is composed of three overlays. The first is identical with the first overlay of the performance program; the criteria developed in the performance program are the input to the design program in the same format to assure that the design will be identical for both programs. The second overlay generates magnetic tape instructions for a digital incremental plotter, which plots the tube pattern to scale (Fig. 1b). Dimensions required for setting up tube sheets and supports on the gantry drill are also included. The third overlay generates magnetic tape which in turn generates the eight-track perforated paper tape containing instructions for the numerically controlled gantry drill.

The results of this computerized programming system are used in the three principal operations of building surface condensers—negotiation, engineering, and manufacturing, as illustrated by the flow chart in Fig. 3.

In the negotiation stage, the detailed thermodynamic analysis verifies customer specifications and provides a technical basis for discussion with the potential customer about application problems. A preliminary tube-sheet layout can be provided to the customer in the proposal.

In the design phase, tube geometry can be optimized with a minimum of time and effort. The most important consideration in this optimization is the location and geometry of the venting plenum (formed by the tube voids at the center of the tube pattern).

The performance printout summarizes the overall expected performance for the specific design. In some cases, this summary will indicate that certain additional design features should be added. For example, desirable features might be multiple patterns to reduce pressure drop, condensate shields to limit water film build-up, or specially shaped tube patterns to reduce outer steam lane velocities. Once performance is satisfactory, the digital incremental plot becomes the record of the specific design accepted.

In the manufacturing phase, the digital incremental plot is again used for positioning the tube plates and supports on the drilling machine before drilling. The instructions for the numerically controlled drilling machine develop a hole pattern identical to the digital plot. And finally, the digital incremental plot is used by quality control to inspect the completed tube plate.

Drilling with the automated gantry machine on a regularly scheduled basis began in January 1967, when three-shift operation was achieved. All drilling performed to date has been on stacked plates, usually four ¾-inch plates or five ⅝-inch plates. The gantry drill, in comparison to drilling on single-spindle radial drill presses, has reduced drilling time significantly. The reduction is based on an average of 15 spindles drilling per cycle. Some condenser tube pattern designs have permitted as many as 36 holes to be drilled simultaneously.

Most rewarding of all, the quality of the finished product has been improved. Both hole-size tolerance and hole finishes have shown improvement over the original method of drilling tube holes. The pitches have been consistently within the engineering specifications with a minimum of drill runout. The automated design-manufacturing approach has both reduced lead time and improved quality—the basic goals of a manufacturing operation.

[1]"Calculation of the Performance of Surface Condensers by Digital Computer," by E. J. Barsness, *ASME Paper* 63-PWR-2, 1963.

EME—The Environmental Experiment Package for the Applications Technology Satellites

L. W. Rustad

The EME program is designed to enhance our knowledge of the earth's ambient characteristics, to verify theoretical information, and to confirm or refine previous measurements.

The purpose of the ATS/EME missions is to learn more about the earth's environment in the 6,500 to 22,400-mile altitude range. The ATS-B experiments are measuring magnetic fields, fluxes and energy spectra of electrons and protons, and the effect of the space environment on solar cells and thermal coatings.

The ATS-A mission will duplicate or supplement some of these measurements and carry other experiments to detect very low frequency radio signals, cosmic noise, and electric fields in the magnetosphere. A list of the ten experiments, their suppliers, and their assignment to the EME-B and EME-A missions is given in Table I. The electronic and structural subsystems are listed in Table II.

The seven experiments for ATS-B and the six experiments for ATS-A are integrated into individual packages, lacking only a primary power source and a telemetry transmitter for fully self-contained operation. Westinghouse responsibility consisted of custom-designing and fabricating the encoder, the power supply, the command interface control unit, and the structure to house this equipment and the experiments; and of performing all necessary qualification and acceptance testing on the completed EME packages to assure the specified performance and reliability. Westinghouse also provided integration support at Hughes of the EME package into the spacecraft, and launch support at Cape Kennedy.

The basic functional components of the EME package are shown in Fig. 1. Telemetered commands from earth are decoded by the satellite telemetry receiver and fed to the EME package; experimental data is pulse-frequency coded by the EME circuitry and fed to the satellite telemetry transmitter for transmission to earth.

Encoder

The basic function of the encoder is to generate signals to control the sequence of gathering information from the experiments and to convert the experimental data into a 10-millisecond burst of frequency. The output of the encoder is fed to the satellite telemetry modulator to modulate the carrier.

The sequence for encoding experimental data is controlled by the encoder programmer, which generates the format for the encoder. This format, in the form of a 256-position matrix (16 frames and 16 channels), determines the order in which data is multiplexed through the encoder.

Experimental data arrives at the encoder as a pulse stream, a binary word (four parallel bits), or an analog signal (0 to 5 volts). In addition to data from the experiments, certain housekeeping parameters such as voltage, current, and temperature measurements are also encoded for telemetering to earth.

The two basic data paths through the encoder are analog and digital, and can be traced in Fig. 2. Analog data is gated through input subcommutators (which provide time-division multiplexing, controlled by programmer gating signals) to one of four analog oscillators. Oscillator output frequency is determined by this input voltage (15 kilohertz for zero volts input to about 5 khz for 5 volts input). All four analog oscillators are connected to

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The ATS Program

The Applications Technology Satellite Program (ATS) has begun supplying additional knowledge of the near-earth environment, as well as performing various meteorological, communication, and navigational experiments. The first two satellites in the program were launched in late 1966 and early 1967. Five satellites will eventually be launched, the last scheduled for late 1968. Each ATS satellite will carry a mix of experimental equipment, including, on the ATS-A, ATS-B, and ATS-E missions, the Environmental Measurements Experiment (EME) packages that gather the near-earth environmental data.

The three EME packages combine varying groupings of from five to seven specific measurement experiments. These experiments are being provided by industrial, university, and government laboratories. NASA's Goddard Space Flight Center, which directs the ATS program, contracted to Westinghouse the design, fabrication, and integration and test of the EME packages for the A, B, and E missions. Each package will accommodate the experiments and will provide the data automation, encoding, command, and power supply circuitry needed to operate them.

The first flight model EME (for ATS-B—a schedule reshuffle by NASA after the missions had been identified accounts for the ATS-B being first) was shipped to the Hughes Aircraft Company, the ATS prime contractor, in April 1966. The satellite (renamed ATS-1) was successfully launched and orbited from Cape Kennedy on December 6, 1966 by an Atlas-Agena vehicle. This satellite is spin-stabilized in a synchronous orbit (altitude of 22,400 miles). Data received from the satellite indicates that its EME package is operating as specified.

The ATS-A/EME flight model was delivered to Hughes in October 1966 and the spacecraft (renamed ATS-2) was launched on April 5, 1967. This gravity-gradient stabilized satellite was to achieve a circular orbit at medium altitude (6,500 miles). A launch mishap placed it instead in an elliptical orbit, varying from a perigee of 115 to an apogee of 6,500 miles, thus taking it through the peak intensities of the Van Allen radiation belts. Despite exposure to this severe radiation environment, the EME has functioned properly to date.

The ATS-E/EME is still in the design phase, with the ATS-E launching scheduled for late 1968. This spacecraft will orbit at synchronous altitude and will use gravity-gradient stabilization.

Table I—EME Experiments for ATS-B and ATS-A Missions

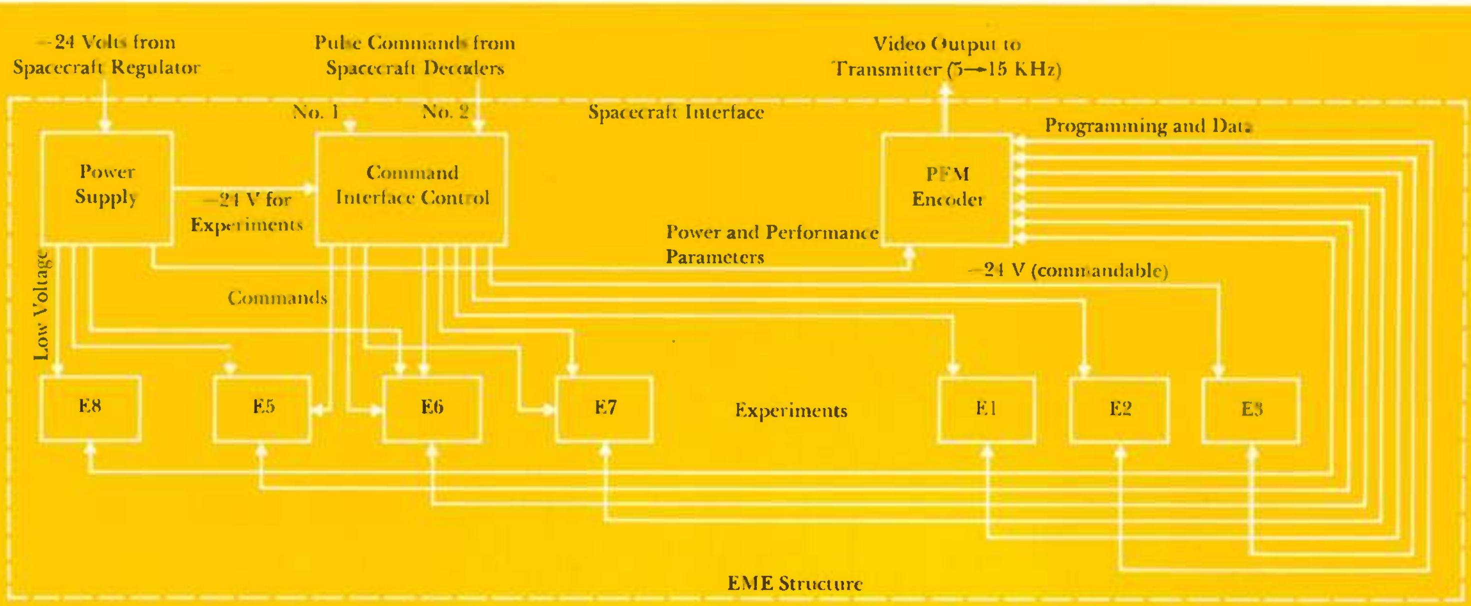
*Experiments**	*ATS-B*	*ATS-A*	*Purpose*	*Source*
Magnetometer (E1)	X		Measures distant magnetosphere field.	UCLA
Suprathermal Ion Detector (E2)	X		Searches for suprathermal particles and motions.	Rice University
Omnidirectional Particle Detector (E3)	X		Studies electron and proton flux and spectrum.	Aerospace Corp
Particle Detector (E5)	X		Measures flux of energetic electrons, protons and radiation.	Bell Telephone Lab
Electron Spectrometer (E6)	X	X	Measures short-term variations in directional flux of low energy electrons.	Univ of Minnesota
Solar Cell Damage (E7)	X	X	Determines life characteristics of cells and coverings.	NASA-GSFC
Thermal Coating (E8)	X	X	Determines effectiveness and life of selected coatings.	NASA-GSFC
Particle Detector and VLF (E9)		X	Particle detector gathers data on electron and proton flux and spectra. VLF detects very low frequency radio signals.	Bell Telephone Lab
Particle Detector (E10)		X	Measures flux and distribution of protons.	Univ of Cal (San Diego)
Radio Astronomy and Electric Field (E11)		X	RA detects and measures cosmic noise signal strength. EF measures potential difference of electric field in magnetosphere.	NASA-GSFC

**One experiment (E4) originally scheduled for ATS-B was not ready in time and was removed from the flight.*

Table II—EME Subsystems for ATS-B and ATS-A Missions

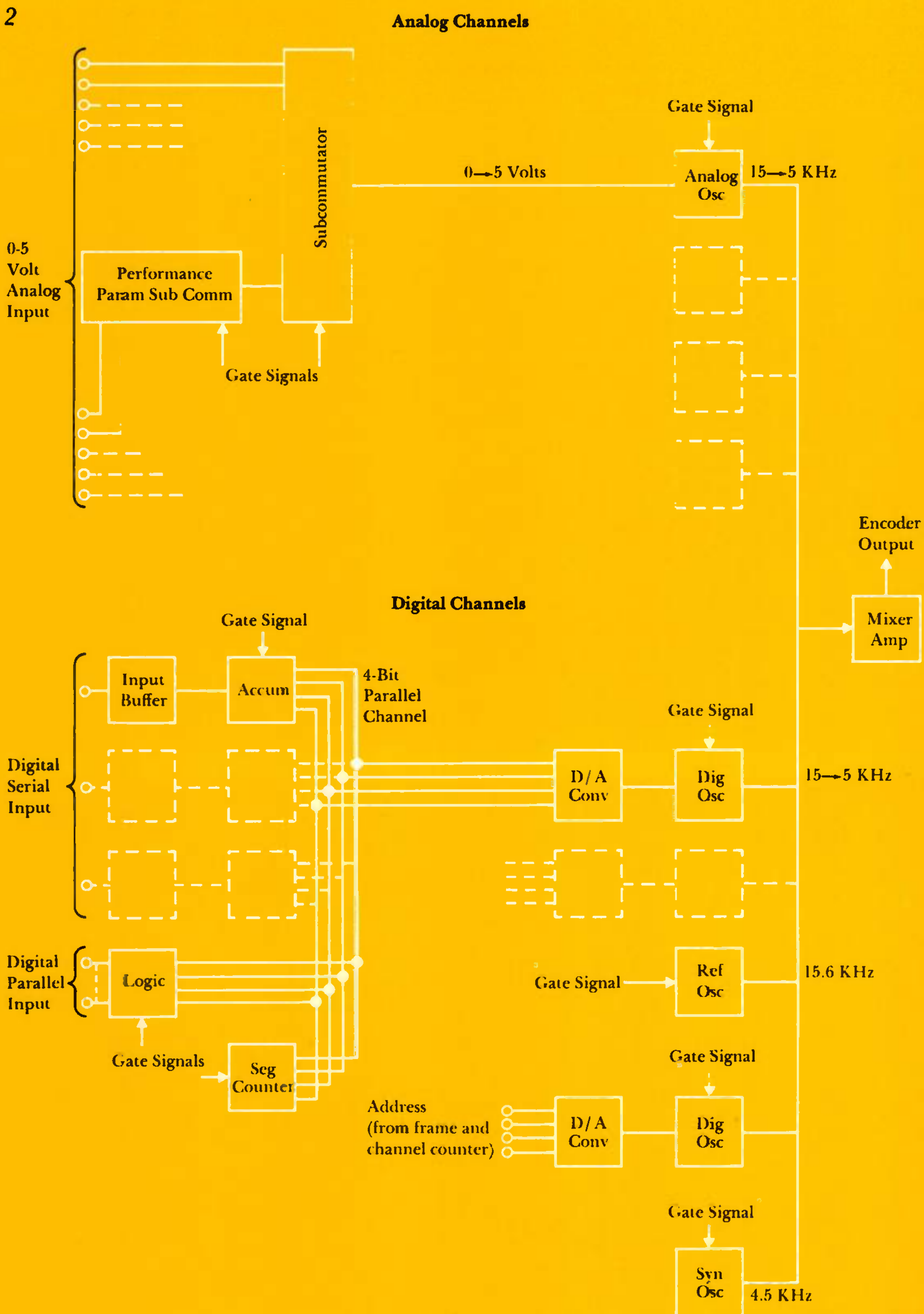
Subsystem	*ATS-B*	*ATS-A*	*Purpose*
Telemetry Encoder	X		Converts analog and digital experiment outputs to PFM format.
Telemetry Encoder plus Auxiliary Encoder		X	Both encoder packages operate together to convert analog and digital experiment outputs to PFM format.
Power Supply*	X	X	Supplies regulated voltages to encoder and various experiments.
15-Volt Regulator		X	Used with Power Supply to supply regulated voltages to the RA/EF experiments (E11).
Command Interface Control*	X	X	Converts spacecraft commands to usable signals and functions.
Structure*	X	X	Provides cable interconnections and suitable dynamic and thermal environment.

**Substantially different design for each mission.*



1—Basic functional components of the EME-B package, which carries seven experiments (see Table I).

2


Analog Channels
0-5 Volt Analog Input
Subcommutator
Performance Param Sub Comm
Gate Signals
0→5 Volts
Gate Signal
Analog Osc
15→5 KHz
Encoder Output
Mixer Amp
Digital Channels
Gate Signal
Input Buffer
Accum
4-Bit Parallel Channel
Digital Serial Input
D/A Conv
Dig Osc
15→5 KHz
Digital Parallel Input
Logic
Gate Signal
Ref Osc
15.6 KHz
Gate Signals
Seg Counter
Address (from frame and channel counter)
D/A Conv
Dig Osc
Gate Signal
Syn Osc
4.5 KHz

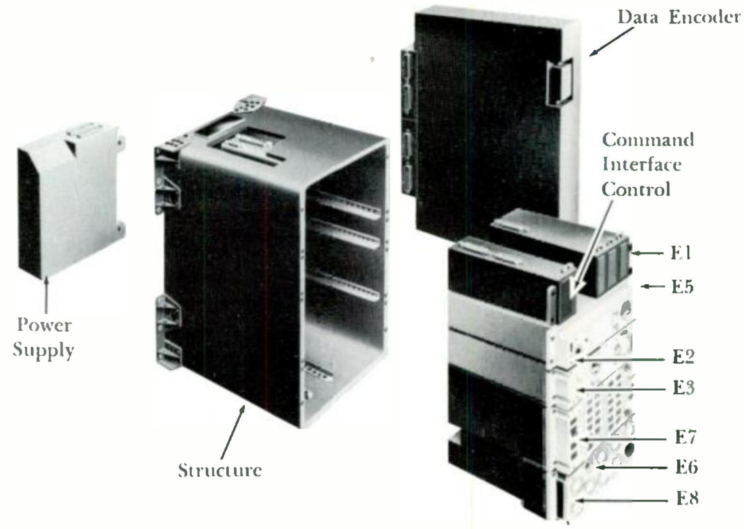
the input of the mixer amplifier. As each analog oscillator is gated on, its output passes through the mixer amplifier to the satellite telemetry modulator.

Most of the digital data from the experiments enters the encoder in the form of a pulse stream. The serial pulses are counted by an accumulator during an integration period. The accumulator total is gated out, four bits at a time, to one of two digital-to-analog (D/A) converters. Digital input in the form of a four-bit binary word is gated directly to the D/A converter. Each D/A converter has an associated digital oscillator that develops an output frequency (15 khz to 5 khz) proportional to input.

Experimental data is gated through the encoder for telemetering to earth in a programmed sequence, or format. A complete sequence consists of 16 frames, each frame divided into 16 separate channel transmissions. A channel is of 20 milliseconds duration—the first 10 milliseconds are occupied by a 15.6-khz reference signal, and the remaining 10-millisecond period contains data. The first channel position (channel zero) in each frame is used for transmitting identification or synchronizing signals: even-numbered frames carry a frame address, which is used at the ground station to determine position in the format; odd-numbered frames carry a 4.5-khz synchronizing signal that is used by the ground station for synchronizing purposes. Reference signals, frame-address signals, and synchronizing signals are developed in the encoder and gated into the data train being telemetered to earth.

Programming Signals—The programmer

3



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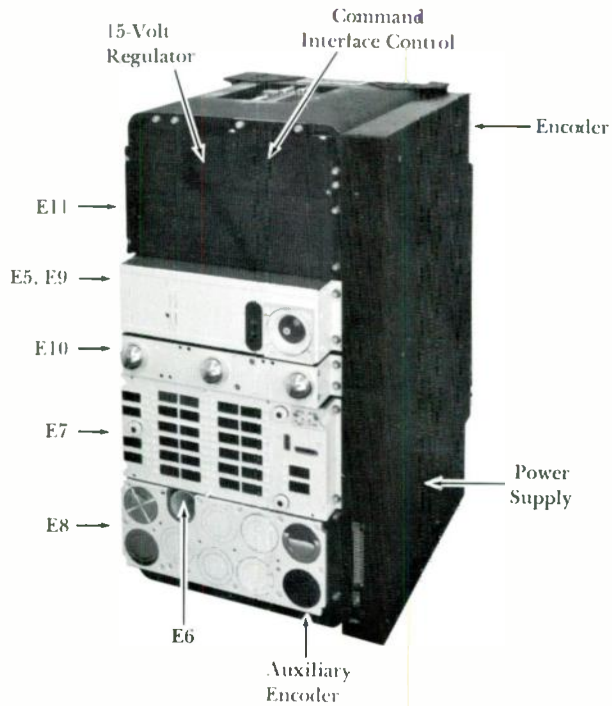


2—The EME encoder provides two basic paths—one for analog and the other for digital data from the experiments. Signals from the reference oscillator, synchronizing oscillator, and address digital oscillator are gated into the data train being transmitted to earth for use in decoding.

3—Basic components and experiments for the ATS-B mission are shown. (Refer to Table I for experiment identification).

4—EME flight package for the ATS-A mission is shown assembled. (Refer to Table I for experiment identification).

generates all the internal gating signals for the encoder and all control signals required by experiments, except for commands and controls generated by the experiments themselves. The programmer is not a physically distinct section of the encoder. Decoding circuits are located in many different parts of the encoder, usually associated with the circuits to be controlled.

Command Interface Control

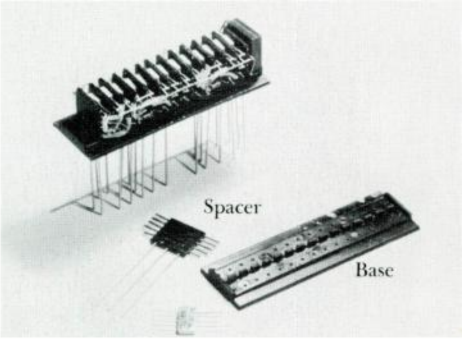
The principal function of the command interface control (CIC) is to provide interface compatibility between the outputs of the Hughes Command Decoders, which decode the telemetered commands from earth, and the EME experiments.

The commands from the decoders are in the form of 50-millisecond pulses. The CIC circuits change these input commands in signal amplitude, pulse duration, and voltage as required to drive relays and dc isolated single-shot multivibrator circuits. These CIC components switch power to the various experiments, drive remote relays, and provide low-voltage-level pulse commands to several experiments for changing experiment modes of operation, i.e., gain, bias, etc.

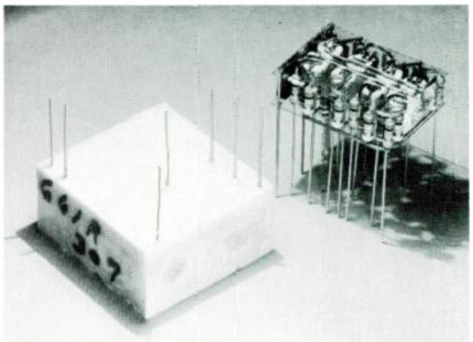
Power Supply

The EME power supply provides regulated voltages to the encoder and certain experiment loads. Power from the satellite is supplied to two independent dc-to-dc transistor inverters; one supplies power to the EME encoder and the other supplies power to the experiment loads. Two independent inverters permit fault isolation between encoder and experiment circuitry and allow operation of only the encoder without operating experiment loads. Since some of the experiment loads operate directly from the satellite electrical bus, independent operation of the encoder makes it possible to operate only a few experiments at a time (for power conservation, fault isolation, etc.).

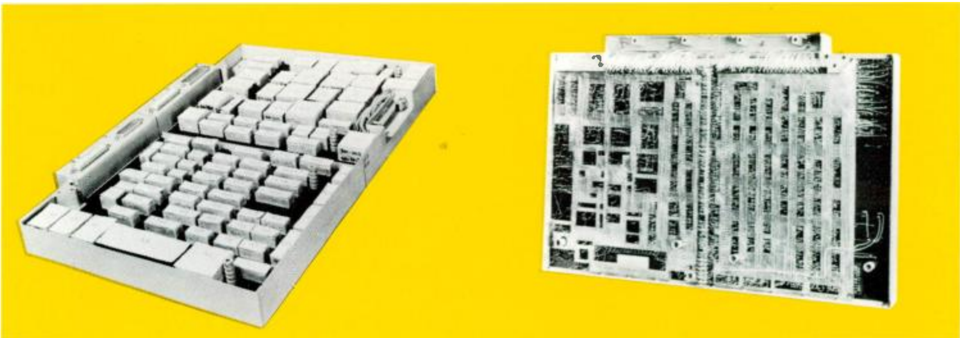
Both inverters are synchronized by means of a stable frequency inverter driver. If the inverter driver should fail, the inverter design is such that the inverters continue to operate as saturating transformer inverters. The stable-fre-



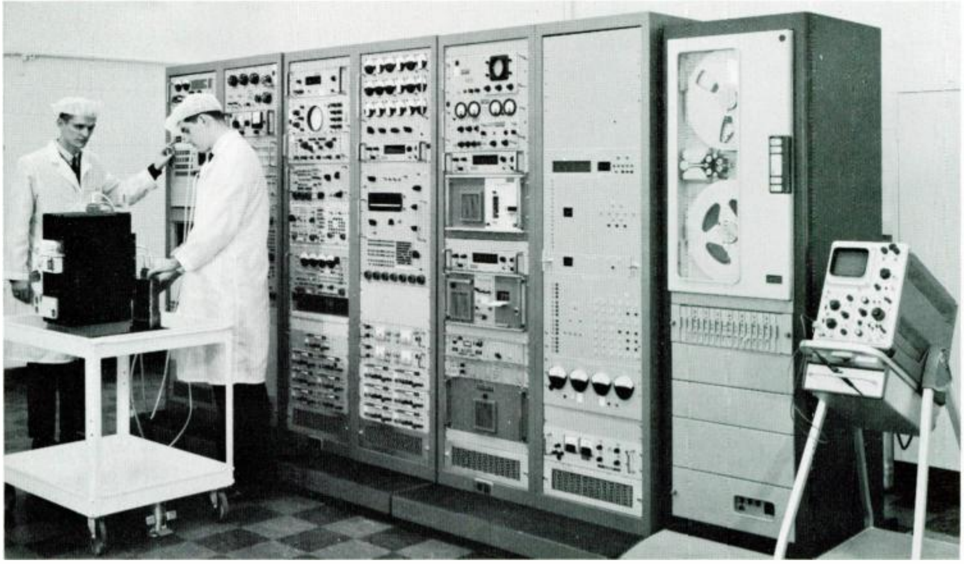
5—Comb-type submodule is used for housing integrated circuits.



6—Cordwood submodules are used for housing components other than integrated circuits. After assembly and test, the submodules are encapsulated in polyurethane foam.



7—Encapsulated submodules are mounted in the encoder module, and after interconnection and test, the wired module is encapsulated on both sides with polyurethane foam.



8—Test stand/data reduction unit decodes the telemetered data from the spacecraft. Experiment outputs through the encoder can be received through rf coax-jumpers or rf data link.

quency driver mode is desirable because noise frequencies are limited to specific bands. However, degraded operation is possible with the inverters free running.

Total current supplied to the EME package is sensed with a magnetic amplifier circuit, and output of this current sensor is fed to the encoder to provide a means of measuring the total EME power consumption. Since parts of the EME can be turned on one by one, that part which draws excessive current can be located with the current sensor.

Voltage Regulators—Where precise voltage regulation is required (such as the encoder oscillators, which require 7.5 volts ± 18 millivolts), the inverter outputs are fed to independent series-type voltage regulators. The encoder regulators are basically the same as the experiment regulators, except for overload protection. Each experiment regulator is designed to turn off in the event of an overload, so that the faulted load is isolated from the rest of the loads and the power supply is protected.

The encoder power supply is turned on and off by a telemetry command through the spacecraft quadrant regulator. No other command is necessary to place the encoder in operation or for the encoder to perform its functions.

EME Structure

The EME is a self-contained structural and experimental entity, with the experiments, encoder, power supply, and command interface control unit integrated into a single package.

Physical arrangements of the experiments for ATS-B and ATS-A are shown in Figs. 3 and 4, respectively. The structure, a wrapped aluminum honeycomb box with necessary brackets and mounting plates, is secured at the rear to the spacecraft center tube for mechanical support and heat rejection. The extended front face, which looks at the space environment through an 8- by 12-inch aperature in the spacecraft solar cell array, contains the sensors for all instruments except the electron spectrometer (E-6), which has a narrow view angle through a tunnel in the thermal coat face, and the magnetometer (E-1). The magnetometer flux-gate sensor head is remotely mounted on a boom extending from the spacecraft on mission ATS-B. (On mission ATS-A, the antennas and preamplifiers for the radiometer experiments are also remotely located in the spacecraft.)

As indicated by Fig. 4, the support electronics are mounted in the structure interior except for the telemetry encoder, which is attached to the side of the structure. The entire EME assembly is approximately 18½ inches high, 10 inches wide, and 13 inches deep. Its weight is approximately 46 pounds for ATS-B and 52 pounds for ATS-A.

Component Packaging

To maximize the use of the limited weight and volume allotments, the electrical components of the encoder, power supply, and CIC are compactly packaged into functional submodules, such as oscillators, mixers, accumulators, voltage regulators, inverters, etc. Two types of submodule construction are used: Comb-type submodules house the integrated circuits, and cordwood type submodules are used for other electrical components.

Comb submodules (Fig. 5) are assembled on black phenolic bases. Spacers molded of the same material, and containing conductors, are mounted in prelocated positions in the base. The integrated circuits are fitted in between the spacers. Welding ribbon is then used to make the necessary wiring interconnections on the side of the submodule.

Cordwood submodules (Fig. 6) are assembled by stacking and supporting the components between two sheets of polyester film. The components are interconnected on both sides of the submodule with welding ribbon. All encoder and CIC submodules (both comb and cordwood) are then protected by encapsulation in a lightweight polyurethane foam. Power-supply submodules are encapsulated in a heat-conducting epoxy resin.

The encapsulated submodules are mounted in the encoder, power supply, and CIC modules (subsystems) and interconnected (Fig. 7). The wired modules are encapsulated on both sides with the same lightweight polyurethane foam.

Ground Support Equipment

The EME ground support equipment consists of the test stand/data reduction unit shown in Fig. 8. The six racks and tape recorder contain a fully integrated set of test equipment for use in complete system test or test of any individual element of the experiments. Experiment outputs through the encoder can be received through rf coax-jumpers or rf data link (pfm telemetry), the format decoded, and individual instrument or full format readouts presented as data frequencies, hexadecimal (base 16) numbers, or decimal numbers. The data is presented in real-time visual displays and real-time printouts, and may be tape recorded. The test stand contains all necessary power supplies and controls for completely independent operation of the EME.

Reliability

The EME is designed to have an in-orbit life expectancy of three years. Achieving this necessitates building-in and verifying a high level of reliability using such techniques as reliability engineering, product quality control, and comprehensive design and test procedures.

The mechanical and electrical designs were developed with emphasis on the need for long life and survival in the space environment. Electrical components were carefully selected and tested to be sure that their performance would exceed both standard commercial specifications and military specifications. All fabrication and assembly steps were carefully monitored. Extensive electrical testing was performed at all reasonable completion levels; thus, submodules were tested both before and after encapsulation. After submodules have been wired into the encoder, power supply, and CIC modules, these modules in turn were tested both before and after encapsulation. After integration of these modules with the experiments, the completed EME's undergo final tests, full environmental qualification tests on the prototype model of each EME configuration, and acceptance tests on the flight models. Reliability was an all-pervading concern from the initial design effort through the final equipment delivery.

New Use for the Fuel Cell . . .
A Combustion Control for Furnaces

W. M. Hickam
J. F. Zamaria

This new system for sensing and controlling the fuel-air ratio in furnaces has passed its first experimental tests.

Although the high-temperature fuel cell has yet to be useful as a practicable electric power source, it may soon enable the basic fossil-fuel generating plant to become more efficient than it has ever been before. This fuel cell, operated in reverse as an oxygen detector, became commercially available in 1962 and has been applied to a variety of analytical problems requiring a sensitive and fast-responding oxygen gauge. The device may now have widespread industrial application—as a monitor to sense and control the oxygen content in furnaces, thereby insuring the hottest, cleanest fire possible. Although still in early stages of development, both research scientists and control engineers believe that this new control arrangement can be made practicable and can both improve the efficiency of the furnace and reduce air pollution products from the smokestack.

Fuel Cell Operation

The basic component of a high-temperature fuel cell is the ceramic electrolyte, composed mainly of zirconia. At elevated temperatures (400-1000 degrees C), this material permits oxygen in the form of $O^=$ ions to migrate through its crystal structure by activated diffusion. The electrolyte has high ionic conduction and negligible electronic conduction under this condition. Other gases, such as nitrogen, hydrogen, water vapor, carbon monoxide, and carbon dioxide cannot penetrate the electrolyte.

To make a fuel cell from this ceramic electrolyte, porous electrodes are applied to both sides of the electrolyte. Oxygen or

W. M. Hickam is a Physicist and J. F. Zamaria is an Associate Engineer at the Westinghouse Research Laboratories, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

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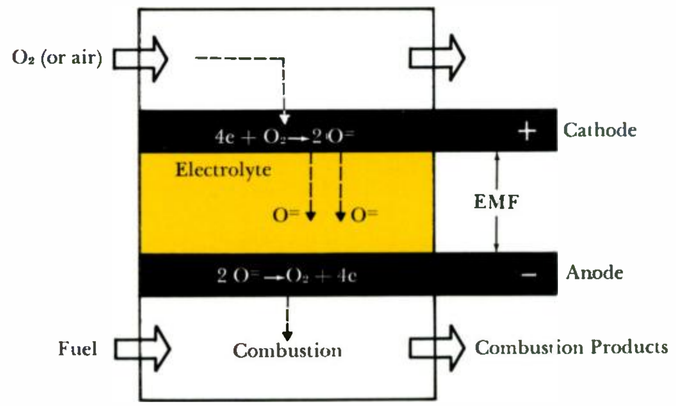

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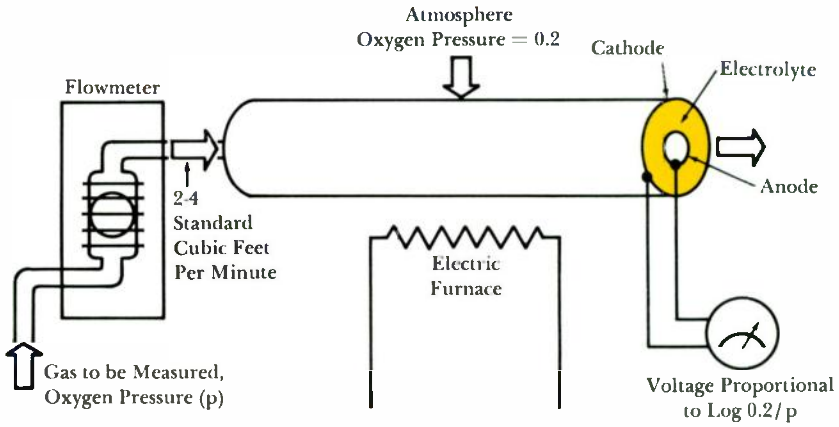

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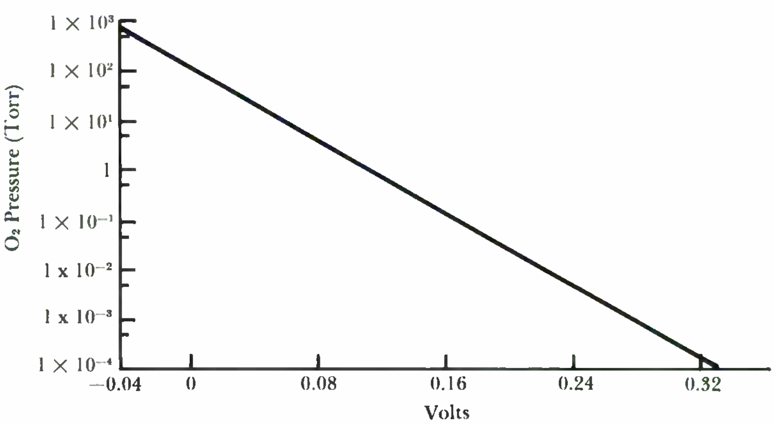


1—Principle of operation of oxygen concentration fuel cell.

2—Oxygen detection consists of passing gas to be measured through heated fuel cell. Voltage generated by cell is displayed on the voltmeter.

3—Pressure versus voltage relationship for the oxygen detector.

air is applied to one electrode and hydrogen or other fuel to the other (Fig. 1). An oxygen molecule from the air adsorbs on the electrode (or cathode), dissociates, acquires four electrons, and enters the ceramic electrolyte as two $O^{=}$ ions. The electrode is positively charged by the process.

The two $O^{=}$ ions pass through the heated ceramic electrolyte to the opposite electrode (anode) and give up the four electrons, causing this electrode to become negatively charged and thus creating a voltage between the electrodes. The oxygen reacts with the fuel to form combustion products, which keeps oxygen pressure low at the anode and heats the electrolyte. The fuel cell is a source of electricity so long as there is a difference in oxygen concentration on the two sides of the electrolyte.

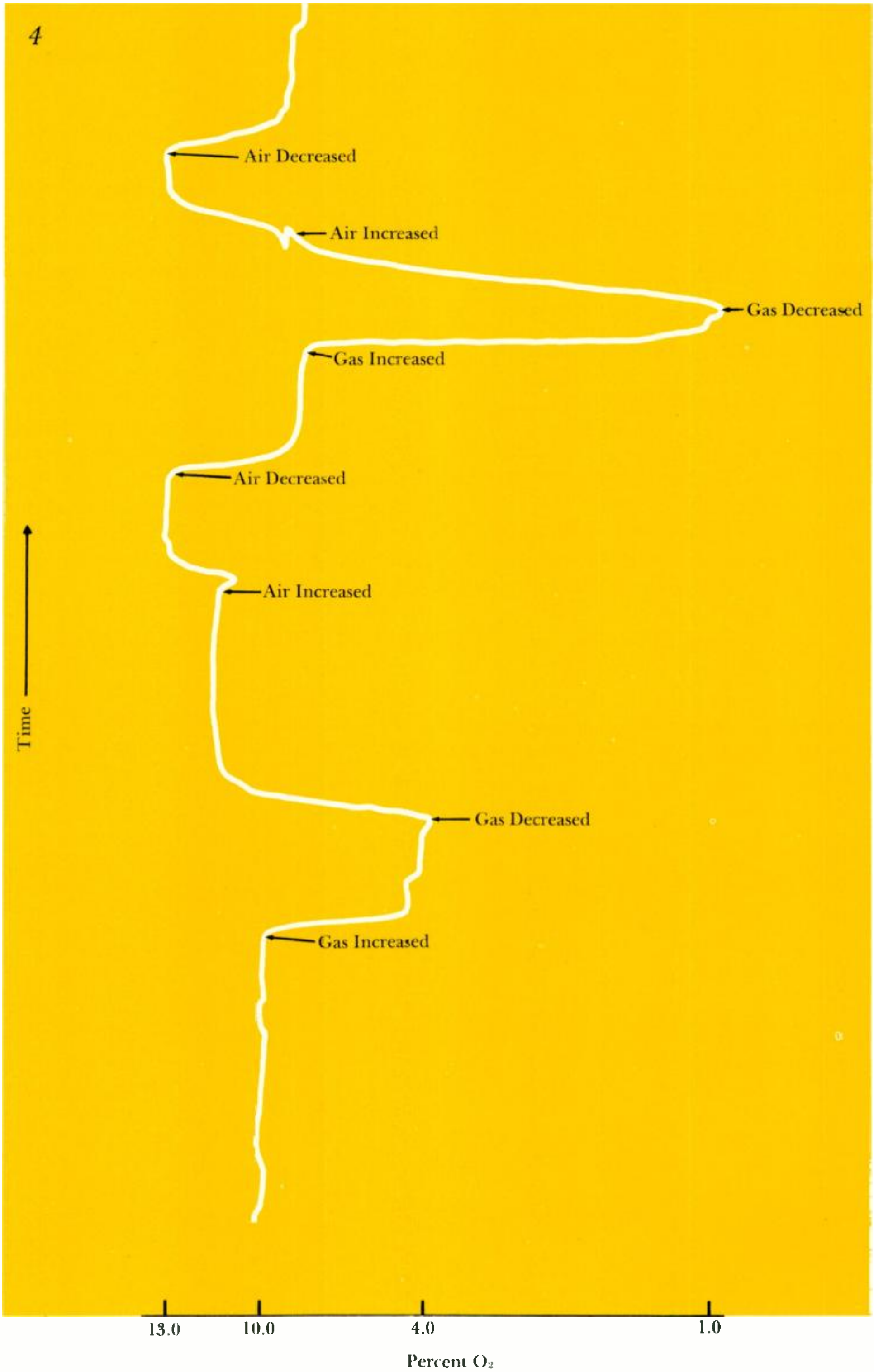
As An Oxygen Detector

When the electrolyte is hot but the fuel supply is removed, the fuel cell becomes an extremely sensitive oxygen detector (Fig. 2). The voltage developed across the electrolyte is proportional to the logarithm of the ratio of the reference partial pressure of oxygen in the air at atmospheric pressure (0.2 atmosphere) at one electrode and the partial pressure of oxygen being measured (p) at the other electrode. The voltage generated for an electrolyte at operating temperature is given by the expression

$$\text{EMF} = 0.056 \log 0.2/p.$$

The polarity of the voltage will indicate whether p is greater or less than the reference atmospheric pressure oxygen.

The oxygen detector developed at the Westinghouse Research Laboratories consists of an electrolyte of lime-stabilized zirconium oxide, in the form of a hollow tube about 7½ inches long and 0.2 inch in diameter. Porous platinum electrodes are placed on the tube's inside and outside surfaces to provide the terminals from which voltage generated by the cell is picked off. The tube is heated (electrically) to 850 degrees C, and the gas to be measured is passed through the inside of of the tube at about 0.05—4 standard cubic feet per hour. Normal atmosphere on the outside electrode provides the ref-



4—Fuel cell detector responds to changes in oxygen content in the stack as air flow and fuel flow to the furnace are adjusted by manual control.

erence oxygen pressure (0.2 atmosphere).

Since limited currents can be drawn from the cell without altering the voltage output, oxygen concentration can be measured with a conventional voltmeter connected to the two electrodes. The response time of the cell to a variation in oxygen concentration is a fraction of a second. The detector will operate over a wide range of oxygen pressure, as shown in Fig. 3.

Monitoring Furnace Flue Gases

Of the various potential applications for the oxygen detector, one of the most promising and most recent to be investigated is use of the cell as a device to sense oxygen concentration in furnace flue gases and provide a corrective signal for furnace combustion control.

Too much oxygen in a furnace flue means that too much air is entering the furnace for the amount of fuel being burned. This excess air cools the fire, lowers the amount of heat obtained from the fuel, and carries unused heat up the stack. On the other hand, too little oxygen in the flue indicates too rich a fuel mixture, which causes incomplete combustion and excess pollution products. Thus, by measuring the oxygen content in the flue gases, the detector can continuously monitor conditions of combustion. The direction of the deviation from a preset value of the detector's output signal specifies the direction of control required to restore optimum conditions, and the magnitude of the signal indicates the amount of correction required.

Initial tests of the fuel cell in a furnace control system have been conducted on a gas-fired heating furnace at the Westinghouse Research Laboratories. Samples of flue gas were fed to the fuel-cell detector by tapping into the furnace stack. The initial tests measured the detector's ability to pinpoint oxygen content in the stack, its ability to follow the normal automatic cycling of the furnace, and its response to air flow and fuel flow changes introduced manually. The results of the latter test are shown in Fig. 4.

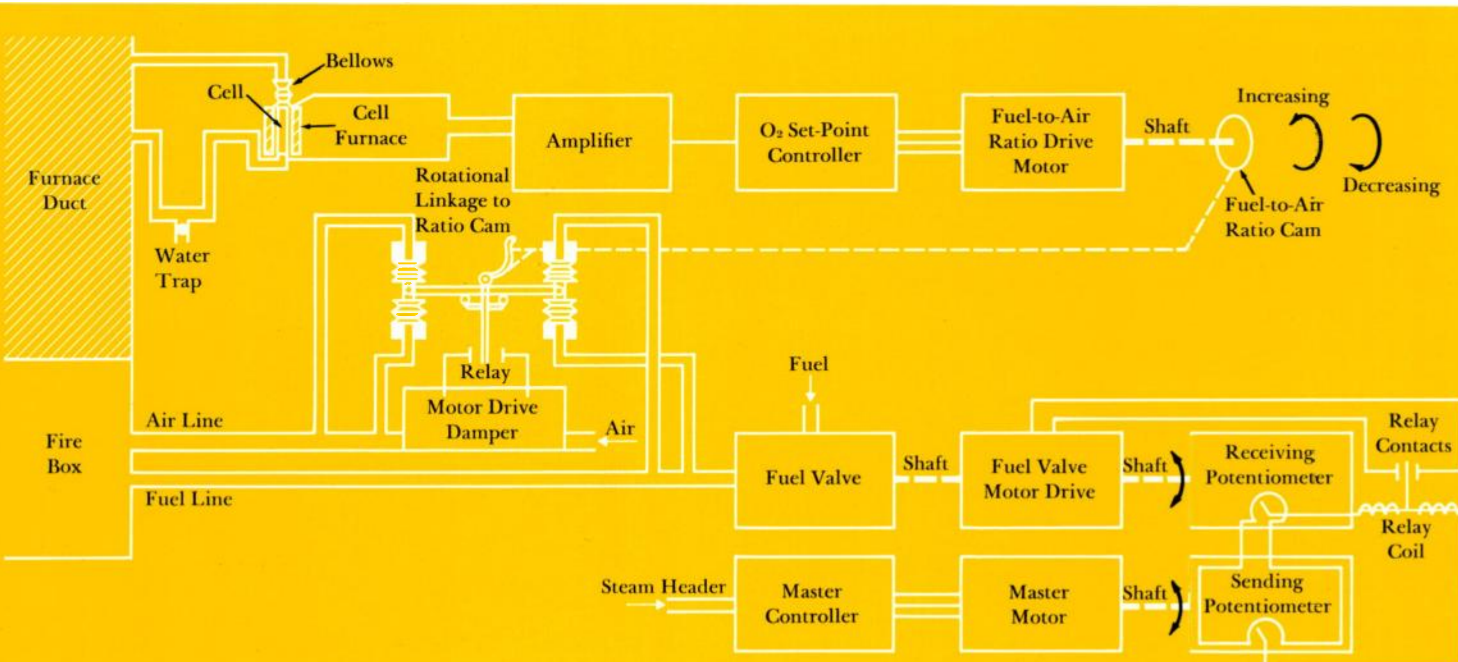
The detector was next incorporated into a simplified control system for this same furnace, using a furnace control system (Fig. 5) developed with engineers from Hagan Controls Corporation (a division of Westinghouse). The signal voltage from the oxygen detector was amplified and used to control electric motors that operate the fuel valve and the air damper of the furnace. This experimental system successfully maintained oxygen concentration of the flue gas at preset levels within the control range of the equipment.

Additional tests confirmed the response time of the fuel-cell oxygen sensor to be less than one-tenth of a second, and demonstrated the ability of the cell to sustain long-time continuous operation.

An Automatic Control System

In large furnace systems, even a fraction of a percent departure from maximum efficiency results in considerable fuel waste. The preliminary investigations described support the feasibility of using a fuel-cell oxygen detector to maintain the fuel-air ratio at an optimum level. Modifications and refinement of the oxygen detector and control system described should permit the development of a full-scale control that is precise, fast, and fully automatic.

5—Proposed automatic control system uses a fuel-cell oxygen detector to monitor furnace stack gases.



Nuclear Reactor Design Checked with Scale Models

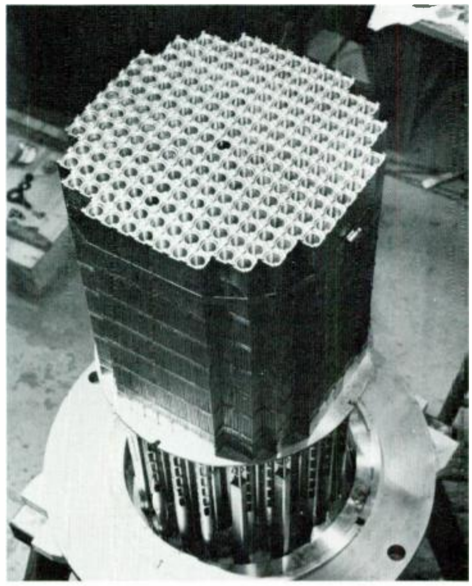
How does one go about proving the soundness of a large nuclear reactor's internal flow design? Checking the design in actual operation would involve a totally unacceptable gamble with safety and performance, so scale models are employed at the Westinghouse PWR Plant Division.

The model in the photographs is a 1/7 scale model of the internal components of the pressurized-water reactor being built for Consolidated Edison Company's Indian Point Number Two nuclear power plant. Scheduled for commercial operation in 1969, the four-loop plant will have a gross capacity of 873 mwe.

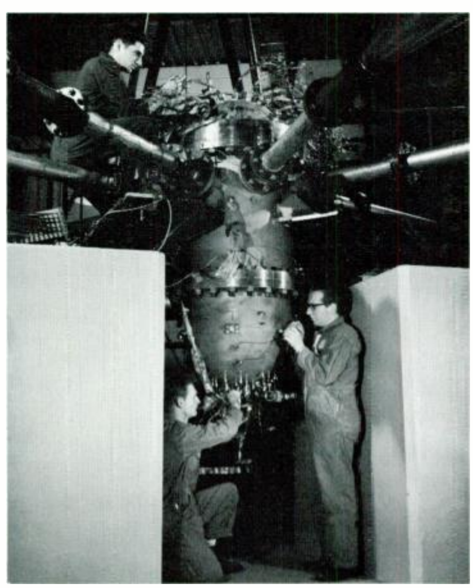
The model is about six feet high by three and one-half feet in diameter. It serves a dual purpose: providing a means of checking main coolant pressure drops and flow distributions within the reactor vessel's interior, and providing for accurate measurements of flow-induced vibration and stresses in the vessel's internal components.

The model is fabricated entirely of stainless steel. Its interior contains remote-indicating instrumentation and various structures simulating the core, support plates, and other major components and hardware. Its core simulation unit, for example, is composed of more than 9600 individual hollow rods sealed at each end. Each rod is about 0.148 inch in diameter by 16 inches long and forms part of the array that goes to make up one of the 197 simulated fuel assemblies.

Pressure-sensing elements installed at strategic points around the precisely detailed internal components are connected to remote manometer boards. About 500 separate pressure readings are obtainable under a wide range of simulated operating conditions. In addition, some 70 strain gauges indicate stresses resulting from varying pressures and their attendant subjection of internal components to vibration. With this data, potential trouble areas can be pinpointed and any necessary changes made at the design stage, thereby insuring optimum operational safety and reliability of the actual components when installed in the nuclear power station.



Nuclear reactor scale model for flow testing includes accurately simulated internal components such as the fuel rods seen here. Before final assembly, the model was instrumented with pressure-sensing elements for measuring coolant pressure drops and flow distributions inside the pressure vessel, and with strain gauges to measure stresses and vibrations.



Tests were run on the model in a water test loop at the Atomic Power Divisions' Waltz Mill facility. The test method locates potential trouble areas so that changes can be made in the design stage.

The Indian Point power station is located near Peekskill, New York. The first nuclear plant there, for which Westinghouse designed the replacement core, is a 275-mwe unit that went into operation in 1962. A third unit, of 965-mwe capacity, has been ordered from Westinghouse; it will be a duplicate of Unit 2. It is scheduled for completion in 1971 and will bring total capacity of the nuclear station to 2200 mwe. Consolidated Edison Company plans, at that time, to retire 700 mw of coal- and oil-fueled generating capacity in New York City, a move that will contribute to reduction of air pollution there.

Automatic Train Control System Will Serve Bay Area Transit

Electronic digital techniques are combined with traditional safety principles in the automatic train control and communication system being developed for San Francisco's Bay Area Rapid Transit (BART). A Prodac 250 computer will operate the many trains as a coordinated transportation system. Because of the short time between trains during peak periods, the computer will continually monitor and, when necessary, adjust schedules and performance to optimize passenger handling over the entire system.

System supervision will require only a part of the available computing time, so the computer will perform other tasks off line. One is simulating the transit system to study effects of schedule changes.

Detection and separation of trains will be accomplished by a control system that makes use of proven track circuits. Signals transmitted through the rails will be picked up by car-mounted antennas connected to the digital control equipment on board. The traditional fixed-block concept will be used to maintain fail-safe train separation.

Between stations, train operating speed will be determined by a precise closed-loop speed control system, again using the track circuits to transmit speed signals. Digital wired-logic equipment on the cars will translate these signals into speed commands.

When a station stop is called for, train control will be transferred from the wired-logic speed control equipment to a small digital computer. This computer will use signals from a wire loop laid between the rails in a square-wave pattern to bring the train to a precise stop at the station platform. Each train will have from two to ten cars, two of which will be "intelligent;" i.e., they will act as head-end control cars, one for each direction of travel.

Aluminizing Extends Lifetime of Transformer Tanks

Aluminizing is providing the electric utility industry with a more reliable transformer tank finish, one that is highly resistant to corrosive environment. Coating the steel tank with aluminum furnishes added protection for distribution transformers located in coastal regions where corrosion is a major problem. Since aluminum is anodic to steel, the coating is protective even if it is scratched.

The effectiveness of metalized aluminum coatings has been demonstrated by test programs conducted by the American Welding Society. After exposure of specimens for nine years in various marine and industrial environments, no corrosion of the base steel was detected despite the fact that some of the aluminum coatings were only three mils thick.

Aluminum is flame-sprayed onto steel transformer tanks to impart corrosion resistance. The treatment is especially valuable for service in coastal areas and in corrosive industrial environments.

The surface to be aluminized must be rough and clean, so a tank being metallized at the Distribution Transformer Division is first shotblasted to remove any accumulated rust and produce the required roughness. Remaining dust particles are removed by air-blasting. Melted aluminum wire is then sprayed onto the surface, producing a thin layer of flattened interlocking particles mechanically bonded to the steel.

Since the flame-sprayed aluminum is slightly porous, a sealing material is applied. It infiltrates the pores of the coating, establishing a permanent barrier. This sealing material is the Westinghouse paint finish used for many years on distribution transformers. Any needed surface repairs are made by simply washing away dirt and applying a new coat of paint, a type of repair not possible with tanks protected by vinyl finishes.

Breeder Power Reactor Plans Being Developed

A research project has been launched to develop plans for a demonstration nuclear power plant employing a sodium-cooled fast breeder reactor with a capacity between 200 and 400 mw. The goal of the three-phase program is a plant that could be placed under construction within three years.

The first phase, begun earlier this year, will provide the Advanced Reactors Division with the technical base to design and construct a prototype fast breeder plant. It will take until 1970 and will cost approximately $35 million. Phase two, construction of the prototype plant, will take about five years and will be followed by the final phase during which the plant will demonstrate its technical and economic feasibility. Division officials hope to have a plant in operation by 1975 or 1976. They are enlisting the support of electric utility companies and the U.S. Atomic Energy Commission for the development program.

Breeder reactors generate more nuclear fuel than they consume, and they also provide more efficient and better-balanced use of fuel. Thus, they could decrease the cost of electric power.

Impeller Hubs Induction-Hardened in High-Volume Facility

Impeller hubs for torque converters are being induction hardened in a controlled atmosphere by Chrysler Corporation at its Highland Park plant. The operation consists of heating by radio-frequency energy, and then water-quenching, in an atmosphere of high-purity inert gases that protects the hubs from oxidation.

The hubs formerly were heat-treated to medium core hardness, and the surface was superficially work-hardened as the parts went through different machining stages. With the new process, however, a specific area can be selectively hardened to meet rigid metallurgical requirements. The process hardens hubs of AISI 1137 steel to 0.020- to 0.040-inch case depth and hardness of Rc 50 minimum.

Use of r-f energy also enables the hub to be hardened after it is welded to the converter casing, saving setup and handling time. All finish machining is done after welding and before hardening. This involves precision machining followed by finishing the journal area to a finish of 10 microinches. Since no scale forms during hardening, further machining and polishing are eliminated.

The installation was developed and supplied by the Industrial Equipment Division. It consists of a 50-kw 450-kc r-f oscillator and two automatic work-handling machines, processing 185 parts per hour on each of two lines. The machines are hydraulically operated and electrically controlled; they are interlocked so high-frequency energy alternately transfers from one heat station to the other. Thus, as one station is heating and quenching one size hub, the other station is positioning a similar part into the inductor and atmosphere chamber and waiting for the transfer of energy.

Torque converters are fed to the load station, impeller hub up, by a gravity roll conveyer. At a signal, the parts are clamped in the overhead carrier and transferred to the heat station over a lift-rotate mechanism. There they are unclamped and the carrier returns to the original position as the lift-rotate elevator raises the parts to the heating chamber. The elevator becomes a scanning unit on the downstroke as the hub is heated and quenched, and the part is rotated to obtain a uniform heat pattern. In the *down* position, the heated part is moved to the discharge ramp by a transfer mechanism while a new part comes to the heat station, completing the cycle. Each machine cycles automatically as long as parts are delivered to it. When necessary, the two machines can operate independently.

Mapping Radar Being Applied in Geoscience Research

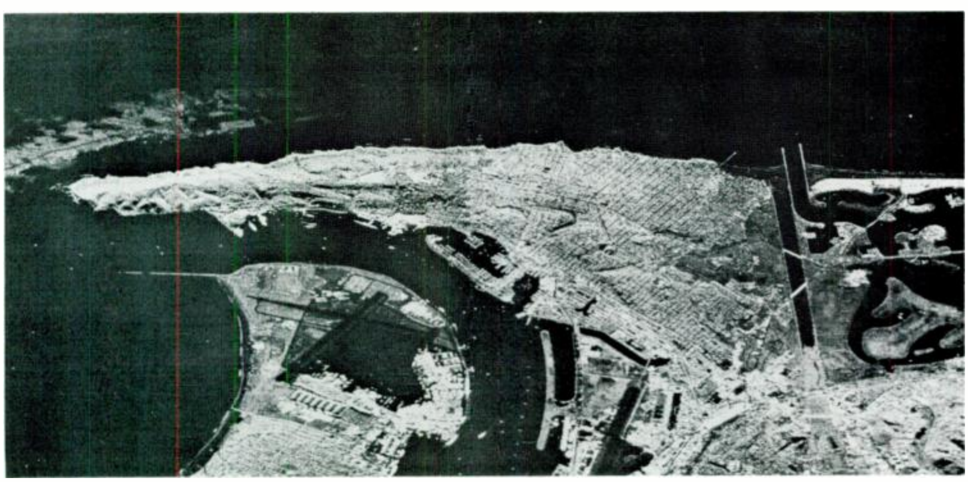
An airborne mapping radar is being used to provide information for the National Aeronautics and Space Administration's earth science resources program. The mapping, or "side-look," radar can cover large areas in almost any kind of weather and at night, and the aircraft does not have to fly directly over the area being mapped. A large number of flights have been made over the past two years to obtain data on remote sensing techniques for the NASA program.

The mapping radar provides high-quality imagery by analyzing radar return signals and displaying them on photographic film. By varying signal characteristics and processing methods, scientists can use it for such purposes as large-scale topographic mapping, investigations of crops and soils, and profiles of geological characteristics. Other studies under way or being considered are sea-ice mapping, sea-state determination, polar ice-cap charting, and analysis of soil moisture content.

Use of radar enables geoscientists to capitalize on the unique characteristics of another part of the electromagnetic spectrum, the microwave region, in addition to the visible and near-visible regions. For example, the accompanying picture shows both the topography of the area and a vegetation characteristic—kelp beds off the tip of the peninsula at upper left. These beds are invisible at times to the eye or to a camera even on sunny days, depending on light conditions. Because they reflect radar signals differently than their surroundings, however, they are visible to the radar.

The mapping radar was developed for the U.S. Army Electronics Command by the Aerospace Division of the Westinghouse Defense and Space Center.

A mapping radar made this picture of San Diego harbor as part of a project to obtain data on remote sensing techniques. The radar is a "side-look" type that converts return signals into a pictorial display on film.



New Literature: Series of Books on Physical Sciences

Publication of *The Binding Force* and *Seven States of Matter* completes the series of Westinghouse Search Books. These books are designed to go beyond the scope of standard textbooks, supplementing conventional courses in the physical sciences with expert presentations of some of the most fundamental problems—and advanced knowledge—in modern science. Each volume is written by scientists at the Westinghouse Research Laboratories and treats a single basic subject from the points of view of several disciplines.

The Binding Force, by Daniel Berg, Robert Charles, Lawrence Epstein, Milton Gottlieb, Lyon Mandelcorn, James McHugh, and Armand Panson, tells why an understanding of the elements of quantum mechanics has become essential to an understanding of the chemical changes and the properties of matter that result from interactions and motions of electrons. It also describes the various ways in which atoms of the elements attach themselves to each other to form chemical bonds.

Seven States of Matter, by Milton Gottlieb, Max Garbuny, and Werner Emmerich, describes states in which matter shows physical properties vastly different from those in the familiar solid, liquid, and gas states. The plasma state is one; another is seen in the strange superfluids that exist near absolute zero temperature. Even at normal temperatures and conditions, there are states of matter hard to classify and possessing unusual and little-known properties—quickclay, monatomic films, and liquid crystals, for example.

Crystals: Perfect and Imperfect, by Allan Bennett, Donald Hamilton, Alexei Maradudin, Robert Miller, and Joseph Murphy, tells how molecules, atoms, and electrons are arranged within various crystals and other solids, and explains how these lattice formations determine the material's chemical and physical properties. Included are discussions of atomic bonding, crystal symmetry, the theory and methods of growing crystals, and how crystal lattice imperfections are created and used.

Math and Aftermath, by Robert Hooke and Douglas Shaffer, presents the story of the applied mathematician's most important activity—finding the problems and preparing them for solution. It includes a description of the process of creating models to bridge the gap between physical explorations and the mathematical problems that aid those explorations.

Science by Degrees: Temperature from Zero to Zero, by Jack Castle Jr., Werner Emmerich, Robert Heikes, Robert Miller, and John Rayne, explains the meaning of temperature as it pertains to the motions of atoms and molecules. It also tells how changes in temperature affect the behavior of matter and how temperature phenomena observed in the laboratory lead to new strides in technology.

Electrons on the Move, by Allan Bennett, Robert Heikes, Paul Klemens, and Alexei Maradudin, discusses the bonding relationships between electrons, atoms, and molecules and goes on from there to explain energy levels, ionized gas, structure of solids, and the control and use of electron motion.

Energy Does Matter, by Werner Emmerich, Milton Gottlieb, Carl Helstrom, and William Stewart, describes how energy fits into the framework of the physics, mathematics, and engineering disciplines.

The Science of Science, by Russell Fox, Max Garbuny, and Robert Hooke, describes the orderly inquiry into the nature of the universe that is known as scientific research. It discusses scientific methods, their effectiveness and limitations, and their applications in today's research.

All of the books are published by Walker and Company, New York, New York. Price is $5.95 each.

Products for Industry

Thyristor motor control for fractional-horsepower dc motors is a static adjustable-speed unit that is compact and fast in response. Uses include multiple drive systems and production applications demanding high-quality drive performance, as in positioning controls and machine-tool drives. The unit is for use with dc motors rated through one horsepower. Characteristics include 100:1 speed range with near full-load torque over the entire range, ±½ percent speed regulation, low drift, and inherent static reversing. Design and packaging are easily modified to suit individual applications; dimensions normally range from 18 x 16 x 9 inches to 28 x 18 x 10 inches. *OEM Drive Group, Westinghouse Industrial Systems Division, Buffalo, New York 14240.*

Insulating varnish, developed for hot bond strength in Class F and H electrical systems, can be used for treating and curing coils, rotors, stators, armatures, and transformers. The B-142-1 varnish air-dries to a firm flexible film, has short baking time, retains high bond strength at operating temperatures, and does not soften under heat. *Westinghouse Insulating Materials Division, Trafford, Pennsylvania 15085.*

Image intensifier intensifies images of low light level with little distortion, high resolution, and high signal-to-noise ratio at high gains. It consists of a two-stage magnetically focused image converter and a power supply. The intensifier can be used as a directly viewed light amplifier or as an image amplifier when coupled to a video camera tube. Viewing screen is 1.5 inches in diameter. Magnification is unity, and typical center resolution is 36 lines per millimeter. Applications include observation of transient events and viewing under conditions of very low light level. *Westinghouse New Products Division, P.O. Box 8606, Pittsburgh, Pennsylvania 15221.*

Vacuum circuit interrupter is a ceramically insulated vacuum-sealed mechanical switch that requires virtually no maintenance. It carries 200 amperes and interrupts 2000 amperes on a 14.4-kv circuit. The WL 23220 interrupter is used in power transmission and distribution equipment to remove short-circuit faults, and also for high-voltage or high-current switching, transformer tap changing, capacitor switching, and motor control. Service life is at least 20,000 operations, and the interrupter is fireproof and explosion-proof. Maximum arcing time to interruption is 0.018 second. Frequency rating is 50/60 cps and maximum line-to-line voltage 15.5 kv. *Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902.*

Type 224 high-power thyristor is water cooled for exceptionally high current capacity in a small package—three inches square by 6 inches high. Applications are in power supplies for welding, large motors, and other uses. The thyristor is rated 400 amperes half-wave average, 630 amperes rms through 1200 volts. Its heat sink requires a water flow of 1½ gallons a minute. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

Image Intensifier

Vacuum Circuit Interrupter

Type 224 High-Power Thyristor

About the Authors

V. E. Vrana has been designing dc machinery for the past 20 years, a background of experience that serves him well in his present work of designing, developing, and applying dc motors for use with the new thyristor dc power supplies. Vrana graduated from the University of Nebraska in 1941 with a BSEE. He joined Westinghouse on the graduate student course but was called into military service that same year, serving in the U.S. Army Corps of Engineers.

Vrana returned to Westinghouse and was assigned to the Motor Division, where he designed dc machinery for naval, marine, steel-mill, and paper-mill applications before taking on his present work with motors for thyristor power supplies. Among his achievements were development of the rod drive m-g set for the Skipjack class of nuclear submarines and design of propulsion generators and drilling motors for Project Mohole before it was canceled. He is now a fellow engineer in large ac/dc product engineering. Besides his design work, Vrana has taught dc machinery courses for the past 10 years in night school.

H. M. Chen, F. R. Karr, and **F. A. List Jr.** are pioneers in the science of using computers for motor design calculations. Starting with relatively primitive computers and limited programs in the 1950's, they and their coworkers have expanded the scope of design calculations for electrical machinery and, in doing so, have improved the machinery itself and reduced delivery time.

Chen graduated with a BE from National Amoy University, Amoy, China, in 1949. He worked as a radio manufacturing engineer with the Ministry of National Defense, Taiwan, until 1955. Then he entered Kansas State College as a graduate assistant, earned his MSEE there in 1957, and joined the Westinghouse Motor and Control Division (now the Motor and Gearing Division). He has worked since then on the programming of engineering problems for solution with digital computers and has been responsible for major program developments.

Karr earned a BSEE and a BS in Engineering Administration at Michigan Technological University in 1951 and joined Westinghouse on the graduate student course. His first permanent assignment was in manufacturing supervision in the Welding Department. He transferred to the Motor and Control Division in 1953 as a motor designer and began programming in 1957. Since 1963 he has served in management positions with responsibilities for computer programming, cost reduction, motor design, and licensee services. Karr is now manager of engineering services, responsible for technical programming, management systems, and licensee services. He earned an MBA in 1964.

List, as manager of large ac/dc engineering at the Motor and Gearing Division, is responsible for the design and development of dc motors and generators and large ac motors. He graduated from the University of Kansas in 1946 with a BSEE degree and has since done graduate work at the University of Pittsburgh. List joined Westinghouse on the graduate student course in 1946 and, the following year, went to the Motor and Control Division as a design engineer. In 1958 he became a supervising engineer for computer application. He then served successively as manager of business systems, assistant manager of motor engineering, and manager of dc engineering. He assumed his present position in 1965. Among the developments List has been responsible for or has contributed to are the design and development of a line of single-phase integral-horsepower motors, high-shock power supplies for submarine service, dc mill motors to AISE standards and large ac motors of high performance.

Leon W. Rustad began his career as a mathematics instructor after graduation from Yankton College (1936) with a BA in Mathematics. In 1940, he joined the U.S. Army Air Corps to become a radar instructor, and in 1942 switched services to become an electronics officer in the U.S. Navy.

Rustad came with the Westinghouse Air Arm (now Aerospace) Division in 1946 to work as a design engineer. To complete his transition from mathematics to engineering, he spent his evenings at Johns Hopkins University and obtained his BS in Engineering in 1950. He then took a four-year course in Business Management Administration which he completed in 1955.

During the past 15 years, he has served as supervisory engineer and as section manager on the design of radar systems, fire-control systems, and spacecraft electronic systems. Recently, he has been assigned to the EME Project, described in this issue. He is presently Program Manager of ATS work that has been contracted to Westinghouse, which includes the EME equipment.

The article that describes the automated techniques used to design and manufacture surface condensers was written by **E. J. Barsness, J. McLean,** and **A. R. Geesaman.**

Barsness graduated from Iowa State University with a BSME in 1958 and came with Westinghouse on the graduate student course. He was selected to attend the Company's advanced mechanics program (1958-9) and, with spare-time study, obtained his MSME degree from the University of Pittsburgh in 1960. Barsness was assigned to the development engineering department of the Westinghouse Steam Divisions late in 1959, where he worked in the areas of heat transfer, fluid dynamics, and thermodynamics. In 1966, he was assigned to the development and application section of the Heat Transfer Division.

McLean obtained his BS in Engineering from Lafayette College in 1951. He came with Westinghouse on the graduate student course, and accepted his first permanent position as a manufacturing engineer in the Westinghouse Air Arm (now Aerospace) Division early in 1952. McLean moved to the Steam Division in 1953, where he was made a supervisor of Industrial Engineering in 1956. In 1957 he participated in a Westinghouse sponsored exchange program with the Ford Motor Company. During this time he was assigned to several Ford plants working in the fields of equipment design, automation, and materials handling. He returned to the Steam Divisions in late 1958 to work as a staff supervisor in a facilities planning section.

In 1964, McLean moved to the Heat Transfer Division to become superintendent of manufacturing. He was made manager of operations, his present position, in late 1966.

A. Richard Geesaman Jr. graduated from Ursinus College with a BS in Mathematics in June 1964. He joined Westinghouse in January 1965 to work on numerical tool control. Most of his work has been in computer programming for design and manufacturing tasks.

W. M. Hickam and **J. F. Zamaria** have worked together to develop new uses for the Westinghouse oxygen gauge and their joint article describes its most recent potential use.

Hickam obtained his BS in Physics from Randolph-Macon College in 1941 and his MS in Industrial Physics from Virginia Polytechnic Institute in 1942. He joined the Westinghouse Research Laboratories to work on commercial mass spectrometers, and soon enlarged his activities to include helium leak detectors, monoenergetic electron sources for positive and negative ion studies, and continued studies of practical applications of mass-spectrometric techniques for analysis of gases, liquids, and solids. He is presently manager of mass spectrometry in the physical chemistry department of the Research Laboratories. In addition to providing mass spectrometry service to the Laboratories and to the company's manufacturing divisions, Hickam also works on such special projects as the oxygen sensor application and physical chemistry studies of liquid sodium.

Zamaria joined Westinghouse at the Research Laboratories upon completion of high school in 1951. He graduated from the University of Pittsburgh with a BS degree in 1966 by attending night school under the auspices of the Westinghouse educational program. While attending college, he served a hitch in the U.S. Army and worked in the mass spectrometry section of the physical chemistry department. There he developed his interest in mass spectrometry and gas measuring devices. Since graduating from college, Zamaria has spent most of his time on the application of the oxygen gauge to the furnace control system described in this issue.

This "spreading resistance probe" was developed for checking the quality of semiconductor devices at various stages of fabrication by measuring electrical resistance between many closely spaced points along the surfaces. When done by the present hand method, the procedure is delicate, tedious, and slow. The new instrument does the job automatically, at least 10 times faster, and with 1000 times the resolution possible with hand methods.

The instrument's developers at the Westinghouse Research Laboratories expect it to be especially useful for process evaluation and quality control in the manufacture of integrated circuits and other semiconductor devices. They also see it as a useful tool in research on crystal growth, semiconductor surfaces, and mechanical properties of materials.

The operator makes resistance measurements by lowering a probe, with a contact end only eight microns in diameter, under a microscope to the semiconductor surface. The instrument makes a measurement and then lifts the probe and steps the specimen a few thousandths of an inch to the next reading location. Probe location is accurate to within one micron. The system plots the measured data and punches out a paper tape used to feed the data into a computer for calculation of the electrical behavior implied by it.