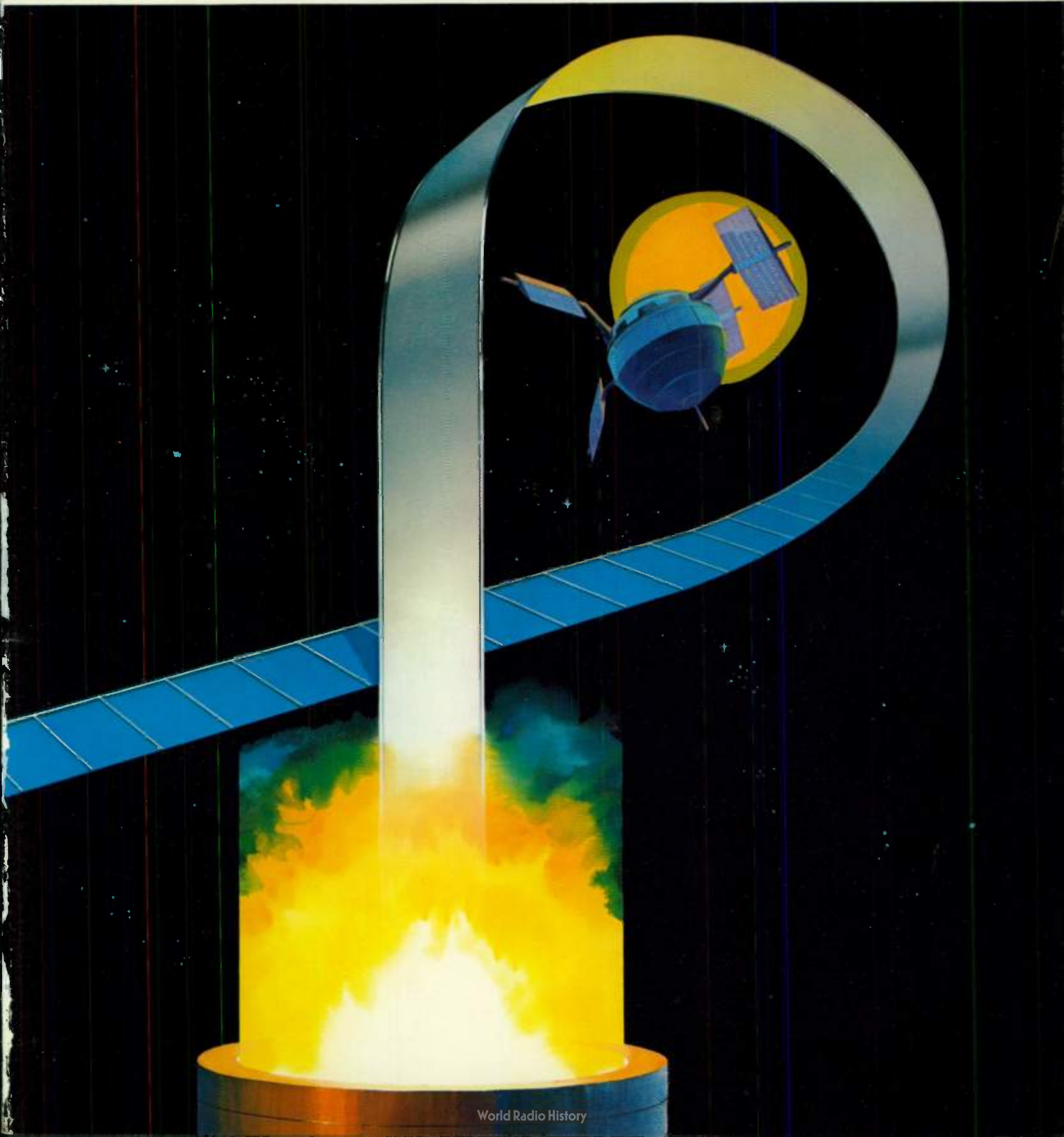
Westinghouse ENGINEER
March 1966



Operating Model of Apollo Lunar TV Camera

Live television from the moon will be broadcast by a camera similar to the above prototype during the first manned Apollo lunar exploration mission. The camera, called the Apollo lunar television camera, is being developed under a contract from the National Aeronautics and Space Administration by the Aerospace Division of the Westinghouse Defense and Space Center.

During the moon exploration mission, the compact camera will produce television pictures that will be relayed to earth and processed and distributed by the Apollo ground system to the world's television networks. The quality of the television pictures produced by the system will be virtually as good as those usually seen on home television receivers.

The Westinghouse-designed lunar television camera will be put into operation when the Apollo spacecraft is launched on the first lunar exploration mission. The camera will continue to transmit during the entire mission including the lunar exploration and flights to and from the moon.

The camera's primary scanning rate is 10 frames per second with 320 scan lines. It has a second mode of operation in which the scanning rate is 0.625 frame per second. This extremely slow scanning rate will enable more detailed observation of the moon's features.

Performance, reliability, and portability are essential characteristics in the Apollo lunar television camera. Eighty percent of its circuitry is, therefore, made up of molecular electronic functional blocks and thin film circuits. About 250 components make up the electronic portion of the camera. If standard components had been used throughout, 1300 would have been required.

The essentials of portability, and consequently light weight and compactness, and reliability dictated certain design constraints. These were: low power requirement, limited bandwidth, simplicity of operation and a 35-year mean-time-between-failures (MTBF) requirement. Other requirements were based on the design environmental conditions, such as ±250 degrees F ambient lunar temperature; 10^{-14} mm of mercury pressure; micrometeoroid and radiation bombardment.

The heart of the camera is the secondary electron conduction (SEC) image sensor. This type of tube was invented and developed by the Westinghouse Research Laboratories. It has the wide dynamic range needed to obtain good pictures at the very low light levels of earthshine during lunar night.

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Cover design: A new silicon single-crystal material in strip form, and the large-area solar cells made from it, form this month's cover design. A space vehicle was included by artist Tom Ruddy to indicate the principal present application of solar cells.

Recent Advances in Spacecraft Control

A. T. Monheit
A. G. Buckingham

Mechanical configurations of satellite vehicles are being developed to use the natural forces of space for control purposes.

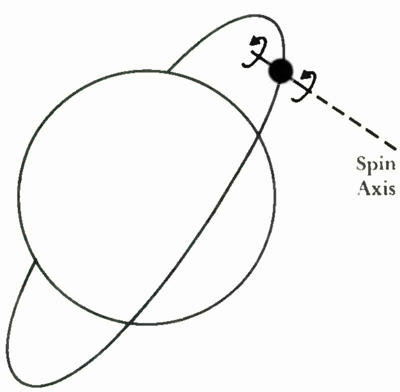
As the Space Age progresses, there is an increasing need for more precise spacecraft control as well as the need to enhance the reliability of these controls through the use of passive techniques. Scientific satellites, such as the Orbiting Astronomical Observatory (*OAO*) and the Orbiting Solar Observatory (*OSO*), must have extremely sensitive *attitude control* to achieve pointing accuracies to within a fraction of a second of arc. Accurate attitude control is also required for operational satellites in areas of communication, navigation, and weather reconnaissance where earth-pointing is required. For satellites that must be kept "on station," such as the *Syncom* communications satellite, *orbit-position control* is required. To be economically feasible, all of these satellites must have long lifetimes.

Spacecraft control systems maintain the satellite in the desired attitude and orbit position as the satellite is subjected to a variety of disturbing torques generated by atmospheric drag, solar radiation, magnetic field, gravity gradient, micrometeroid impact, and even movement of components within the satellite itself. In some of the more recent control concepts now under development, spacecraft designers are finding ways to convert some of these disturbing torques into useful control torques. Such control techniques will help make possible the long operational lifetimes so necessary for economic application of satellite systems of the future.

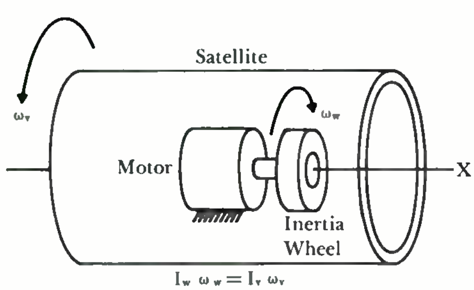
Attitude Control

Early spacecraft were basically spin stabilized, as shown in Fig. 1. These vehicles could achieve long periods of attitude control with a minimum expenditure of energy. Spin-stabilized spacecraft such as the *Syncom* (communications satellite at synchronous altitude) are still very much in use. Antennas located on the spin axis will cause a doughnut-shaped beam to remain in a relatively fixed position with respect to earth. However, spin stabilization does not permit the use of narrow-beam antennas that can provide such significant economies in transmitting power. For example, at medium altitudes (6000 miles), an earth-pointing satellite requires only one sixth the transmitting power required by a spin-stabilized satellite; at synchronous altitude (22,400 miles), transmitting power can be reduced by a factor of 12.

A number of methods are being developed to provide the complex attitude control required on many of today's satellites and at the same time minimize the energy requirements aboard the satellite:



1—Spin stabilization fixes one axis in space with respect to earth. Antennas are placed on this axis.



2—With inertia-wheel control, unwanted angular momentum can be absorbed by accelerating the inertia wheel.

Inertia-Wheel Control—In orbiting observatories such as the *OAO* and *OSO*, the satellite must scan portions of the celestial sphere in a defined pattern that requires oscillating control of satellite attitude. The extremely fine pointing accuracies required cannot be achieved with magnetic or gravitational forces because these forces are weak and not predictable to the precision required for this application. The angular momentum exchanges required to generate the oscillating scan patterns would require an excessive mass to be stored aboard the vehicle if mass expulsion devices, such as gas jets, were used. Therefore, inertia-wheel control provides the primary means of attitude control for this type of satellite.

The principle of inertia-wheel control is shown in Fig. 2. A single-axis control is illustrated, but the same principle applies to the three-axis system generally used. As the motor accelerates the inertia wheel in one direction, the reaction torque of the motor acting on the satellite causes the satellite structure to accelerate in the opposite direction. The satellite obeys the well-known physical law: angular momentum of a system must remain constant, assuming no external disturbing torque. Thus, angular momentum can be transferred between components of the system—from the satellite structure to the inertia wheels, or from the wheels to the structure, depending on the control direction required. For example, to rotate the satellite structure clockwise, the inertia wheel is rotated counterclockwise. The momentum transfer obeys the familiar relationship,

$$I_w \omega_w = I_v \omega_v$$

where I_w and I_v are the moments of inertia of the wheel and vehicle respectively, and ω_w and ω_v are the corresponding angular velocities. Thus, oscillating control of satellite attitude can be obtained by transferring momentum back and forth between the structure and the inertia wheels.

When external disturbing torques cause unwanted satellite rotation, the disturbance is sensed and inertia-wheel speed altered to absorb the unwanted angular

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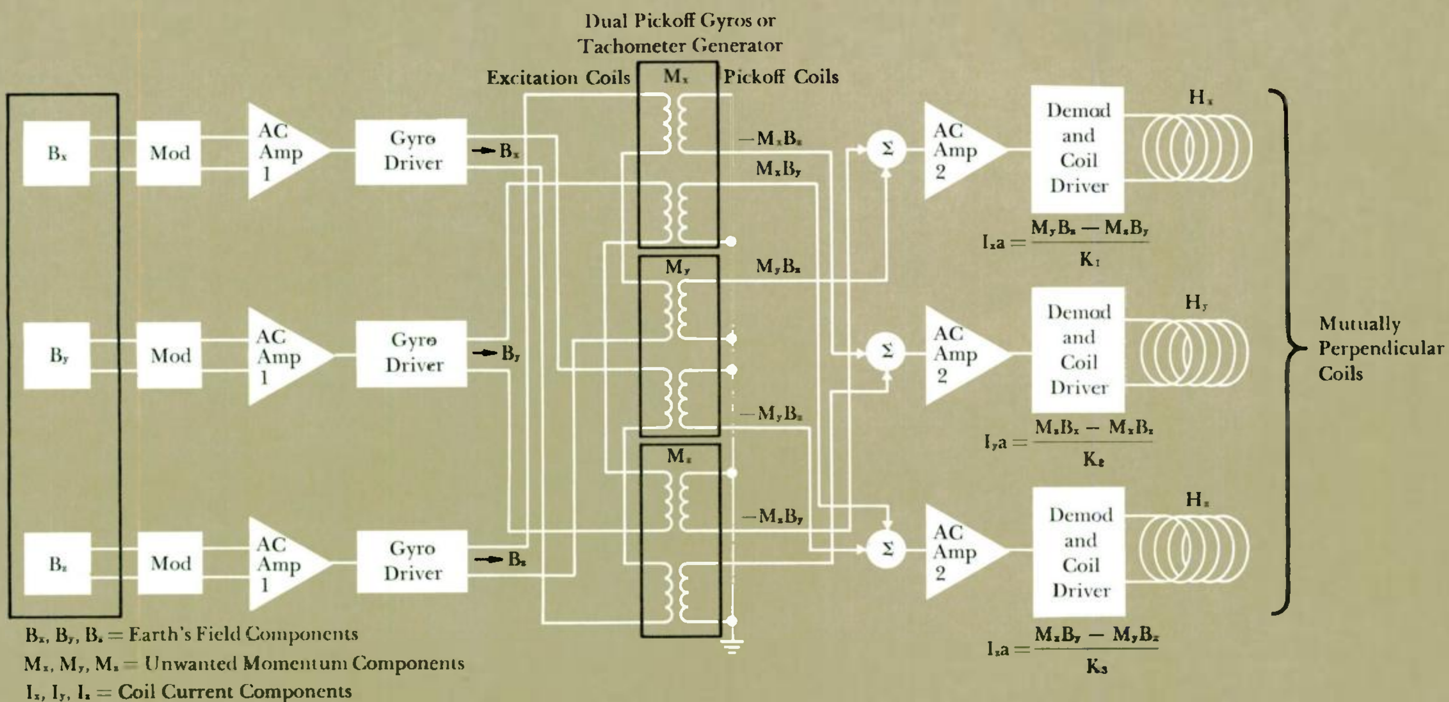
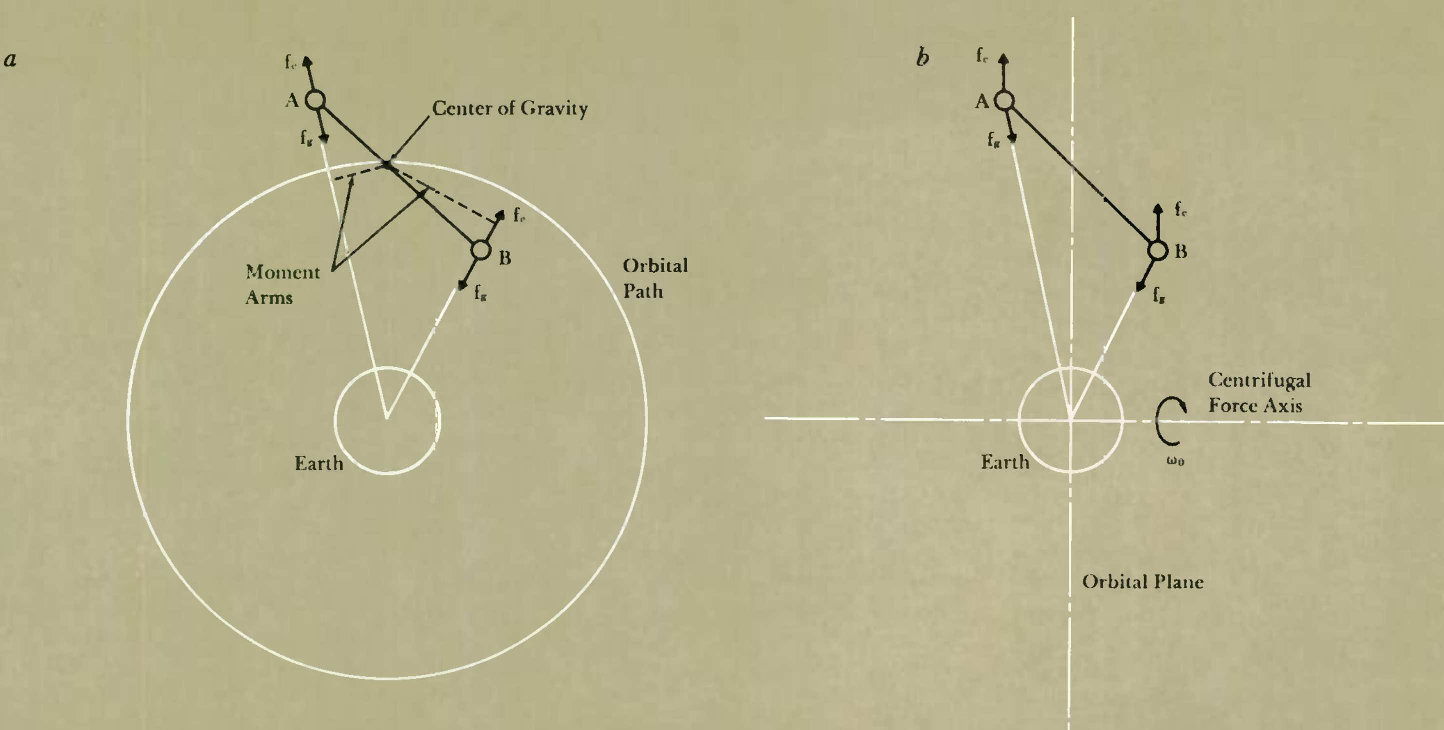
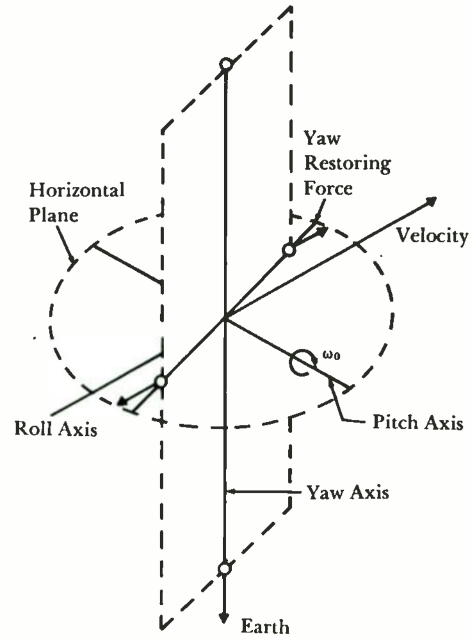


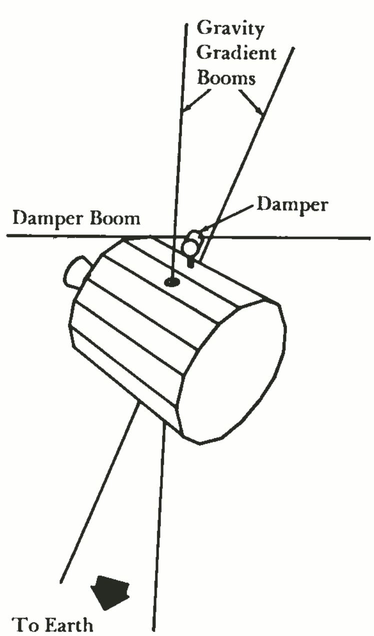
3—Momentum transfer system uses current-carrying coils to generate a flux vector that interacts with the earth's field.



4—Hypothetical "dumbbell" satellite configuration demonstrates the use of gravity gradient for a motivating torque in the pitch axis *(a)* and in the roll axis *(b)*.



5—Yaw restoring force is developed by the rotation of an earth-pointing satellite about the pitch axis as the satellite orbits the earth.



6—"Ames X" damping system uses long rod coupled to satellite through a magnetic hysteresis or eddy-current damper.

momentum. The angular momentum from external forces builds up over a period of time and is absorbed by the wheel until maximum wheel speed is reached. At this time, the momentum of the wheel must be "dumped." This can be accomplished by a gas or magnetic control system that applies torque to the satellite in the opposite direction to the external disturbing torque so that momentum transfer can be used to slow down the inertia wheel.

Magnetic Control—The strength of the earth's magnetic field varies from about 0.5 oersted at the earth's surface to about one percent of this amount near synchronous altitude. Any magnetic material that is aboard the spacecraft tends to align itself with the earth's field. Therefore, efforts are made in satellite design to make the net magnetic moment add up to zero except for deliberately generated control torques. The basic torque-producing mechanisms that can be implemented are the hysteresis and eddy-current losses in materials, and the torque produced by magnetic materials or current-carrying coils.

In recent years, these mechanisms have been used in a variety of satellites. The *TRAAC* (Transit Research and Attitude Control) satellites used hysteresis and eddy-current loss in iron rods to despin the satellites; the magnetic moment of a coil was used to align the satellite with respect to the earth's field. The *Tiros* weather satellite carries current-carrying coils that can be switched on and off from ground to change the orientation of the spin axis. The *OAO* and *OSO* scientific satellites use three mutually perpendicular coils to generate a flux vector, which interacts with the earth's field to remove unwanted momentum accumulated by on-board reaction wheels. Coil currents are programmed by a completely on-board system (Fig. 3), which measures the amount of unwanted momentum and the earth's field strength and direction, and generates the required coil currents to provide continuous attitude correction. Magnetic coils controlled from the ground will be employed on NASA's *Advanced Technology Satellite* to generate the desired control torques.

The mechanism of hysteresis and eddy-current loss in magnetic materials is also being used in the gravity gradient dampers to be described.

Gravity Gradient Control

Earth-pointing satellite control systems that use gravity gradient as the motivating torque are now being developed, and have the advantage of being passive systems. The torque produced by gravity gradient is a function of orbital altitude, and of satellite configuration and attitude. Gravity gradient torques are minute, only about 10^{-5} to 10^{-6} foot-pounds, but since the perturbing torques are also minute, gravity gradient control can be effective in controlling spacecraft attitude to within one to five degrees.

Gravity gradient control can be illustrated with the "dumbbell" configuration shown in Fig. 4. This hypothetical arrangement has two equal masses rigidly connected by a weightless rod. When the satellite is in a stable orbit, the total gravitation force about its center of gravity pulling it towards earth,

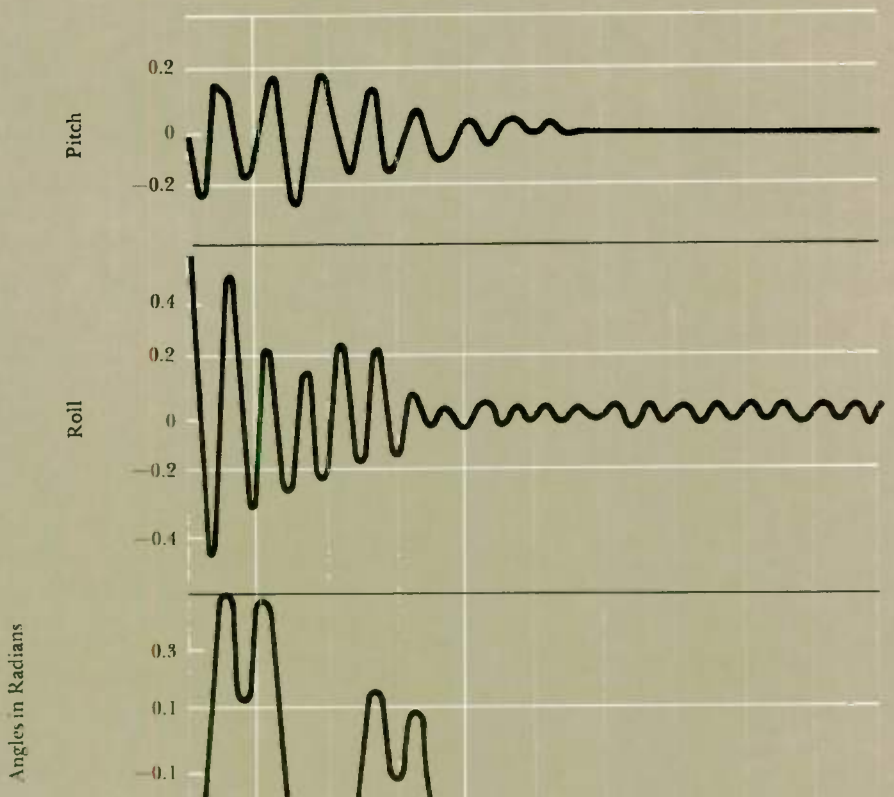
$$f_g = \frac{G\, m_s\, m_e}{r^2}$$

is just balanced by the opposite total centrifugal force,

$$f_c = m_s\, \omega_o^2\, r$$

where G is gravitational constant, m_s is total mass of satellite, m_e is mass of the earth, r is distance from the satellite's center to the earth's center, and ω_o is satellite orbital angular rate.

The forces on the satellite, when the satellite is not aligned towards the center of the earth, are shown in Fig. 4a. The centrifugal force on the *A* mass is greater than that for the *B* mass since it is further away from the center of the earth. However, due to the unique geometry, the torques produced by the unequal centrifugal forces cancel each other, since the greater force has the smaller moment arm and vice versa. With the gravitation force the force on the *B* mass is greater than the *A* mass and now the unequal moment arms reinforce the differences in torques. These unbalanced torques acting on the rigid body tend to align the



7—Time response of initial orientation of Ames X gravity gradient controlled satellite, as determined by digital simulation.

dumbbell with its longest axis pointing to the center of the earth. The restoring torque is proportional to dumbbell inertias, and inversely proportional to the cube of the distance from the center of the earth.

From a practical standpoint, gravity gradient stabilization is much more effective at low altitudes than at high altitudes. For example, a medium-altitude (6000 miles) satellite will develop only about 1/20 of the restoring torque of a low-altitude (200 miles) satellite; and a synchronous-altitude satellite can develop only 1/200 the restoring torque of a low-altitude satellite.

The preceding discussion illustrates the earth-pointing effect of gravity gradient control in the axis perpendicular to the orbital plane, the *pitch axis* (Fig. 5). The gravitation torque in the *roll axis* results from an identical effect on the same set of dumbbells, as is shown in Fig. 4b, but due to the geometry of the situation, the centrifugal forces are now parallel; since their moment arms are now equal they tend to reinforce the gravitation torque, resulting in a restoring torque some 33 percent greater in roll than in pitch.

Attitude control in the *yaw axis* is also often required. For the hypothetical configuration shown in Fig. 5, yaw-axis control is achieved by adding a smaller set of dumbbells perpendicular to the first set. Assuming that the gravity gradient torque has oriented the main axis towards earth, the auxiliary dumbbells tend to be constrained to the orbital plane and therefore will rotate in the horizontal plane. Since an earth-pointing satellite rotates at the orbital rate (ω_o) about the pitch axis (because the satellite is orbiting the earth), the centrifugal force developed on the minor dumbbells by pitch axis rotation opposes rotation about the yaw axis, and aligns the minor dumbbell axis in the orbital plane (or roll axis in Fig. 5). This yaw-restoring force is small compared to the gravity gradient forces acting on the other two axes.

The restoring torques have been discussed in terms of a hypothetical dumbbell-type configuration; actually, the critical parameters of control to be considered in spacecraft design are the relative inertias, and their effect on restoring torque:

$$T_{pitch} \sim (I_{roll} - I_{yaw})$$
$$T_{roll} \sim (I_{pitch} - I_{yaw})$$
$$T_{yaw} \sim (I_{pitch} - I_{roll})$$

Thus, pitch-axis inertia must be greater than roll-axis inertia, which in turn must be greater than yaw-axis inertia.

A well-known astronomical phenomenon that is attributed to this inertia effect and illustrates gravity gradient stabilization is the moon's attitude in its orbit about the earth—the same side always faces earth. Since the moon is not a perfect sphere but has differences in major-axis inertia, it has become gravity gradient stabilized with respect to the earth.

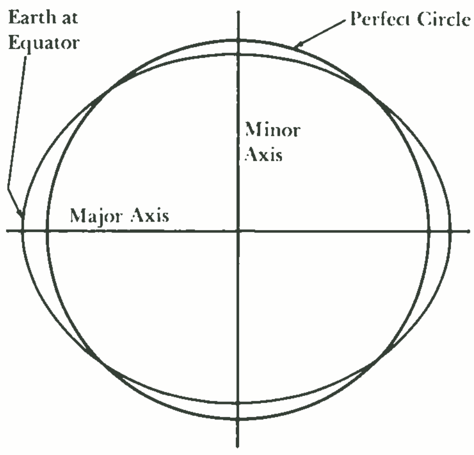
An arrangement of spacecraft inertias will not in itself produce good gravity gradient stabilization; if such a configuration were placed into orbit, it would tend to slowly oscillate about its axes with a period of about half its orbit period. Some form of damping mechanism is required to absorb the energy in the oscillation. In one satellite already in orbit, a combination of magnetic controls and spring damping is used: Energy is absorbed in the hysteresis loss of magnetic rods as the satellite oscillates with respect to the earth's magnetic field; spring damping is achieved with an extremely weak spring, some 40 feet long, which extends above the satellite. As the satellite oscillates, the centrifugal force acts to move the spring in and out, and energy is absorbed by mechanical hysteresis built into the spring.

Still other damping methods are being developed. One of the more recent, dubbed the "Ames X" system, uses an additional long rod that is coupled to the satellite structure through a magnetic-hysteresis or eddy-current damper. As the satellite oscillates, the damper boom oscillates with respect to the body, and energy is absorbed in the damper. This method is being used in the Westinghouse *Navigation Satellite System*, shown in Fig. 6. Digital simulation has been used to calculate the response of this system. Assuming an initial 40-degree offset (Fig. 7), the satellite will reach a stable steady state attitude within five or six orbits. The natural frequency of the satellite oscillations can be seen to be about half the rotational period.

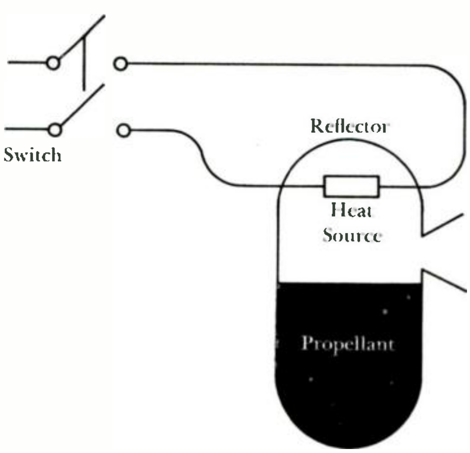
The development of gravity gradient systems is moving along at a substantial rate. Such systems have been orbited and have proven satisfactory at low altitudes; future efforts are pointed toward the development of systems for medium and synchronous altitudes.

Orbit-Position Control

The principal of the "Stationary" satellite is well known. A satellite is launched into an equatorial orbit with a period exactly equal to the daily rotation of the earth. As far as an observer on earth is concerned, the satellite, although orbiting, appears stationary. The advantages of such a 24-hour synchronous satellite for communications have already been demonstrated by the *Syncom* satellite. Similar advantages exist for navigation and weather satellites.



8—Earth's equatorial bulge causes a periodic oscillation of a synchronous satellite about the nearest minor axis.

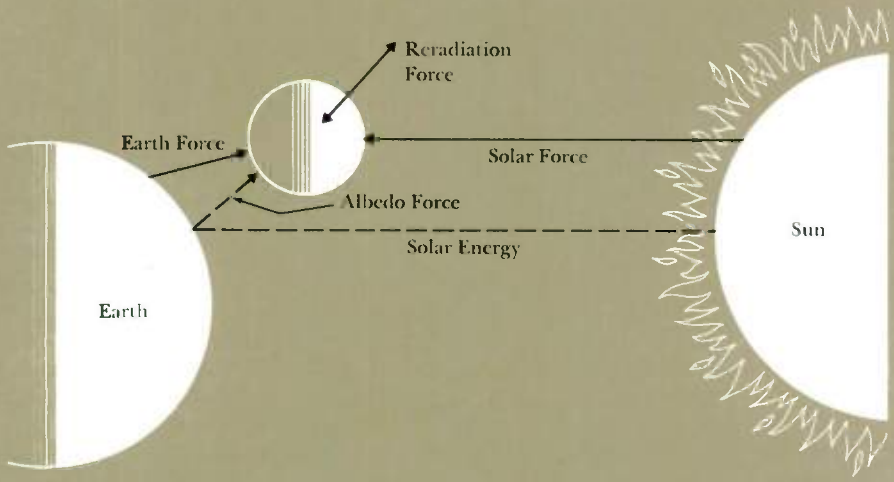


9—Subliming solid-propellant thruster develops the extremely low thrusts required by gravity-gradient-stabilized satellites.

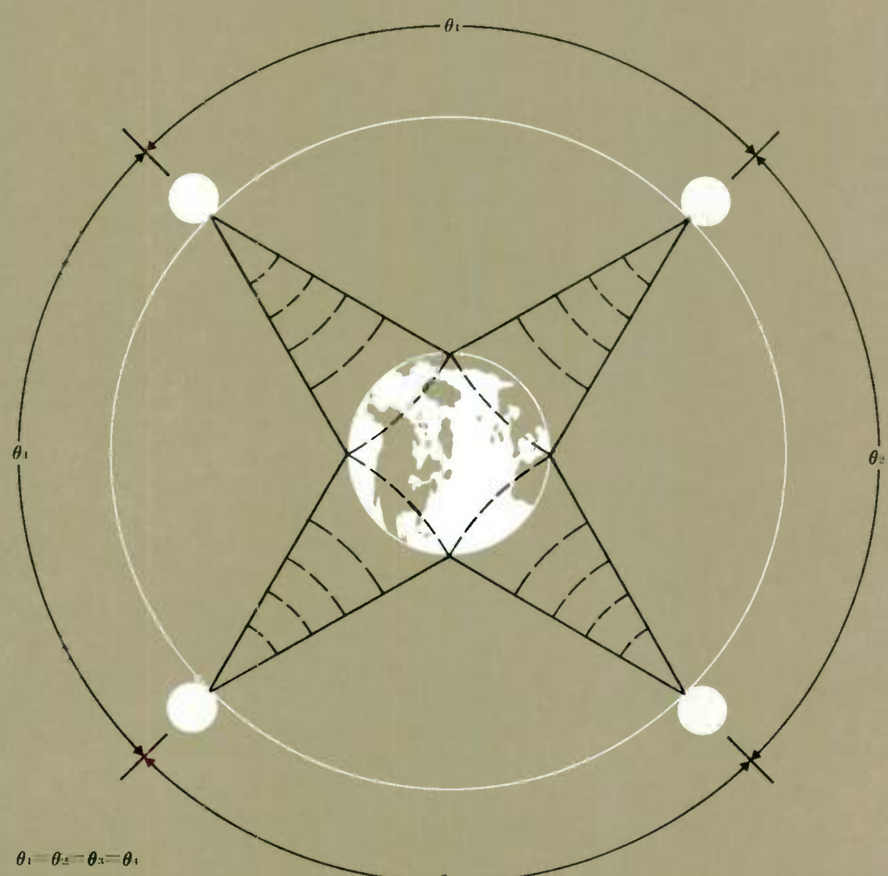
Even though a satellite is launched exactly into its proper orbit and is initially "stationary," with the passage of time an unattended satellite will drift with respect to earth. This drift is due to perturbing forces that arise from lunar and solar gravitational effects and from the nonspherical shape of the earth. Lunar and solar gravitational effects cause a change in orbital inclination away from equatorial so that the satellite makes a figure eight with respect to an earth observer. However, the effect is small, only about one degree per year.

A more serious perturbation is caused by the nonspherical shape of the earth at the equator. On a plane passing through the earth's equator, the earth is an ellipse rather than a perfect circle, as shown in Fig. 8. The effect on the satellite is a longitudinal drift along the equator. This drift is actually a periodic oscillation about the nearest minor axis of the gravitational ellipsoid. Although the oscillation is slow, in the order of many months, some form of orbit-position control is required. A satellite could be placed on the equator exactly on the minor axis and should not drift. But unfortunately, the minor axes are estimated to be over the Pacific Ocean and Indian Ocean, locations that would be unsuitable for most satellite applications.

Fortunately, the amount of control force required for orbit-position control is small, and can be provided by a small gas jet applied on a once-a-month basis. In the *Syncom* system, a nitrogen gas system with a one-pound thrust is used for fine velocity corrections, so that about two and one-half pounds of gas are adequate for the life of the satellite. Since *Syncom* is a spin-stabilized satellite, with its spin axis perpendicular to the orbital plane, the gas thrusts are timed to the spin rate. The control system is primarily ground operated.



10—Solar and thermal forces acting on satellite come from the sun, the earth, and from within the satellite structure.



11—Orbit-position control is used to maintain equal angular spacing between satellites.

When a gravity gradient controlled satellite is used in synchronous orbit, its long 100- to 200-foot fragile booms present a unique problem. If station keeping were done with even a one-pound gas thruster, the fragile construction and high inertia of the long booms would cause them to buckle and permanently deform. Therefore, thrusts must be no greater than 10^{-4} to 10^{-5} pound on a gravity gradient stabilized satellite.

These extremely low thrusts are achieved with small subliming solid rockets, shown in Fig. 9. This type of rocket consists of a charge of subliming propellant, which when vaporizing, discharges through an exhaust nozzle to create thrust. The propellant will sublime only when radiant heat energy is applied, and therefore is controllable in an on-off mode. The thrust periods are considerably longer than those of a cold-gas system, but a subliming rocket does have the advantage of not requiring an auxiliary attitude control system since the gravity gradient control is adequate to handle any unbalancing torques created by the subliming rocket thruster itself.

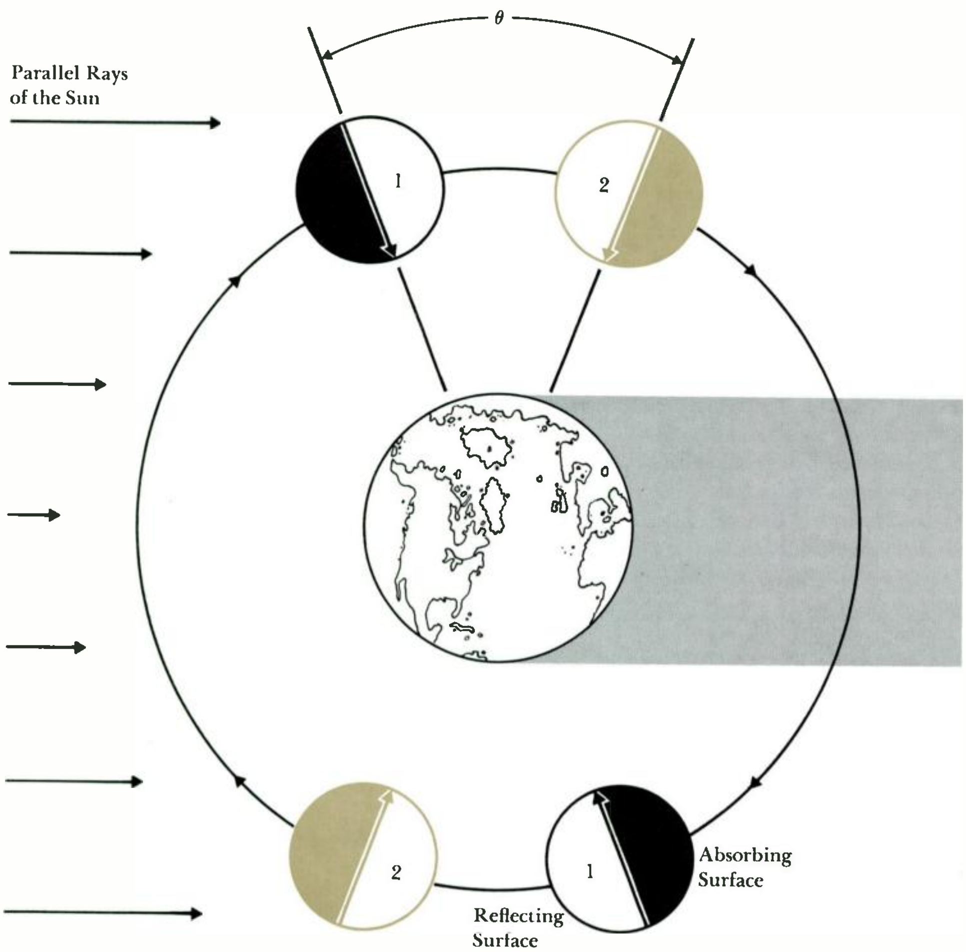
Solar Pressure—Incident solar energy on the surface of a satellite will produce pressure on the surface. This pressure varies inversely with the square of the distance from the sun—in the vicinity of the earth, solar pressure is about 10^{-7} pounds per square foot. The force exerted on the satellite is a function of satellite size and surface characteristics. For example, solar energy impinging on a perfectly reflecting surface will produce twice as much solar force as will be produced on a perfect absorbing surface. The effect is analogous to the forces on a surface produced by a ball that bounces and one that sticks to the surface on contact—the bouncing ball will cause double the force on the surface.

The solar forces acting on a satellite are complex (Fig. 10). In addition to direct rays from the sun, forces are exerted by reradiation from the earth and from reflections from one part of the satellite to another. Furthermore, as the satellite heats, it radiates heat which in turn produces a propulsive force. The Westinghouse Aerospace Division has been investigating for NASA the effects of solar pressure on a satellite such as *Echo* to determine if this pressure effect due to the sun's radiation could be effectively put to work to assist in controlling a satellite's orbital parameters. The study results indicate that solar pressure could be used to accomplish orbit-position control.

Orbit-position control, applied to a group of satellites, would be used to produce a symmetrical array of satellites about the earth with equal angular spacing between the satellites, as shown in Fig. 11. Normally, an axis of each satellite must be pointed continuously toward earth to satisfy the needs of a weather reconnaissance, navigation, or communication function. Rotation of the satellite about this axis exposes different sides of the satellite to the sun so that the variation in total solar force needed for orbit-position control can be provided.

The use of solar force for orbit-position control is illustrated in Fig. 12. As the satellite orbits the earth, one surface is presented to the sun when the solar force is in the direction of the satellite motion and the other surface is presented to the sun when the solar force is in opposition to the motion of the satellite. If the two surfaces have different reflective characteristics—for example, one a reflector and the other an absorber—the forces on each half of the orbit will be unequal so that a net gain or loss of energy in the orbiting system will result. This change of energy is equivalent to a change in orbital period. For the two satellites shown in Fig. 12, satellite number 1 loses energy and number 2 gains energy, which therefore increases the angle θ separating the satellites. The procedure can be reversed by rotating each satellite 180 degrees about its earth-pointing axis. Calculations by Westinghouse Aerospace engineers have indicated that with an *Echo* type satellite, angular separations of 150 degrees could be achieved in about 30 days.

Solar pressure could be employed to effect orbit-position control on any satellite by adding some sort of flat sail surface. Although the technique is best suited to large inflatable structures, it could be useful for any vehicle with large area-to-mass ratio. Although the magnitude of thrust is low, its effect on a satellite can be controlled, and its propulsive effect is continuous.



12—Solar pressure can be used for orbit-position control of an earth-pointing satellite by controlling the orientation of reflecting and absorbing surfaces. In this case, satellite 1 loses energy and satellite 2 gains energy each orbit, increasing separation angle θ.

Future Control Systems

During the past several years, much effort has been expended to define the natural forces of space, such as gravity gradient, magnetic field, and solar pressure. The mechanical configurations of vehicles have been manipulated to use these forces for control purposes. However, the ungainly mechanical characteristics of these vehicles—for example, gravity gradient booms in six directions with lengths of a hundred feet or more for use at synchronous altitude—points up the need for continued research for more reliable and mechanically simpler methods of attitude control. When the sensors aboard some of the existing scientific satellites reveal more about the force fields in space created by free electrons, photon flux, and ions—to mention a few—it is possible that even simpler and more reliable methods of control can be obtained by ingenious manipulation of these force fields.

Electrical Connectors for Outer Space Application

Frank C. Rushing

This new connector design provides weld-proof contacts that make electrical contact within an explosion-proof enclosure.

A new electrical connector, designed for use by astronauts in space, will perform reliably under environmental conditions of high vacuum, wide temperature range, dust, salt vapor, high humidity, and explosive atmosphere. These extremes can be encountered in space and in pressurized space vehicles. Another feature of the connector is its extreme simplicity of engaging and disengaging, so that it can be operated easily by an astronaut when his manual dexterity is limited by a pressurized space suit, or by an unfamiliar gravitational field.

Two versions of the space connector have been developed and tested: (1) a four-contact bulkhead connector, shown in Fig. 1, which would be used for carrying electrical energy from a fixed location in the spaceship to a movable equipment, either within or outside the spaceship, and (2) a connector-handle arrangement that was developed to connect an extension cable to a lunar television camera (Fig. 2), and simultaneously serve as a handle to hold the camera by. For the latter device, the short cap of the bulkhead connector is replaced by the handle. A guide is included on the camera portion of the connector to simplify the initial engagement between the two parts of the connector.

Weld-Proof Contacts

The high vacuum of outer space creates a problem of particular concern to the designer of an electrical connector. A good electrical connection requires intimate contact, preferably soft metals wiped together under pressure. Unfortunately, these conditions in a high-vacuum environment also provide an ideal situation for cold welding. And although considerable progress has been made in the development of materials that will resist welding, their performance under a variety of conditions in an extremely high vacuum is still questionable. Therefore, the approach to the problem for the new space connector is to use contact materials that are least likely to weld, and to use these materials in a mechanism that will negate the effect of any welding that might occur.

The contact mechanism is diagrammed in Fig. 3. The travel of one of the mating butt-type contacts is constrained to a lengthwise path, while the mating contact rotates about a hinge axis. Thus, the lateral component of motion of the hinged contact relative to the lengthwise motion of the mating contact produces a wiping action between contact surfaces, and insures good electrical contact. Furthermore, the hinge arrangement provides the mechanical advantage necessary to develop high mechanical shear between contacts during engagement and disengagement.

The flush-mounted, butt-type contacts are easy to keep clean. An accumulation of dust on either connector half can be conveniently knocked off or brushed away.

Explosion-Proof Enclosure

For general application in space, an electrical connector must also be sealed and protected against moisture, salt fog, and possible explosive atmospheres—

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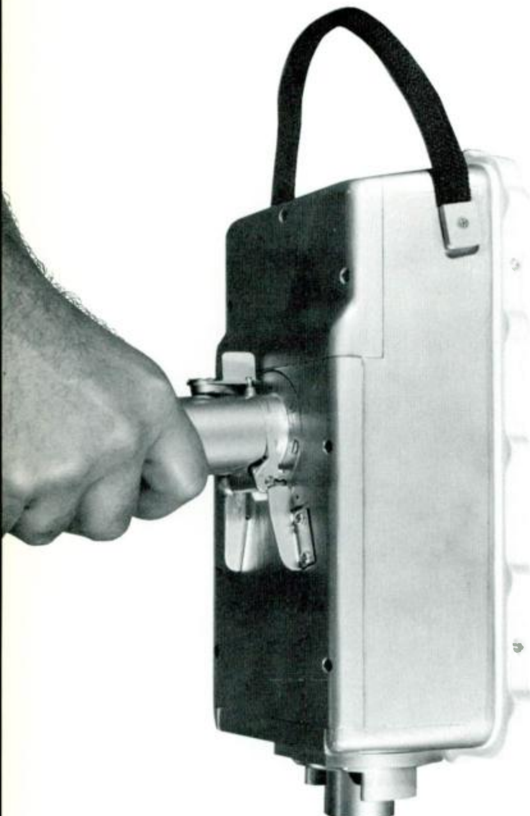
a

b

1—Bulkhead connector developed for use by astronauts in space, shown *(a)* engaged, and *(b)* disengaged.



2—Electrical connector has been modified to also serve as a handle for this television camera (mock-up).

conditions that can occur within closed and pressurized spacecraft. The seal arrangement developed to accommodate the hinged connector arrangement is diagrammed in Fig. 4. A close-fitting, sliding tubular sleeve, spring loaded against stops, surrounds the hinged-contact support surface; the mating contact support surface is mounted on a spherical seat. Thus, when the connector halves are swung together, the sliding sleeve first strikes the spherically supported surface, aligning this surface to the sleeve, as shown in Fig. 4a. As the connector continues to close, the spring force on the sleeve holds it firmly against the spherically supported surface so that electrical contact is made within an enclosed and sealed space.

During disengagement, the action is reversed and the electrical contacts separate before the seal opens.

The sleeve also provides spring loading when the connector is closed so that when the external latch snaps into place, it will hold the connector closed with a detent action.

The external latch design is such that it can be easily released, even when the operator is wearing heavy gloves.

Cable Anchorage

When electrical connectors are used with an extension cable, the cable must be anchored to the connector so that it can withstand hard pulls with no strain on the electrical connections. In the space connector, this is accomplished by anchoring the braided-glass cable sheath as the principal support, aided by separate ties for each conductor, as shown in Fig. 5. Both cable sheath and conductors are lashed to a dielectric spool. The conductors then pass through a moisture seal to the connector terminals.

Space Materials

All materials used in building the connector have been chosen to be compatible with the severe environment of outer space. For example, the contact materials used in the lunar TV connector are niobium disellenide for one contact and silver for the mating contact. These contact materials have demonstrated that they can withstand high shearing action with no noticeable damage to the contact surfaces. Niobium disellenide is a Westinghouse-developed material for static or sliding electrical contacts and is the best known material for contacts in the high vacuum of outer space.

The dielectric components are made primarily from Polyimid, and moisture seals are made from silicone rubber. The housings are of silver-plated aluminum. Austenitic stainless steel is used for the shaft, springs, and pins. Beryllium copper is used for the terminal parts. All joints are lubricated with molybdenum disulfide.

Tests

The connector has successfully passed significant environmental tests: vibration, vacuum (2×10^{-9} mm Hg), temperature (+250 and −290 degrees F), high humidity, salt fog, explosion, pure oxygen, and endurance (70,000 operations).

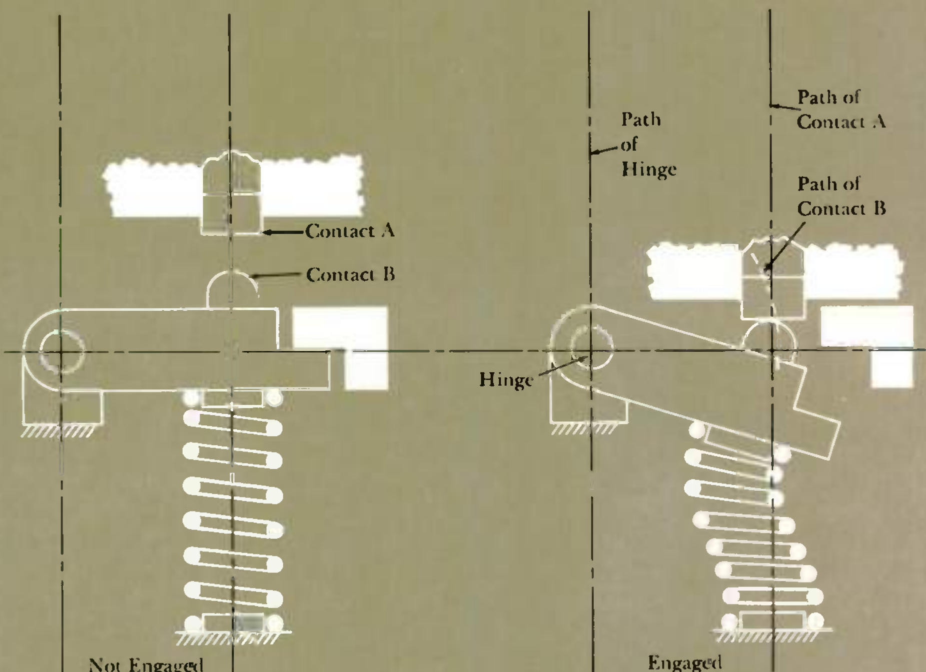
The contact-wiping and shearing action was tested by purposely welding silver-against-silver contacts with a capacitor discharge. When the connector was opened, the contacts sheared apart with negligible opening force, and with no deterioration of contact performance on subsequent operations.

During the various environmental tests, the connector contacts carried 0.25 amperes at 28 volts. Contact resistance produced an almost constant voltage drop across the contacts of about 3 mv, both before and after tests. Mechanical wear to the contacts was negligible.

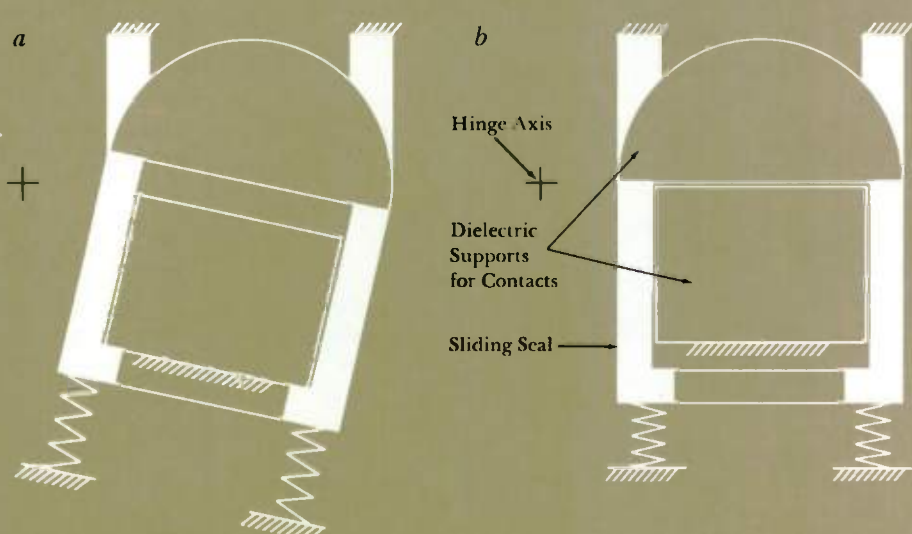
High-Density Connectors

The connectors described have four electrical contacts. However, it is possible to apply these same general operating principles to connectors with a much higher density of circuits—up to at least 25 contacts per square inch. Studies have been made to verify feasibility.

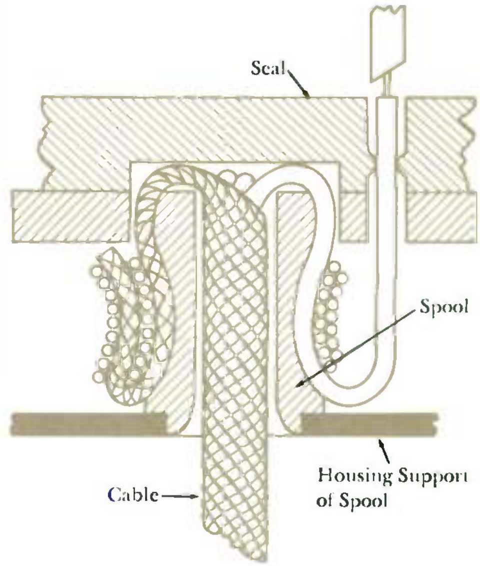
This type of connector can meet the requirements not only for space, but for any other application where facility of operation, durable service, environmental protection, and good cable anchorage are required.



3—Hinged contact provides lateral movement, creating a wiping motion between mating contacts.



4—Connector seal consists of sliding tubular sleeve, which mates with ball-seated contact support surface before electrical contacts are made.



5—Cable anchor and seal prevents strain on electrical connections and seals connector.

New Silicon Strip Material Applied in Large-Area Solar Cells

K. S. Tarneja

Solar cells made from a new silicon strip material can be much larger in area than conventional cells, and they require far less processing. Power-producing panels made with them are potentially more reliable, lighter, and less expensive.

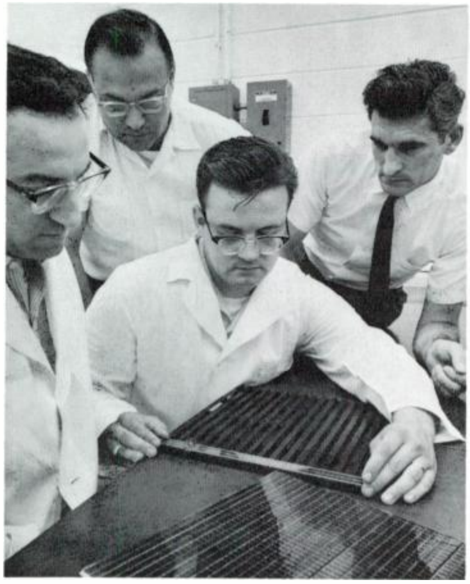
Improvements in solar-cell power systems are being sought by industrial and government organizations because the systems will be needed for powering equipment in many space vehicles for a number of years to come. Such proposed long-life power systems as thermionic generators, magnetohydrodynamic generators, and regenerative fuel cells are still far from ready, and thermoelectric generators heated by radioisotopes are impractical for many space vehicles because the radiation shielding required adds too much weight.

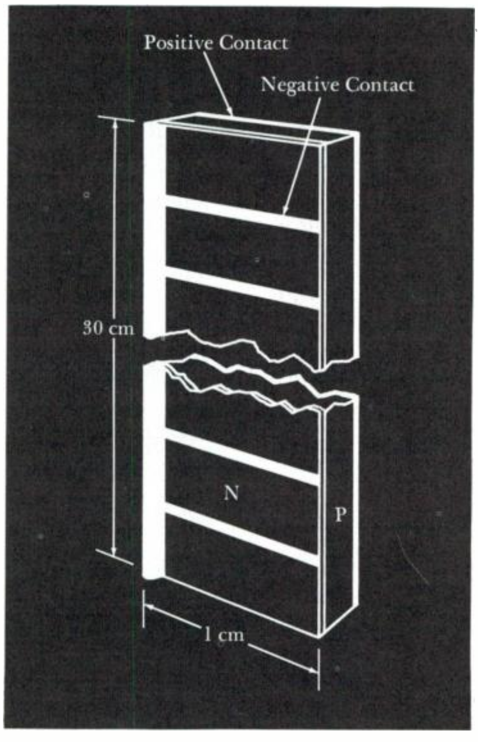
Besides being presently available, solar cells have the advantage of using an energy source—sunlight—that doesn't cost anything and doesn't have to be carried along. They are, moreover, the most efficient devices at present for converting this free energy to electrical energy. The same advantages qualify solar cells, potentially, for commercial ground applications that are now overlooked because of the cells' relatively high cost per watt of power output—applications such as readout cells and as self-contained solar power supplies for remote telephone lines, police call boxes along highways, and transistor radios.

Three principal goals in the improvement programs are to increase the power output per unit of weight and volume, to improve system reliability, and to decrease system cost.

A promising approach at Westinghouse is the fabrication of semiconductor solar cells from strips of silicon known as silicon web material. This approach produces cells of much larger area than that of conventional cells, an important advantage because the power output of a cell depends on its area. In any power application, a number of cells are mounted on panels and connected in series and parallel to achieve the desired rating; the number connected in series determines voltage output, and the number connected in parallel (depending on the areas of the individual cells) determines current output. The result, then, of using large-area cells is far fewer connections in a panel of given output, with consequent increased reliability potential and decreased cost potential. Reduction in the number of connections also reduces weight, an especially important consideration in space applications because an average of 20 to 25 percent of the weight of present unmanned spacecraft is in power systems. Moreover, the web cells require far less processing than do conventional cells, and far less silicon material is wasted in processing—factors that also hold much potential for cost reduction.

K. S. Tarneja is at the Westinghouse Semiconductor Division, Youngwood, Pennsylvania.





1—Large-area silicon solar cell is made by diffusing an N-type impurity into a piece of P-type "web" material to a depth of about half a micron. Cells 30 centimeters and more in length have been made, giving them much greater surface area than the conventional 1- by 2-cm cells. Panel modules are made by attaching these large-area cells to a lightweight substrate. The modules seen here measure one foot square.

Cells measuring 1 by 30 centimeters have been made from the new material, although there really is no inherent limit to cell length; such practical considerations as the size of processing facilities and the space available for the finished cell are the limiting size factors. This is in sharp contrast to conventional cells, which usually measure 1 by 2 cm.

Panel modules made from web cells have a power-to-weight ratio significantly higher than that of most panels of conventional design. The modules have successfully completed laboratory environmental tests required to qualify them for use in space applications, and they will be evaluated in actual flight.

Solar-Cell Fundamentals

Only silicon semiconductor solar cells have been used in spacecraft thus far, because other types are too expensive or do not perform as well. The basis of the silicon solar cell is the P-N junction, a region in a silicon single crystal at which a P-type layer and an N-type layer come together. A cell is made by diffusing an N-type impurity into one surface of a P-type wafer, or the other way around. (The diffused layer is only about half a micron thick, so the solar cell is essentially a diode with an extremely shallow junction.) Electrical contacts are then applied to the two surfaces (Fig. 1).

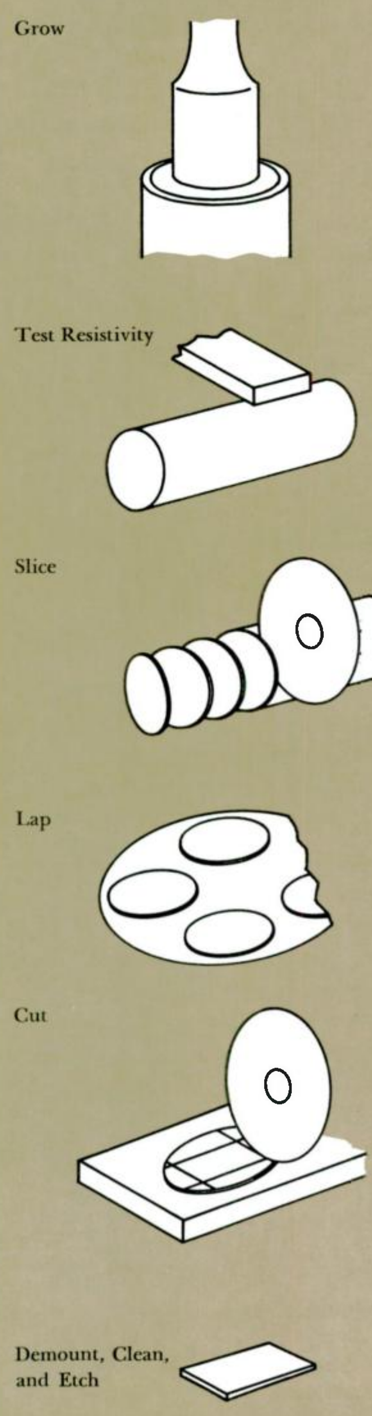
The carrier concentration gradients at a junction provide the driving force to maintain a built-in junction field.[1] When hole-electron pairs are generated by conversion of the energy of absorbed light quanta in the crystal, minority carriers diffusing into the junction transition region find themselves accelerated by the junction field and thereby "collected." The result of this disturbance of the dark conditions of equilibrium is a photovoltaic voltage, which is capable of driving current through an external load and also causes an internal shunt current to flow across the junction in the forward direction. The junction depth is made small so that the greatest number of photogenerated minority carriers can diffuse into the junction transition region before losing themselves through recombination.

Silicon Web Cells

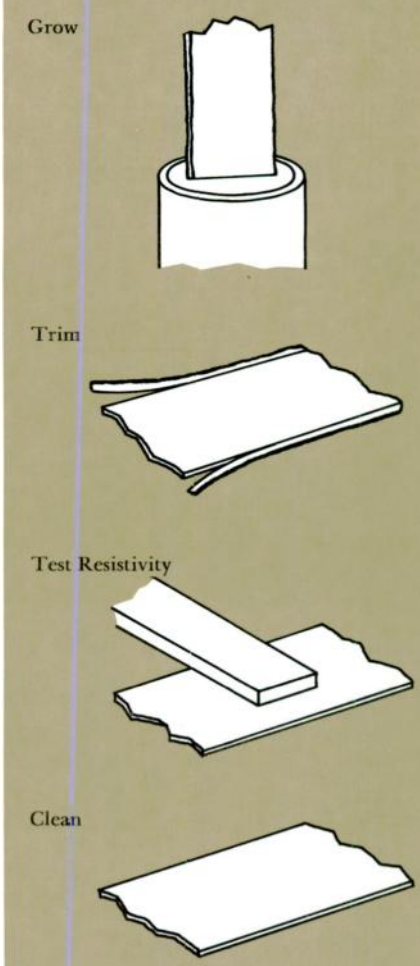
The conventional procedure in making silicon solar cells has been to grow cylindrical single crystals about an inch in diameter and then saw these bars into wafers 0.025 inch thick (Fig. 2). The wafers are lapped to remove gross surface defects caused by sawing and then are cut into 1- by 2-cm blanks, which are cleaned and etched to remove remaining surface defects. The blanks are diffused, contacts are applied, and the cells are tested.

Silicon web material, on the other hand, is grown as a single-crystal strip of the desired thickness (Fig. 3). Development of the technique began at Westinghouse in 1958 with the controlled growth of germanium dendrites—narrow single-crystal ribbons grown from a melt. These dendritic ribbons were found to be excellent for small semiconductor devices, but their usefulness was limited because they could be grown only about 0.05 inch wide. This limitation gave rise to further development and eventual production in 1960 of the wider silicon web material, a material suitable for fabrication of solar

2—Conventional Material



3—Web Material



[1]Tarneja, K. S., and Riel, R. K., "Improvements in Photovoltaic Energy Converters," *Westinghouse ENGINEER*, November, 1963.

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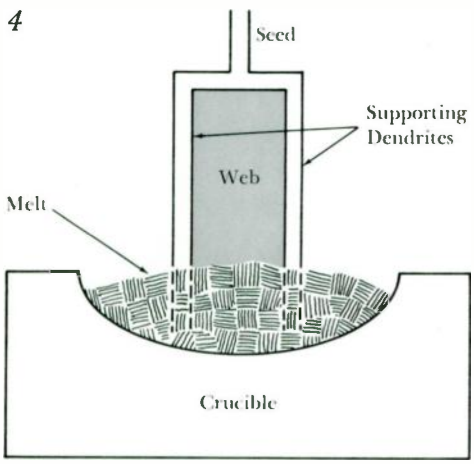

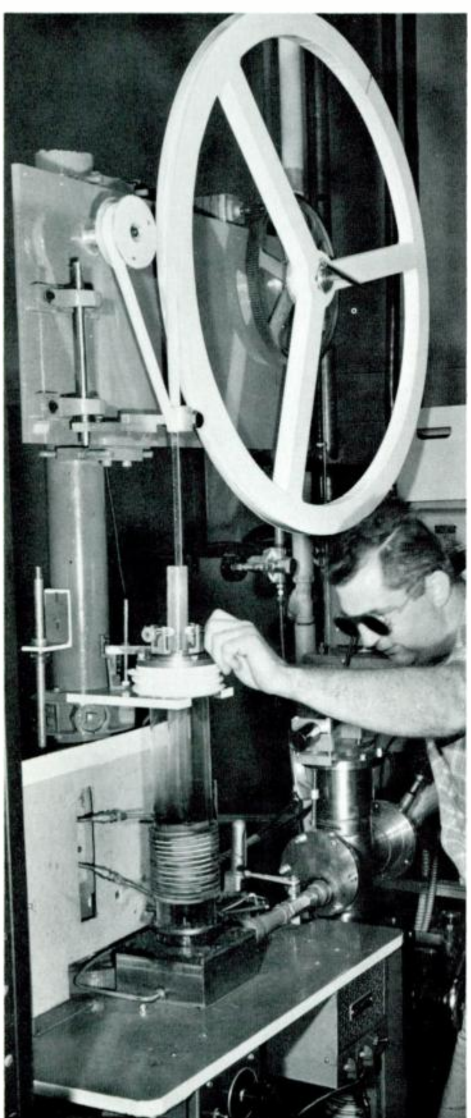

4—**Silicon web is grown by withdrawing parallel dendrites from a melt at the rate at which they are growing. The liquid film drawn up by surface tension between the dendrites solidifies to form the "web." The material is wound on a reel as it is grown; there is no inherent limit to length.**

cells as well as other silicon semiconductor devices.[2]

The growth mechanism of silicon web is much less complicated than that of the dendrites: it simply freezes from a thin flat liquid film (or "web") of silicon drawn up by surface tension between two parallel dendrites (Fig. 4). The two dendrites, which form beneath the surface of the liquid melt, can grow in long continuous lengths. The speed of a motor-driven pulling mechanism is adjusted so that the dendrites are pulled from the melt at the same rate as they are forming under the surface of the melt; as the dendrites emerge through the surface, they form a rigid frame that supports the web until it solidifies. There is no apparent limit to the length that can be produced, and continuing development is increasing the maximum width that can be obtained (about 2 cm at present). Since the crystal structure of both the web and the dendrites is derived from a single "seed" used to initiate growth, the structure is maintained throughout the entire length.

During growth, the silicon web with its edge dendrites is wound on a reel until the run is ended. It is then unwound and scribed and broken into convenient lengths (usually 30 cm). The edge dendrites are trimmed off, and the pieces are then ready for fabrication into solar cells. The surface of the web as grown is mirror-like and free from mechanical damage, a necessary condition for high-efficiency solar cells and other semiconductor devices, so no lapping and etching are needed. Resistivity is uniform over long lengths, and dislocation density (number of crystal imperfections) is low—comparable to that of the best conventional crystals.

Because sawing, cutting, lapping, and etching are not required, the number of operations needed to prepare the material for diffusion is greatly reduced. So is the amount of material wasted. These wide differences in processing requirements account for the cost-reducing potential of silicon web. Web material should be worth about five times as much to a user as conventional single-crystal silicon because virtually all of it can be used, while only about a fifth of the conventional crystal is finally sold in finished devices.

The other main advantage of using silicon web for solar cells is, of course, the larger surface area. Since the power output of a solar cell is directly proportional to its surface area, the large-area cells produce more power than the conventional ones. The result is reduction in the number of cells and connections needed for a panel of desired output, with consequent reductions in assembly costs, weight, and volume. Having fewer connections also makes for much greater reliability.

The web material also has advantages for production of other semiconductor devices, and rectifiers and transistors have been made successfully from it. The main advantage of web for these devices is the material's freedom from surface damage as grown.

Controls for the furnaces in which silicon web is grown are being improved to permit production of wider material and also to make operation easier and production runs longer. The latter improvements will fit the process to volume production techniques so that the web material can compete with conventional material in cost as well as in quality. Fixtures are being developed for adapting photographic and encapsulating techniques (which are used in making many semiconductor devices) from the conventional circular slices to the rectangular web strips.

Solar-Cell Characteristics

As with other power sources, the uses and potential uses of solar cells depend on the device characteristics. The measurable

[2]Poliquin, P. P., and Winter, W. E., "Current Achievements in the Growth and Use of Silicon Dendritic Web," *Proceedings of the National Aerospace Electronics Conference*, May 11-13, 1964, Dayton, Ohio. (Copies available from NAECON, 1414 E. Third St., Dayton, Ohio.)

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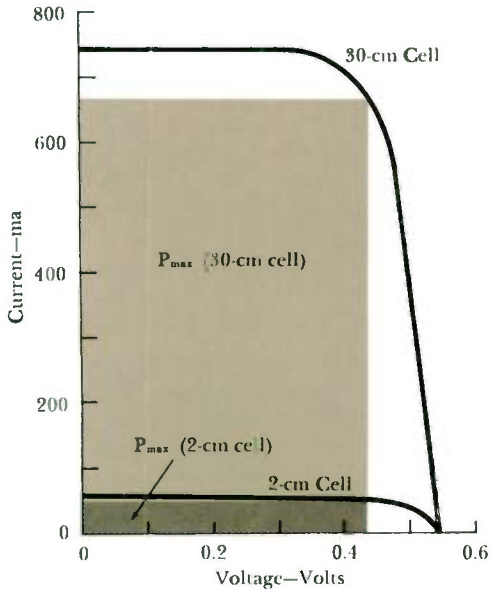

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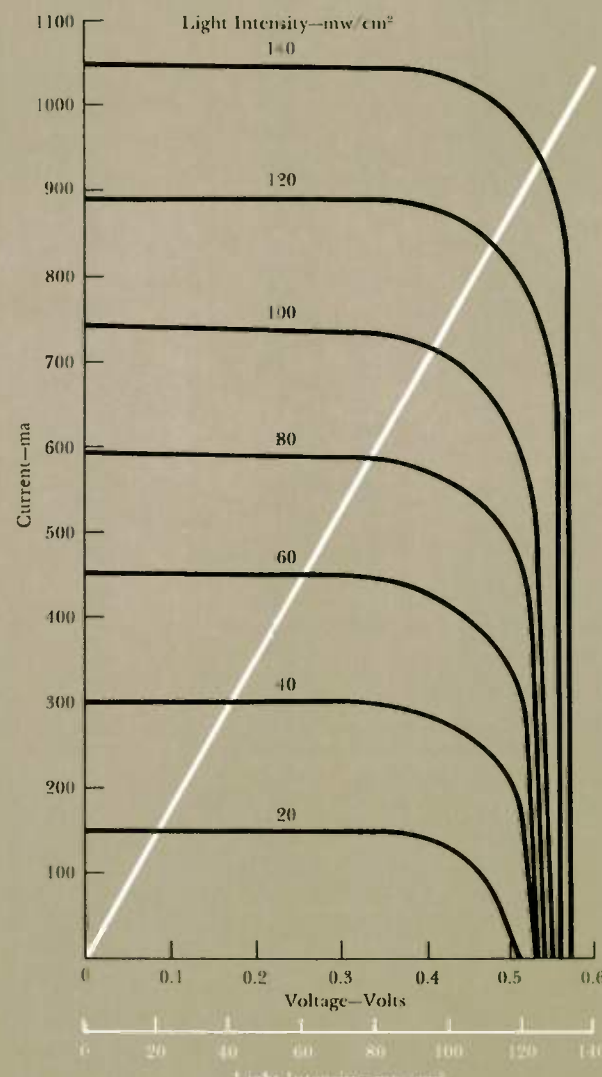

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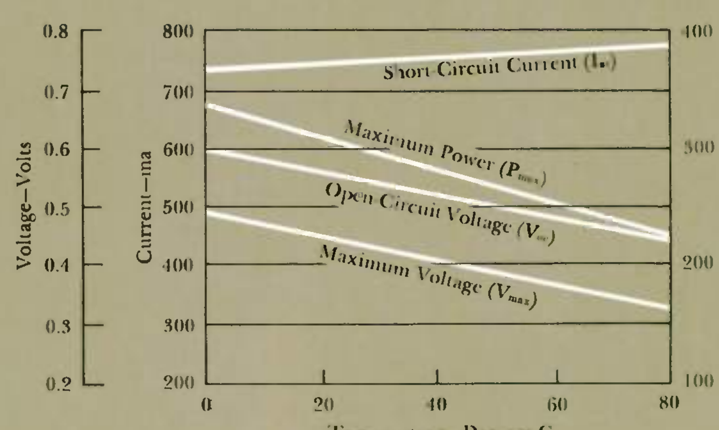

5—Typical voltage-current characteristics of a large-area cell (1 by 30 cm) and a conventional cell (1 by 2 cm). Short-circuit currents and open-circuit voltages are indicated by the end points of the curves. The largest rectangle that can be drawn under each curve shows the maximum power (P_{max}) delivered by that cell: 290 milliwatts (mw) for the large one. Intensity of the tungsten light source used for the measurements was one sun (100 mw per square cm).

6—Current increases directly with light intensity (white curve). The black curves show how this increase affects the voltage-current characteristic of a cell 27 square cm in area.

7—Effect of temperature on solar-cell characteristics. Voltage decreases as temperature increases, causing a corresponding decrease in power. The cell is the same as in Fig. 6, and light intensity was 100 mw per square cm.

quantities that account for solar-cell characteristics are:

1) Short-circuit current (I_{sc})—the load current obtained under a given illumination when load resistance is zero;

2) Open-circuit voltage (V_{oc})—the output developed across an infinite load resistance;

3) Power delivered to the load (P);

4) Maximum power delivered to a matched load (P_{max})—the product of the voltage (V_{max}) and the load current (I_{max}) at the maximum power transfer conditions;

5) Efficiency (η)—the ratio of maximum power delivered to the load to total incident solar radiation power.

Open-circuit voltages of cells are the same regardless of area, but the large-area cells produce more power because their short-circuit current is higher (Fig. 5). Short-circuit current is, in fact, a direct function of cell area. Short-circuit current also is directly proportional to light intensity (Fig. 6).

Solar-cell output is temperature-dependent, with power decreasing with device temperature (Fig. 7). The parameter affected directly is open-circuit voltage.

Efficiencies as high as 14 percent have been achieved in conventional solar cells. Early cells fabricated from silicon web were on small areas (1 by 2 by 0.05 cm), and these too had efficiencies as high as 14 percent. Large-area web cells (1 by 30 by 0.05 cm and even larger) are now being fabricated with efficiencies as high as 12 percent, and they are being improved constantly.

Radiation Resistance

Because solar cells are used extensively in space, designers are concerned with minimizing damage to the cells from the electron and proton fluxes found outside the earth's shielding atmosphere. Both types of radiation inflict damage that reduces conversion efficiency. The basic effect is a decrease in short-circuit current caused by reduction of carrier lifetime in the base region. The N-on-P configuration has come to be used in place of the former P-on-N type because it is inherently more radiation resistant. (Minority carriers in the P-type base are electrons, and the diffusion constant for electrons in silicon is approximately three times the diffusion constant for holes.) Also, the use of base material with higher resistivity than that formerly used increases initial lifetime in the base region and thereby enhances radiation resistance.

Therefore, most of the web cells now being made at the Semiconductor Division are of the N-on-P type made by diffusing phosphorous into P-type material of 10 ohm-cm resistivity.[3] Diffusion is the most critical step in production of high-efficiency cells. It has to be controlled very accurately to achieve shallow diffusion depth (about 10^{-5} cm) along with the high surface concentration needed to keep the resistance of the diffused layer low. These goals are achieved by passing phosphorus vapor, with oxygen and nitrogen as carrier gases, over the web material in a furnace. The furnace has a constant-temperature zone in which temperature can be held within one percent of a preset value. This control, and accurate control of diffusion time, produce the desired concentration and junction depth.

Solar-Cell Panels

Open-circuit voltage of a cell is in the range of 540 to 550 millivolts (mv), and short-circuit currents are 25 to 30 milliamperes (ma) per square centimeter. For power applications, a number of cells have to be connected in series and parallel arrangements, the arrangement depending on the requirements. A panel module with eight 15-cm web cells connected in series produces 1.5 watts (3.2 volts and 488 ma). A module made from the conventional 1- by 2-cm cells would need 60 cells to produce the same output and would require both series and parallel connections, increasing the number of connections from 40 to 112.

The web cells in the module are mounted on an aluminum substrate and are covered with quartz covers 0.006 inch thick for radiation shielding. The module measures three by six inches and weighs 0.1 pound. Since its power output is 1.5 watts, its specific power (ratio of power to weight) is 15 watts per pound. This is a significant increase over the 10 to 12 watts per pound afforded by most of the conventional panel designs. For example, if a satellite's power requirement was 200 watts, conventional solar-cell panel modules for it would weigh 17 to 20 pounds, but the panels of improved design with large-area web cells would weigh only 13 pounds.

These modules have successfully completed the laboratory environmental tests (such as vibration, shock, acceleration, and thermal cycling) required to qualify them for use in space applications. Other Westinghouse power modules using the web cells are now being evaluated in a program, which involves an actual flight experiment, under the direction of the U.S. Air Force.

The cells also are being used in studies aimed at development of lighter solar-cell panels. Westinghouse is supplying 2000 of the 1- by 30-cm cells to Hughes Aircraft Corporation under an Air Force contract for fabrication of a lightweight flexible panel.

Conclusion

Solar cells of the N-on-P and P-on-N varieties can be successfully made from silicon web material. The use of this material increases design flexibility by making it possible to produce cells of various lengths, a capability not possible with cells made from conventional silicon starting material. Use of silicon web also carries a definite potential for cost and weight reduction and reliability improvement in solar-cell panels. These factors could enhance the usefulness of solar-cell power supplies in space technology and also help make them economically feasible for other applications.

Acknowledgements:
Much of the work described here was supported by the U. S. Air Force Aero Propulsion Laboratory of the Research and Technology Division, Wright-Patterson Air Force Base, Dayton, Ohio. The author gratefully acknowledges the work of H. A. Wehrli in growing the web material for the large-area cells described and of E. R. Stonebraker in making the electrical efficiency measurements.

[3]Tarneja, K. S., Hicks, J. M., Babcock, R. V., and Stonebraker, E. R., "Radiation Resistance of Webbed Dendritic Solar Cells," *Proceedings of the Fourth Photovoltaic Specialists Conference, Vol. 1*, June 2, 1964.

Electro-Hydraulic Control Improves Operation and Availability of Large Steam Turbines

E. G. Noyes
M. Birnbaum

This new turbine control system has been designed to accommodate the increasing complexity of the turbine control function on today's power systems.

A new speed and load control system for large steam turbines combines a solid-state electronic controller with a high-pressure, fire-resistant fluid supply system. The design features and response characteristics of the system can improve the operation, reliability, and availability of new power plant installations. This new control has been developed to replace the conventional low-pressure hydraulic governing system on large steam turbines. Presently, 20 large units on order either require or are being considered for the application of this new control system.

Turbine Control

The conventional hydraulic or mechanical type of turbine control was originally designed for local manual operation, when power systems consisted of a few isolated machines under individual control. Rotor speed was the only feedback used for closed-loop control, and the speed-governing system was usually mounted on, and considered an integral part of, the turbine. The readily available low-pressure lubrication oil provided the hydraulic motive fluid.

On today's power systems, the turbine control function has become more complex; large interconnecting ties with close frequency control have changed the function of the turbine speed-governing system to an open-loop control for maintaining steam flow and load. Thus, the turbine-control system, with its inherent nonlinear valve position-flow characteristic, has become a valve-positioning subloop, interlocked with other plant control functions. Furthermore, it is desirable today to design most steam turbine units with some provision for remote control. In fact, complete remote operation supplemented by digital computer monitoring appears to be the rule for many of the larger installations.

In addition to the increasing complexity of the turbine control function, the conventional low-pressure hydraulic control components on large turbines have increased in size to the point where inertia, friction, and time delays are beginning to affect the performance and accuracy of conventional governing systems. These considerations led Westinghouse turbine control designers to take a new look at the design criteria for turbine control systems.

As a result of this reevaluation, the new electro-hydraulic turbine control system was developed. The solid-state electronic controller is ideally suited to remote supervision and load control with appropriate feedbacks. The controller in turn supervises the positioning of high-pressure hydraulic actuators. High-pressure motive fluid permits the use of small, fast-response hydraulic components.

Basic Electro-Hydraulic System

An overall system diagram of the electro-

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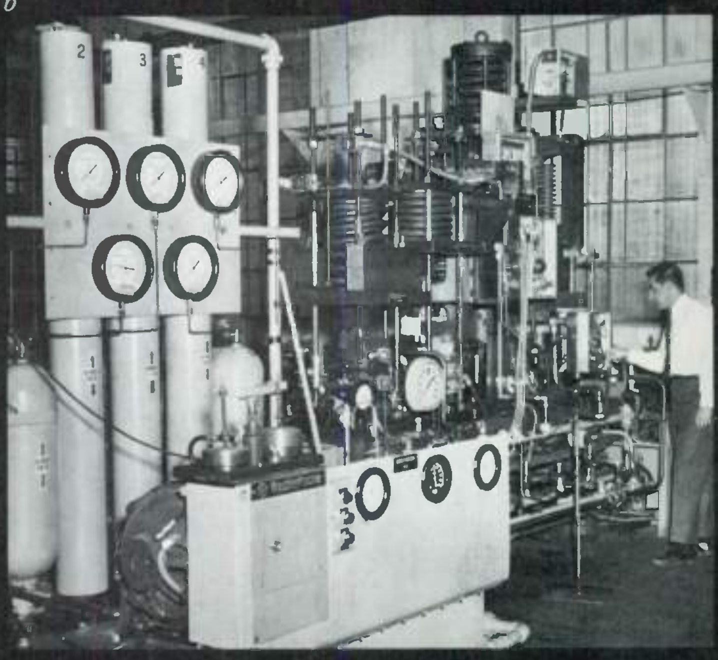
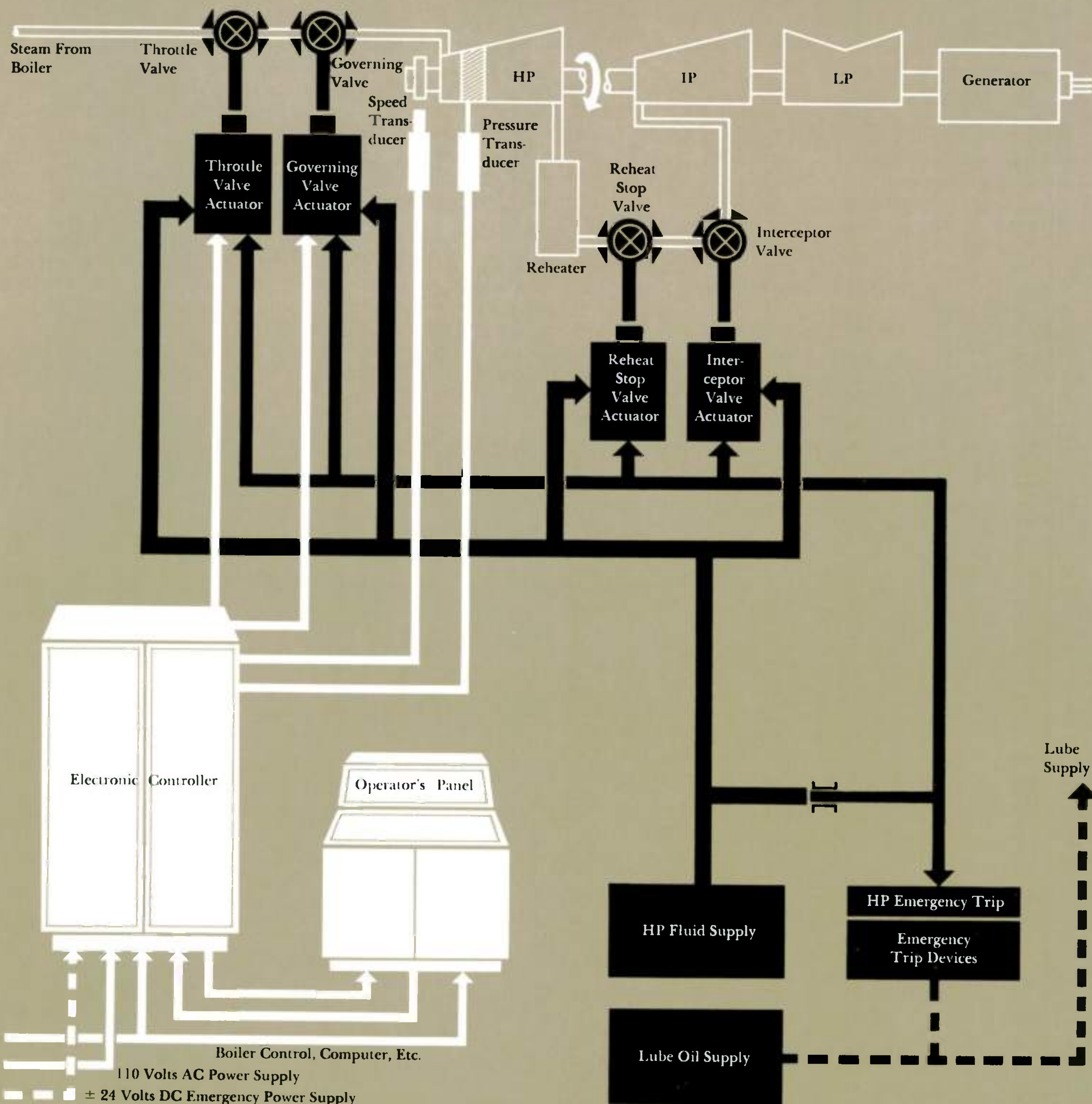
The electro-hydraulic control system has undergone an extensive development and evaluation program in the Steam Division Laboratory. The prototype system on test includes (*a*) the electric governor controller cabinet (left) and the operators panel, mounted on a simulated plant console, and (*b*) the high-pressure supply system and accumulator assembly (foreground) and four valve actuator assemblies.

a

b





1—Electro-hydraulic control system for large steam turbine-generators.

hydraulic turbine control system is shown in Fig. 1. Steam flow is controlled at the main and reheat inlets by conventional valve arrangements. During normal operation, inlet steam is regulated by the control valves with the throttle valves wide open.

During a controlled start, the control valves are wide open and the throttle valves regulate steam flow in response to the wide range speed control characteristic of the electro-hydraulic control system. Before synchronization, control is transferred from the throttle valves to the control valves, and the throttle valves are opened and are under the control of protective trip circuits only.

Each valve is positioned by an electro-hydraulic actuator. These actuators are controlled by signals from the electronic controller, with the motive force provided by a high-pressure hydraulic supply system. The electronic controller develops the positioning control signals by comparing turbine speed and first-stage turbine pressure with reference values established by other plant control systems or initiated by the operator. Since first-stage pressure is directly proportional to steam flow and not subject to other system time delays, this feedback signal provides a near-linear relationship between turbine load and reference setting. Thus, a load reference adjustment produces a proportional change in steam flow with only negligible time delay.

Electronic Controller

The electronic controller is basically an analog computer, consisting of a number of solid-state dc operational amplifiers and signal input and reference channels. A block diagram of the controller is shown in Fig. 2. It consists of seven functional subsystems:

1) Digital reference system
2) Primary speed channel
3) Throttle valve positioning system
4) Transfer control
5) Control valve positioning system
6) Manual controllers and error detectors
7) Auxiliary speed channel.

The *digital reference system* is used in place of the conventional motor-driven potentiometers for selecting desired speed and acceleration rates, or load and loading rates. It is an all-solid-state system using NOR logic modules and binary-coded-decimal counting techniques.

For local control, the operator enters the desired reference speed and acceleration rate (or load and loading rate) into the reference system by means of pushbuttons. The digital reference system generates pulses at a frequency corresponding to desired speed and acceleration rate. These pulses are amplified and converted to an analog voltage proportional to pulse frequency.

For remote operation, such as load-frequency control or centralized boiler turbine control, the reference system can be adjusted by raise-lower commands to the pulse generator.

The *primary speed channel* is similar to that used on the DACA electric governor.[1] A frequency proportional to turbine speed is obtained from a reluctance pickup coupled magnetically to a notched wheel on the turbine rotor. These pulses are amplified and converted to an analog voltage that is proportional to turbine speed.

The difference between the reference voltage and the speed voltage provides the primary input to the valve-positioning systems. To assure maximum stability, both speed and reference channels use identical digital-to-analog conversion circuitry; also, the speed and reference channels have a common heat-sink construction to minimize drift caused by thermal effects. With this approach, an accuracy of 0.1 percent of operating speed over a ten-to-one speed range can be maintained from approximately 31 to 130 degrees F.

The *throttle valve system*, which consists of an automatic controller and position control for each valve, provides wide-range speed control during starting. The voltage output of the throttle valve automatic controller is proportional to the speed error input, and establishes the desired throttle valve position by driving the push-pull coils of the servo valves, which control the hydraulic actuators. All throttle valves are positioned in unison during starting. The control valves are automatically biased for full admission during the startup period.

Control of the turbine is transferred from the throttle valves to the control valves prior to synchronizing. Upon operator command, the *transfer control* automatically removes the bias from the control valves, placing them under the automatic controller, and applies a wide-open bias signal to the throttle valves.

The *control valve system* is similar to the throttle valve system. The input voltage to the servo amplifiers is derived from the automatic controller. By individually biasing the input of the servo amplifiers, the control valves are positioned in sequence as required by the turbine design requirements.

The load limit and initial throttle pressure control (P_o) limit the voltage output of the automatic controller. The set point for the load limit is determined by the operator. The limit action of the initial pressure controller is derived from its proportional plus integral characteristics. Upon loss of throttle pressure below the set point, this controller reduces load to a preset minimum level. The operator can put the pressure limit function in or out of service.

When synchronizing, the breaker action automatically converts the digital reference system from speed to load and establishes a fixed on-line speed reference corresponding to rated speed. The required speed regulation setting is obtained by a gain adjustment of the speed error to the automatic controller. Steady-state speed regulation is defined as the change in steady-state speed, expressed in percent of rated speed, when the power output of the turbine is gradually reduced from rated to zero power output:

$$R_s = \left[\frac{N_o - N}{N_r}\right] \times 100$$

where R_s is steady-state speed regulation (percent,) N_o is speed at zero power output, N is speed at rated power output, and N_r is rated speed.

For normal on-line operation, the load reference is the means for control and its

[1]Noyes, E. G., Richards, R. L., and Davidson, J. D., "Steam Turbine-Generator Automation," *Westinghouse ENGINEER*, July-September 1962, pp. 103-7.

calibration is independent of the speed regulation gain adjustment.

The first-stage pressure feedback (P_I) from the steam turbine is compared to a preset load reference. With first-stage pressure control in service, the characteristic of the automatic controller is changed from proportional to proportional plus integral. The integral characteristic of the controller causes the valves to be positioned and steam flow controlled to minimize the error between the load reference and first-stage pressure feedback.

The relation between load and reference for first-stage pressure control in service is linear, and nonlinear for out of service. To assure a smooth and bumpless transfer between these operating modes, a manual integral controller, continuously tracking the output of the automatic controller, assumes momentary control while the digital reference system is automatically readjusted.

The *manual controllers* with automatic tracking serve as backup and provide direct operator control of valve position. In the event of an excess error between speed and speed reference, or load and load reference, the control of the unit is switched automatically to the manual backup controllers by error detectors. The manual control mode permits on-line maintenance of all input channels and automatic controllers.

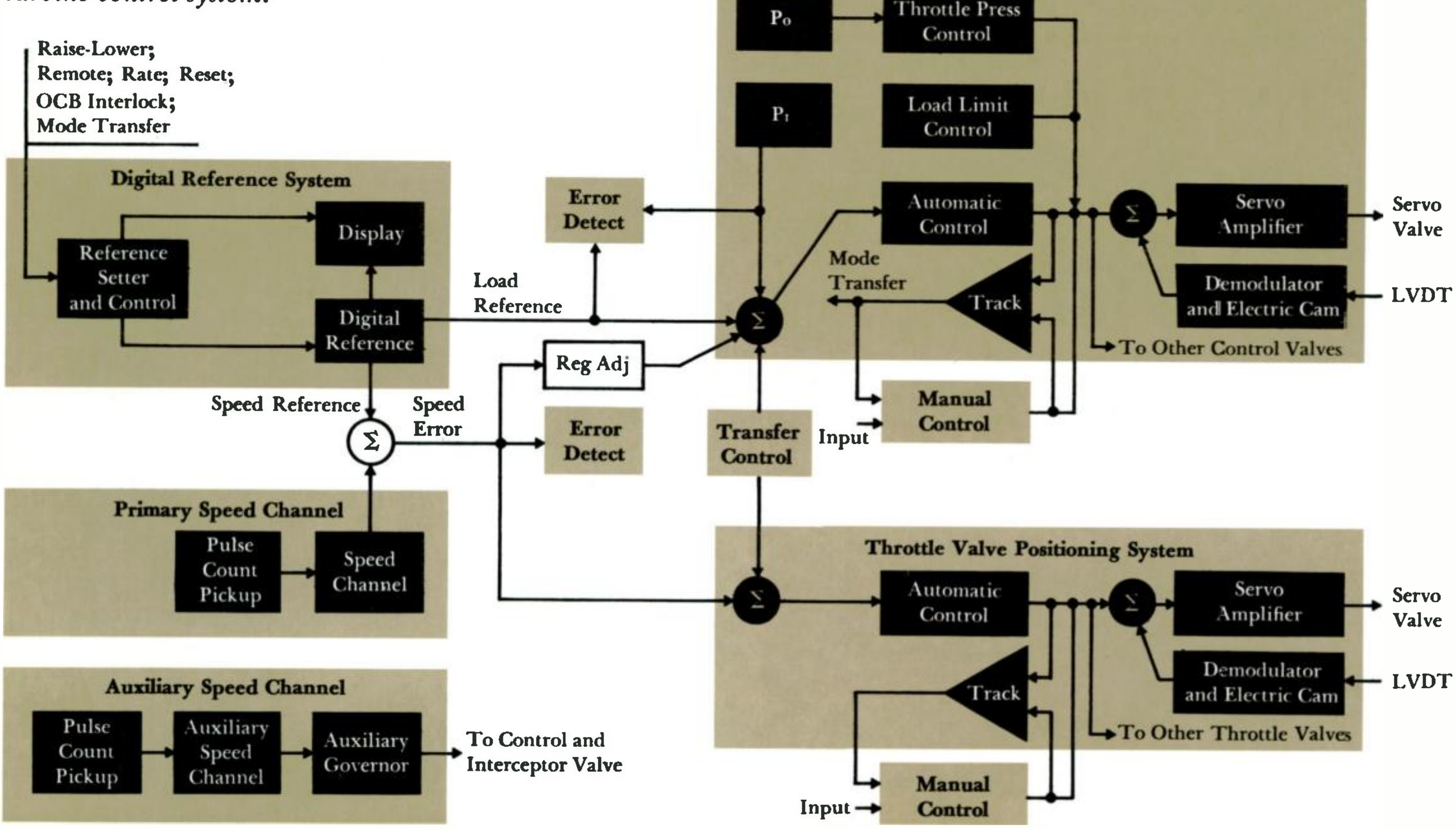
An *auxiliary speed channel* converts frequency pulses generated by a separate reluctance pickup to a proportional analog signal for the control of overspeed. The auxiliary governor responds to a combination of acceleration and speed and actuates the solenoid valves for quick closing of the interceptor and control valves.

Operating power for the controller is obtained from two regulated dc power supplies, +24 and −24 volts. Emergency power can be supplied either from industrial type batteries or from separate regulated power supplies. This approach to backup power provides protection from internal failure of the normal power supplies and permits on-line maintenance of this equipment.

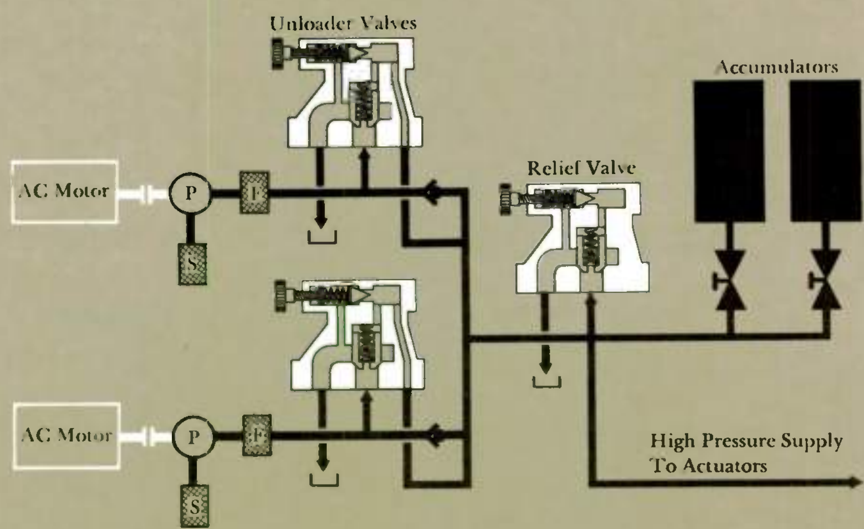
All control functions of the electronic controller are organized on individual plug-in printed circuit cards and are cage mounted in a duplex electrical cabinet. These rack-mounted modules with their associated test points facilitate troubleshooting and maintenance during on-line operation. The cabinet also contains power supplies, a blower unit, and readily accessible terminal strips for interconnecting wiring.

Electronic components were selected for their demonstrated reliability on earlier equipment and are applied with considerable safety factors. Silicon planar

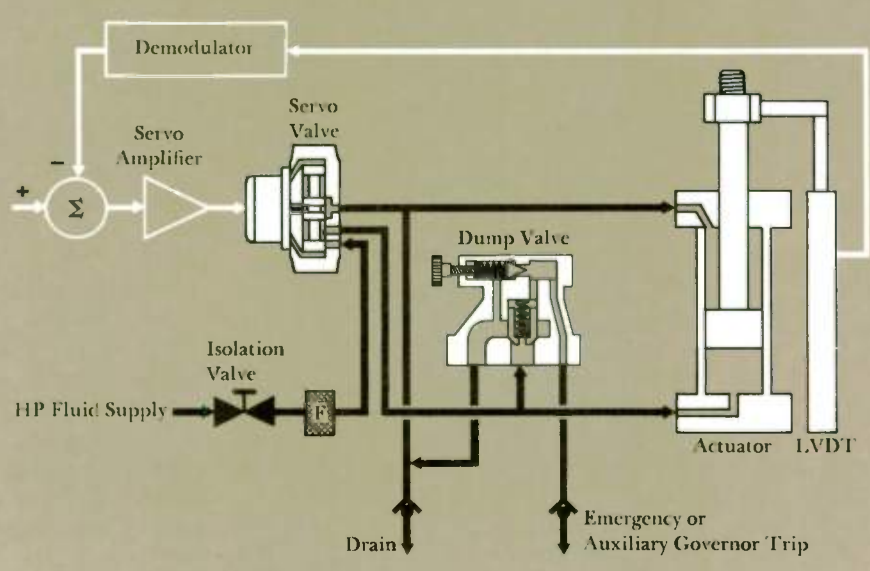
2—Block diagram of electro-hydraulic turbine control system.



3—High-pressure fluid supply system.



4—Throttle and control valve actuator.



type semiconductors are used extensively and are operated at no more than one-fifth of rated current or power. Pulse-width modulation and switching techniques are used wherever possible to minimize power dissipation and extend component life.

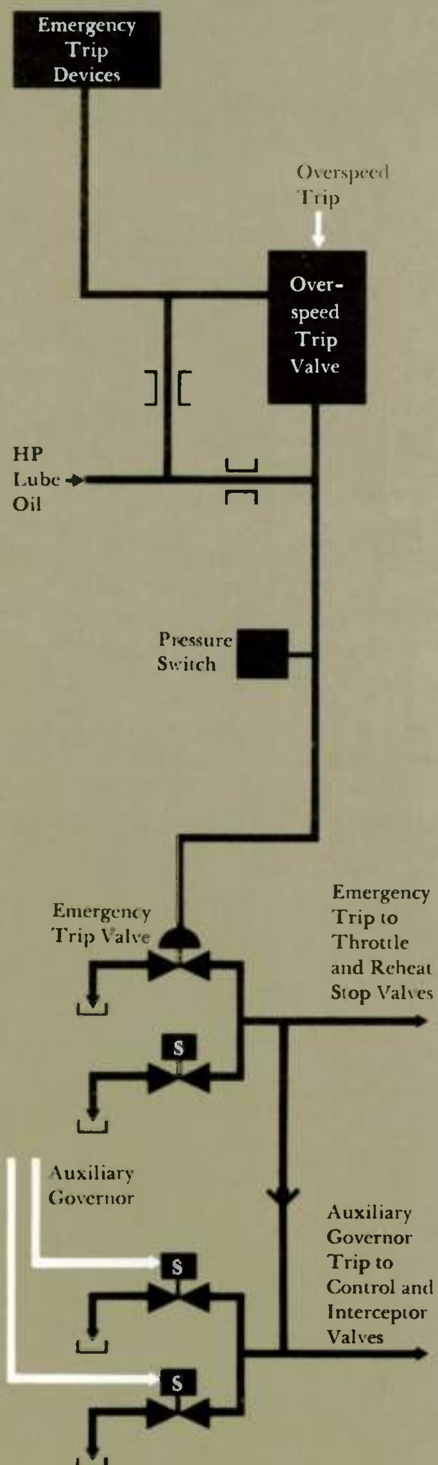
Fluid Supply System

The high-pressure fluid supply system, shown in Fig. 3, is of the unloading type and is completely separate from the lubricating oil system. A dual-pump system is used with one pump serving as a backup to the other. The positive displacement pumps, driven by ac motors, are mounted on a small reservoir containing the fire-resistant synthetic-base fluid. They operate with a submerged suction. The high-pressure fluid is discharged through metal mesh filters and isolation check valves and stored in a bank of nitrogen-charged piston accumulators. Unloading valves on the pump discharge divert the fluid to the reservoir when the pressure increases to approximately 1900 psig. During this unloading period, the discharge pressure of the pump is reduced to atmosphere and system demands are met by the fluid stored in the accumulators. When the system pressure drops to approximately 1600 psig, the accumulators are recharged to the higher pressure level. This cyclic loading of the pump reduces power consumption and increases pump life and efficiency. The backup pump starts automatically from low header pressure.

Contamination is controlled by stainless-steel construction and ten-micron filtration. A small quantity of fluid is bypassed from the supply header to a fuller's-earth filter to control system acidity.

Suitable shutoff and check valves are included in both pumping systems to provide isolation for on-line maintenance. Interconnecting tubing and fittings are minimized by use of block-mounted modular components.

Valve Position Actuators—The schematic diagram for the throttle and control valves requiring proportional position control is shown in Fig. 4. The flow of high-pressure fluid through an isolation valve and a ten-micron metal mesh filter to the



5—Emergency and auxiliary governor trip system.

actuator is controlled by a servo valve. The position control and linear variable differential transformer (LVDT) position feedback signals are summed at the servo amplifier to provide a position error signal. The servo amplifier modulates the servo valve in response to this error signal to accurately position the actuator and steam valve. The servo valves are mechanically biased to assure fail-safe operation for loss of the electrical signal.

A dump valve with the pilot actuated by the emergency trip header provides quick closing independent of the electrical system. When the header pressure is released, the operating fluid is diverted to drain. Heavy springs on the turbine valve assembly provide the force for quick closing.

The on-off position control characteristic required for the reheat inlet valves simplifies these actuator assemblies. The same isolation and dump features are used, but the servo valve and LVDT are eliminated. The supply headers to the actuators are orificed to limit the rate of opening.

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

The servo position loop described is optimized to obtain a steady-state position accuracy of less than 0.005 inch, a transient response of approximately 10 cps at 90 degrees phase lag, and a valve-closing time for dump conditions of 0.1 to 0.15 second. This performance assures adequate overspeed protection and stable operation for changes in steam forces or fluid supply pressure.

Emergency Trip System—The high-pressure fluid trip headers connected to each valve actuator assembly are controlled by a diaphragm-operated emergency trip valve and solenoid valves as shown by the system diagram in Fig. 5.

When the trip valve is opened, either by overspeed or other emergency conditions, the pressures in the two headers are released, initiating quick closing of all steam valve actuators. A solenoid valve actuated by a pressure switch on the petroleum oil trip header serves as a backup for the diaphragm valve.

A redundant solenoid valve arrangement controls the trip header for the main inlet control and reheat interceptor valves. These solenoid valves are energized by the auxiliary speed channel and governor system to limit overspeed.

Turbine Control Interface Unit

The operating needs of the modern power plant require the coordinated interchange of input-output signals and system status information between control centers. The turbine control equipment that is required to coordinate centralized boiler-turbine control, digital computer operation and plant annunciator system is included in an interface unit.

The interface unit, containing all of the hardware required for the application, is rack mounted in the controller cabinet. This approach provides a flexible means for coordinating the control requirements of modern installations.

Conclusion

This new turbine control system has been subjected to an extensive development and evaluation program in the Steam Division Laboratory. The fundamental soundness of the control principles and the performance of system components have been confirmed by exhaustive testing of a prototype system operating in conjunction with an analog computer simulating the steady-state and dynamic characteristics of a turbine-generator unit. With this prototype installation, the performance of the system has been demonstrated for repeated unit startups and generator electrical tripouts.

The experience accumulated on this prototype system has verified the distinct advantages of the electro-hydraulic turbine control system with regard to design application, reliability, performance, operator convenience, and improved unit availability.

High-Speed Trip Mechanism for EHV Power Circuit Breakers

W. V. Bratkowski
W. H. Fischer
R. J. Radus

Two-cycle interrupting time is made possible with a unique combination of a "flux-transfer" trip device and a low-inertia fast-reset trigger mechanism.

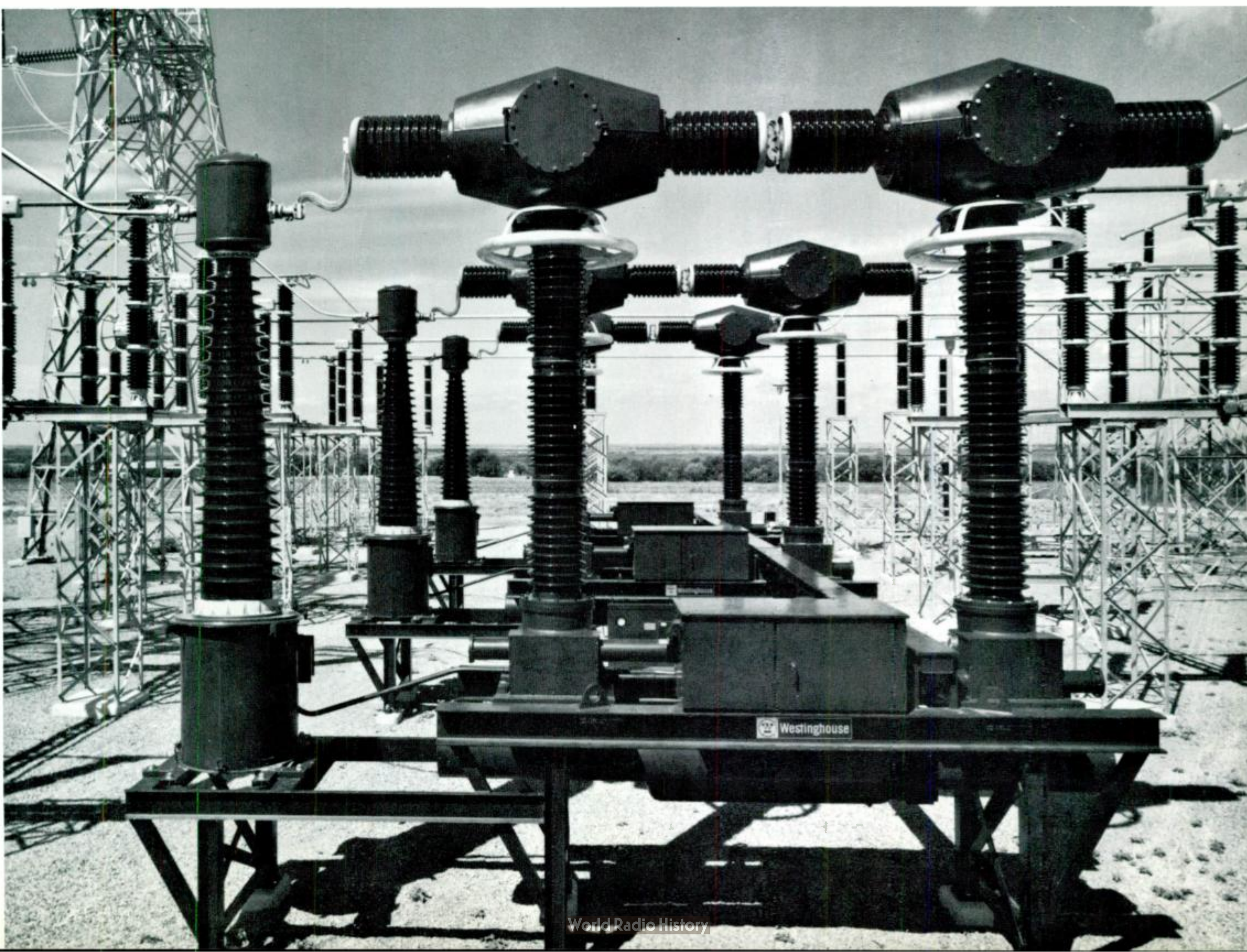
W. V. Bratkowski and R. J. Radus are with the Westinghouse Research Laboratories, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. W. H. Fischer is with the Power Circuit Breaker Division, Westinghouse Electric Corporation, Trafford, Pennsylvania.

With the increasing use of extra-high-voltage transmission, many utility system engineers now desire power circuit breakers with faster interrupting times. A reduction from three-cycle to two-cycle interruption would provide significant improvements in power system stability margins, minimize voltage dips, reduce fault burning, and reduce equipment damage during faults. To provide these desirable operating margins, the SF_6 extra-high-voltage breaker has been modified to make it capable of two-cycle interruption. The general features of this new SF_6 modular circuit breaker have been described.[1] The reduction from three-cycle to two-cycle interruption was made possible by a new high-speed-trip mechanism.

[1]Van Sickle, et. al., "A Modular SF_6 Circuit Breaker Design for EHV," *Westinghouse ENGINEER*, March 1965, pp. 44-9.

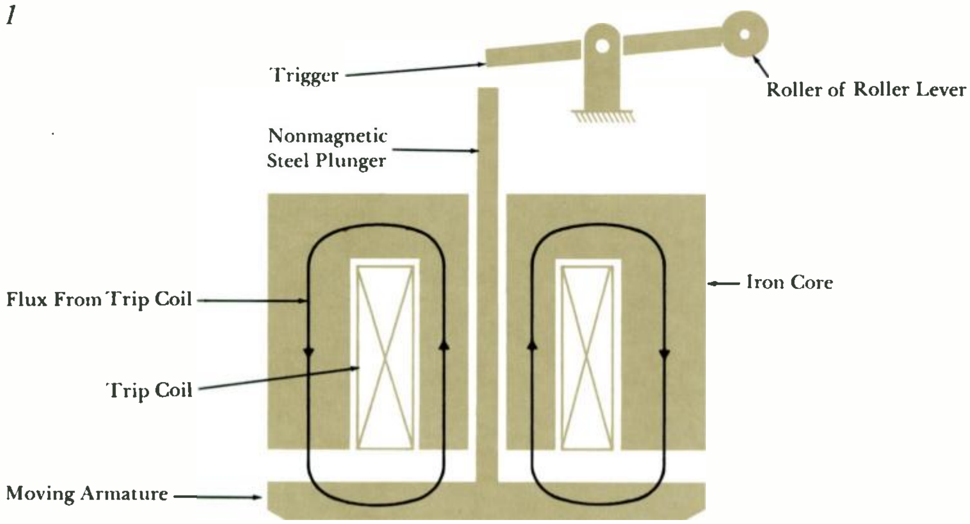
Reducing Tripping Time Needed

A considerable reduction in overall interrupting time can be accomplished by reducing tripping time—the time from the receipt of the electrical trip signal to the actual release of the circuit breaker operating mechanism. The conventional trip-solenoid arrangement used with three-cycle breakers can release the breaker operating mechanism in 0.7 cycle (11.7 milliseconds). However, an analysis of contact separation time for EHV breaker designs indicated that to



Two-cycle modular SF_6 circuit breaker is installed in 345-kv substation of the Texas Electric Service Company.

1



1—In conventional solenoid trip, trip signal energizes coil, creating flux which pulls armature closed, thereby releasing the roller lever.

assure two-cycle interruption, tripping time must be 0.3 cycle (5 milliseconds) or less.

The conventional tripping solenoid for a three-cycle breaker consists of a 300-turn trip coil surrounded by an iron core, and of a moving armature assembly (Fig. 1). When the trip coil is energized, the moving armature assembly is attracted to the iron core; the plunger is driven upward, kicking off the trigger and unlatching the breaker operating mechanism. However, because of the current build-up time required to magnetize the solenoid, and because of the mass of the moving armature and plunger, a 0.3-cycle tripping operation is not practical with a conventional solenoid. Therefore, a new tripping mechanism has been developed using a high-speed magnetic release circuit, an arrangement that is inherently faster operating than a solenoid for the same electrical power.

The new trip device uses a controllable permanent magnet field to hold the breaker in the latched position. The faster release or operating time for a given electrical control power is possible because the change (reduction) of permanent magnet field which initiates tripping is done in a high magnetic permeability loop. With high permeability, the required reduction of holding flux can be made with fewer control ampere-turns. Fewer ampere-turns means less control winding inductance and, consequently, faster build-up of control current to the tripping value. Thus magnetic release in the new trip device is done with less delay in current build-up and without the need for moving mass.

Operation

The new trip magnet assembly is shown in Fig. 2. The two-piece pole assembly provides two possible magnetic paths for flux from a ceramic permanent magnet. With the keeper in the *reset* position, (Fig. 2a), most of the flux concentrates in the low-reluctance path provided by the moving keeper. The magnet holds this keeper with a force of 200 pounds, opposing a 100-pound downward force applied by the roller load through the trigger mechanism. Thus, a 100 percent safety factor is presented to prevent accidental tripping by mechanical shocks.

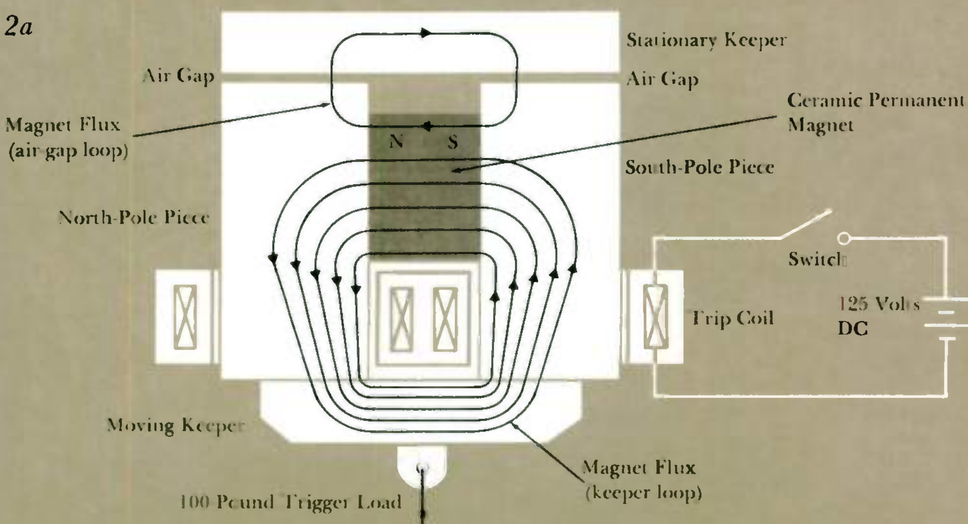
To initiate a trip operation, the trip coil assembly is energized (Fig. 2b). Two trip coils, one around each pole piece, are connected in series and wound so that flux produced by the coils opposes the permanent-magnet flux in the moving keeper. This flux opposition decreases the magnetic flux in the moving keeper circuit (the permanent-magnet flux transfers from the moving keeper loop to the air-gap loop). The holding force on the keeper is reduced, allowing the 100-pound trigger force to initiate motion for release of the keeper-trigger mechanism.

Once the keeper-trigger mechanism is tripped, the magnet must be reset before the main circuit breaker mechanism arm returns to its original starting position. The final design is such that the keeper-trigger system is tripped and the keeper reset as the circuit breaker mechanism arm leaves the trigger arm on the initial trip. Trip coil current is immediately cut off by the breaker mechanism movement. This resetting action is done without the need of any electrical or mechanical turn-on energy. A spring-loaded two-piece trigger system shown in Fig. 3 is used to accomplish this action. With such a system the magnet is ready for reclosure almost immediately.

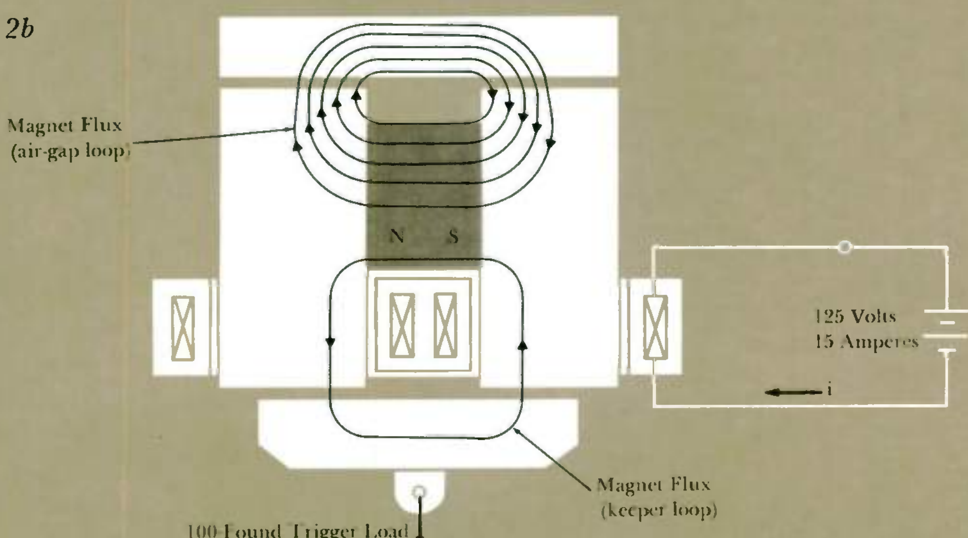
Since the trip system of a circuit interrupter is subjected to shock loadings, the possibility of tripping due to mechanical shock was taken into consideration in the design of the keeper trigger system. The trigger was balanced and the moments about the actuating shaft of the keeper-trigger system were also balanced to minimize the effects of shock loading. In addition to holding the keeper-trigger system, the magnet force also aids in preventing premature tripping.

Acknowledgment:
The authors wish to acknowledge the valuable contributions of Mr. E. Frisch, Consultant for the Westinghouse Commercial Atomic Power Division and the Westinghouse Astronuclear Division, and Mr. R. C. Van Sickle, Advisory Engineer for the Westinghouse Power Circuit Breaker Department, during the planning and execution of this project.

2a

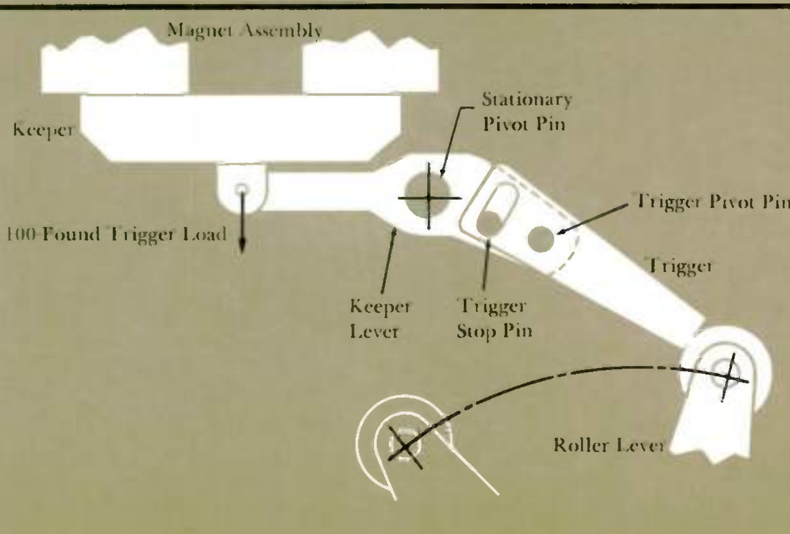


2b

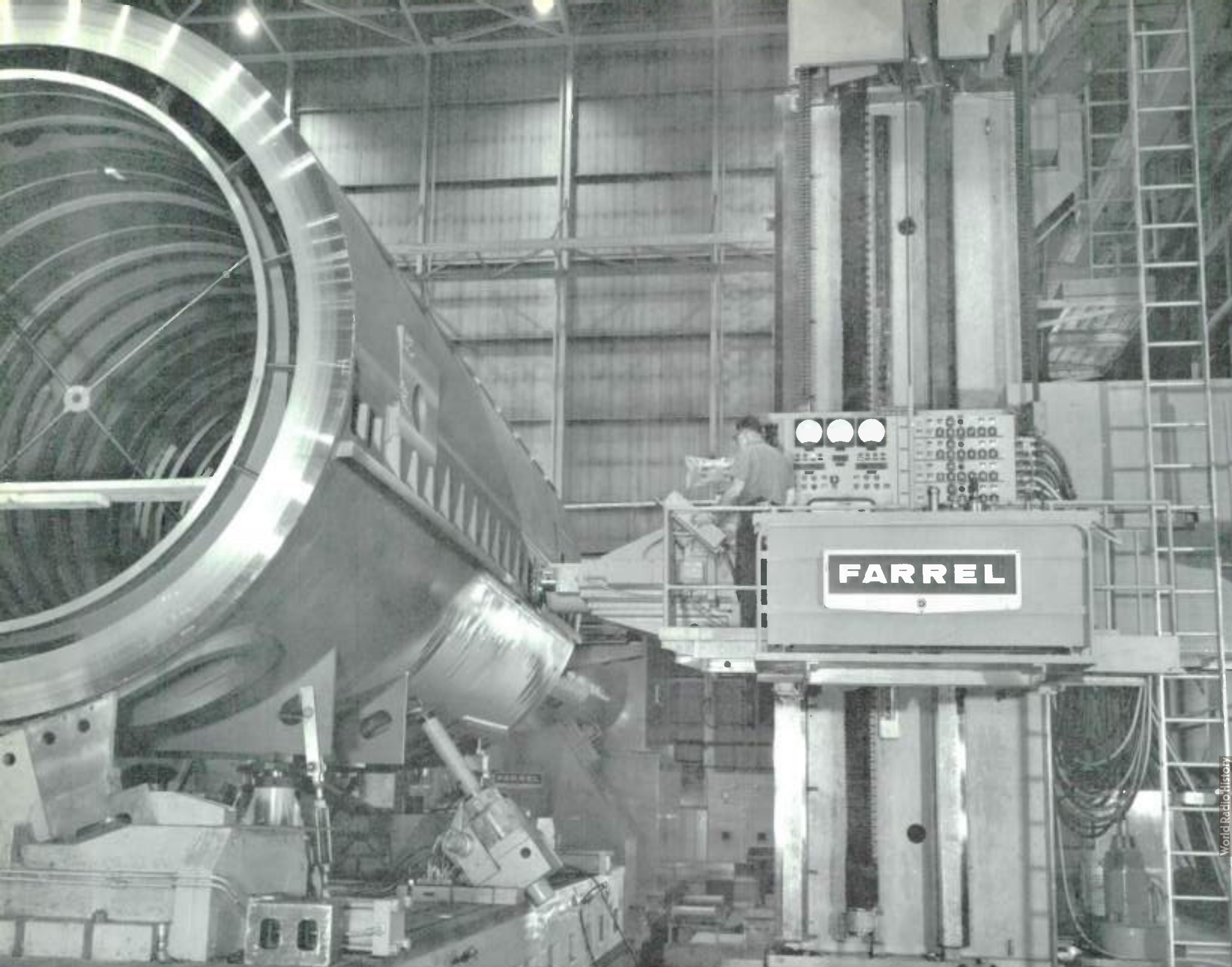


2—In new trip magnet assembly, the moving keeper in its closed position *(a)* "transfers" most of the permanent-magnet flux to the keeper loop, holding keeper closed with a 200-pound force; when trip coil is energized *(b)*, trip-coil flux opposes permanent-magnet flux. This results in greater reluctance in the keeper circuit so that magnet flux "transfers" to air-gap circuit, thereby allowing keeper to be opened by the 100-pound trigger load. Permanent-magnet flux will return to keeper loop when keeper is closed again.

3



3—Pivoting action of the trigger permits the roller lever to be closed without disturbing keeper from the reset position.


FARREL

FARREL

Large Generator Frames Machined Accurately and Efficiently At One Work Station

Performing all machining operations at one work center saves time and improves quality and uniformity.

With the trend in the electric power industry toward larger generators, facilities for machining generator frames are fast becoming inadequate. The problem has been solved at the Westinghouse Large Rotating Apparatus Division by installation of a giant machining center that performs all machining operations on large frames accurately and efficiently at one work station.

This eight-axis machining center, thought to be the world's largest machine tool, improves production efficiency by eliminating the waste motion previously encountered in transporting the frames to several machining centers throughout the shop. The improved machining capability also increases accuracy through reduction in the number of setups required. Moreover, it facilitates innovations in design and construction to further improve performance and reliability.

The machining center has two separate units, on adjacent sides of a 14- by 40-foot indexing table, that process frames up to 16 feet in diameter and 38 feet long. Both of these units have four axes of motion, and both are tape-controlled. The total space encompassed for milling, drilling, and tapping is 10,300 cubic feet. The machining center was built by Farrel Corporation, Rochester, N.Y.

The side unit operates lengthwise along the table and is basically a 10-inch horizontal boring, drilling, and milling machine. It has a special head equipped with independent milling and drilling spindles so that the large milling cutter can be permanently mounted. The end unit has a 24-foot boring arm whose end rotates when boring and facing. Five interchangeable heads perform boring, facing, drilling, tapping, and milling operations.

The foundation for the machining center rests on 115 large steel beams driven to solid rock. Seven miles of steel reinforcing rods were laid and 800 cubic yards of concrete poured.

A numerical control system with punched-tape input is used because it minimizes the deviations normally experienced due to variables in blueprint reading, workpiece measuring, and machine and cutter positioning. The control includes means for checking to assure that the machining plan has been executed successfully. The end unit and side unit can operate simultaneously, and the two may be sequenced so that they complete their operations at the same time.

Although the machining center is primarily a tape-controlled unit, certain functions require manual intervention (for example, tool changes, spindle-drive gear changes, boring-bar adjustment, and head changes). Also, some machining operations are scheduled for manual or dial mode, and operator control stations provide these functions. All tape input commands and selections are duplicated in manual control devices, thus permitting the operator to control the machining completely in the dial and manual modes if necessary.

A typical generator frame requires 30 distinct milling, facing, boring, and drilling sequences, requiring literally thousands of operations. (More than 750 holes may have to be drilled.) Consequently, manual programming, with every movement programmed as a separate instruction, would take a great deal of tedious effort. So would the punching of these instructions on paper tape. To keep programming from becoming a bottleneck in production processing and to minimize errors, the control system is programmed with the assistance of a computer. The CAMP II system for automatic point-to-point programming is used.[1] This system has a language that is easy to learn, since it uses such general shop terms as "drill," "tap," and "face mill," and it performs calculations quickly and accurately.

The programmer prepares a manuscript that describes the machining operations, using the dimensions shown on the drawing. This manuscript is punched on cards, which are fed into the computer, and the computer then generates tapes for the machining operations.

Many tapes can be reused, even though orders for duplicate generators are the exception rather than the rule. The reason is that certain machining patterns are common; it is the location of these patterns on each frame that varies. Proven machining tapes can be used again and again because the machining center's control system has "offset capability," which means that a point around which a machining pattern has been programmed can be shifted to any location. This is done by dialing in the dimensional variance and offsetting the spindle the desired amount. Tapes for standard patterns are being accumulated to reduce tape-making and storage requirements.

[1]Cumming, D. C., and Knarr, C. M., "The CAMP II Numerical Control Programming System," *Westinghouse ENGINEER*, May 1963, p. 70.

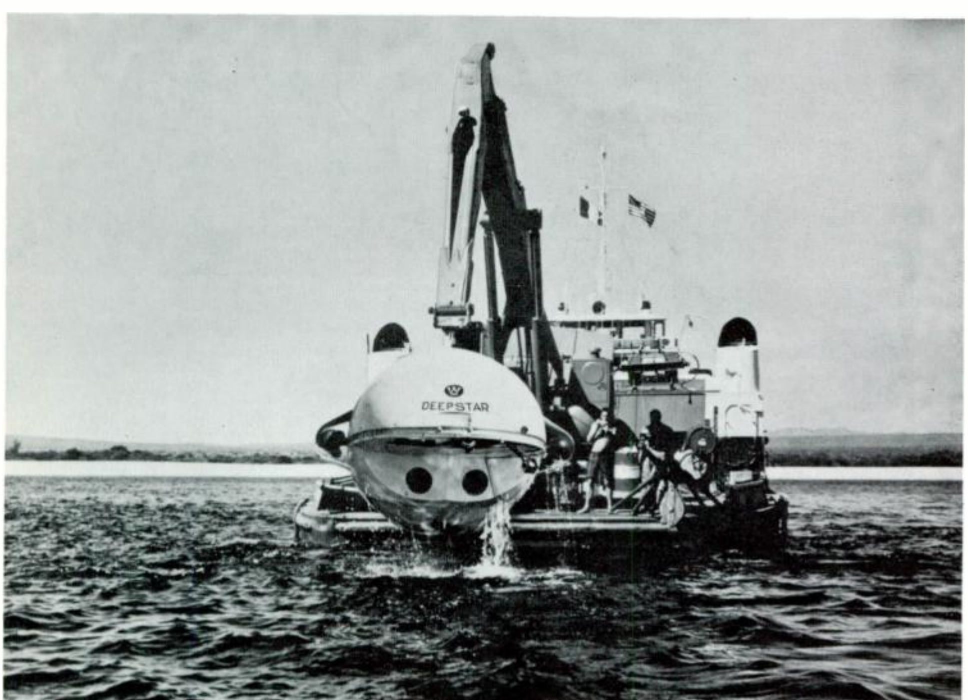
Numerically controlled machining center for large turbine-generator frames has a side unit (top) with a horizontal boring, milling, and drilling spindle; this unit is elevated and traversed as required to machine the sides of the frame. The machining center's end unit (bottom) has its own control console. Though basically tape-controlled, all operations can also be performed by manual control. A table positions the frame for all machining operations.

Deep-Diving Vehicle Operates 4000 Feet Down

Deepstar-4000, a diving vehicle designed to descend as deep as 4000 feet and stay there up to 24 hours, has been put into service. It is the first of a family of undersea vehicles: the family, as presently planned, will include *Deepstar-4000*, *-2000*, and *-13,000*. (The number designations indicate maximum designed operating depths.) *Deepstar-2000* is under construction, and *Deepstar-13,000* is in the design stage.

Deepstar-4000 moves about untethered under its own power at underwater speeds of up to three knots. It is manned by a crew of three—a pilot, an observer, and a copilot-observer. It is available to users through a charter facilities program that includes the submersible vehicle, its "mother ship" with support and handling equipment, and an experienced crew of pilots, divers, technicians, and engineers. The charter service provides equipment, experience, and personnel to perform such work as placement, observation, and recovery of instruments and equipment in buoys, in suspended arrays, and on the ocean floor; underwater photography; deep-sea environmental studies; military and commercial salvage operations; ocean-bottom exploration, sampling, and coring; systematic observation by marine biologists and geophysical scientists; advanced development work on sensors, on underwater lighting, on propulsion and control, on sonar equipment, and on deep-sea instruments; and ocean-floor mapping.

Deepstar-4000, a deep-diving undersea vehicle, carries a crew of three. A mother ship launches and retrieves it, but the vehicle requires no connection with the surface when in use.



The *Deepstar* design is based in part on that of the *Diving Saucer*, which has been operating since 1959. The *Diving Saucer* was conceived by the underseas explorer Captain Jacques Yves Cousteau and developed by his research organization, the French Office for Undersea Research.

Design criteria for the *Deepstar* submersibles included safety and recoverability, achieved largely by a pressure-resistant hull with positive buoyancy so that the vehicle does not require power for return to the surface. Size and weight were limited to allow transportation by land, sea, or air. Freedom of movement, to perform many kinds of useful work, necessitated a high degree of control and maneuverability.

The nine-ton *Deepstar-4000* has a teardrop fairing 18 feet long, 7 feet high, and 11½ feet wide. A pressure hull inside this fairing houses the crew. To withstand the pressure of 1800 pounds per square inch exerted by the sea at 4000 feet, the crew compartment is spherical and made of high-strength alloy steel. The sphere was made from two hemispheres spun from plates, machined accurately, and welded together. Mounted within the fairing, but outside the pressure sphere, are most of the major operational components, such as batteries, pumps, buoyancy material, ballast tanks, propulsion motors, and hydraulic systems. This part of the vehicle is flooded, so the components are built for immersion in seawater and to withstand the water pressure at operating depth.

Electric power is supplied by three lead-acid batteries with a total capacity of 400 ampere hours at 115 volts output. Navigation and recording equipment, located inside the pressure sphere, includes a gyrocompass, two-way radio, tape recorder, two echo sounders, and a fathometer. External accessories include an underwater telephone; a high-intensity movie lamp with hydraulic remote control; mountings for a movie camera, strobe flash, and 70-millimeter still camera; an arm with sample-collecting tongs, also operated by hydraulic remote control; a sample basket; and other illuminating lights.

Two ports allow observation, and a mercury ballast system controls the pitch of the vehicle. The submersible is propelled by two propellers driven by 4.5-horsepower ac induction motors. The motors are open to the sea, eliminating the necessity for a pressure housing.

Weights attached to the fairing cause the vehicle to descend. When the desired depth is reached, weights are dropped until the craft is neutrally buoyant; for ascending, a large weight is dropped. Fine control of depth is either by a system of ballast tanks that can take on or discharge seawater or by dropping small weights. The vehicle's life-support system provides a 48-hour oxygen supply for the crew of three.

A 136-foot surface support vessel, the *Burch Tide,* serves as the submersible's mother ship. Its hydraulic crane and a lifting eye atop the submersible are used to launch and retrieve the diving vehicle. Other facilities aboard the *Burch Tide* are battery chargers, air compressor, oxygen supplies, and vans housing a shop for field maintenance, photo darkroom, electronic test equipment, storage, and spare parts. Three other vans provide living quarters.

Programmed Control System for Transfer Machines

A stored-program control system has been developed to improve the control of transfer machines—the automatic machines that perform sequential operations on such components as cylinder blocks, engine heads, and transmission cases. It is an adaptation of the Prodac-50 stored-program control and was developed through a joint study with the transfer-machine builder, Buhr Machine Tool Company.

The system has several advantages over the conventional wired-logic control panels. First, its greater capacity enables it to be programmed to type out a message if a line stoppage occurs, telling the operator what the fault is, where it is, and the cause. Second, if the transfer line is rearranged, the system can simply be reprogrammed to operate the new line at a fraction of the cost of installing new wired-logic controls. Moreover, the system requires considerably less floor space than the conventional controls.

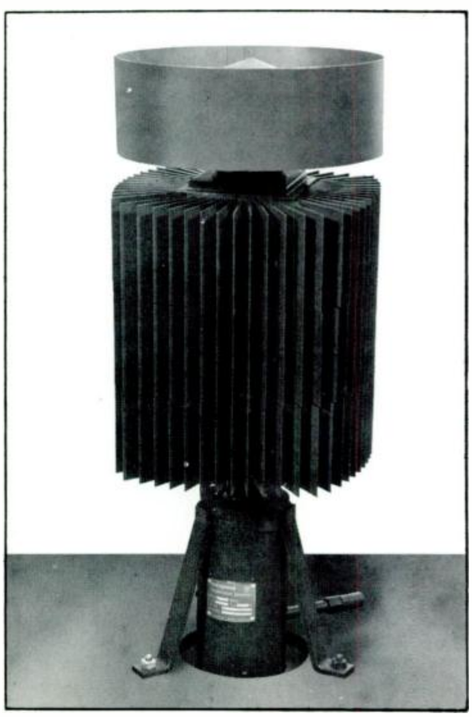
Thermoelectric Generator Has Replaceable Modules

A new thermoelectric generator is made with 12 individual and replaceable thermoelectric modules so that, if any of the modules are damaged in the field, they can be replaced instead of having to replace the entire assembly as would be necessary with most previous generators. The modular construction has the added advantage of allowing the modules to be connected in a variety of series and parallel arrangements for better electrical matching of the generator to its load.

Standard ratings are 20 and 35 watts, and higher ratings can also be built. The units are especially suited for operation in remote areas, including unattended operation. Typical uses are for emergency power, microwave relay stations, cathodic protection for gas wells and pipelines, instrumentation sites, oceanographic research, navigational aids, and mobile communication facilities. A prototype unit has been continuously tested for a year and a half; it has continued to operate without protection in the most adverse conditions, including winds of more than 100 miles an hour and driving rain and snow.

A unit can be converted in the field from one fuel to another—butane, propane, or natural gas—by changing orifices. A line of accessory equipment, such as voltage regulators and dc-to-dc converters, has been designed for use with the generators.

Thermoelectric generator is assembled from individual modules, permitting variations in series and parallel connections and replacement of damaged modules in the field.



Static Power Supplies for Continuous Casting Facility

Static thyristor power supplies will be incorporated in the variable-voltage drive systems for the new continuous casting facility of the Weirton Steel Division of National Steel Corporation. The drive systems will provide reliable controlled power for mold lubrication and for the rolls that withdraw the cast bars from the molds, straighten them, and convey them away. The new equipment is scheduled for installation later this year in the company's Weirton, West Virginia, works.

When the plant is in operation, molten steel from basic oxygen furnaces will be transferred by a 300-ton ladle to the continuous casting machine. It will be poured into twin receptacles called tundishes, from which it will be admitted to four molds at a controlled rate. The material will solidify in the molds sufficiently to be withdrawn from the open bottoms continuously as four strands of steel. (Maximum cross-section dimensions of each strand will be 11 by 40 inches.) Pinch rolls will move each strand to a straightener, and roll tables will then convey the straightened bars away from the machine. A mold-level control will enable the machine to operate at constant strand speed by controlling stoppers in the tundish.

Mercury-Lamp Rated Life Increased by 50 Percent

Improved processes, materials, and manufacturing controls have permitted a 50-percent increase in the rated life of mercury vapor lamps—from 16,000 hours to 24,000 hours. The new ratings mean that in many applications, such as street lighting, mercury lamps will not need replacement for several years.

The largest factor in rated-life improvement is the Lifeguard arc tube, which contains an improved electrode that drastically reduces blackening of the lamp. This tube's emission material is embedded inside the electrode, completely shielded from the arc discharge and thus protected from being eroded away. As a result, far less material is deposited on the arc tube during burning, so more of the light produced gets through the lamp and is usable. This feature not only lengthens useful life but also maintains excellent light output during the lamp's lifetime.

Another factor in the sharp increase in rated life is close quality control. For example, regular spectrographic analyses are made of the tungsten used in the electrode to insure that any harmful impurities will be discovered before the electrode is assembled into the lamp.

Coaxial Flash Lamp Provides More Energy for Lasers

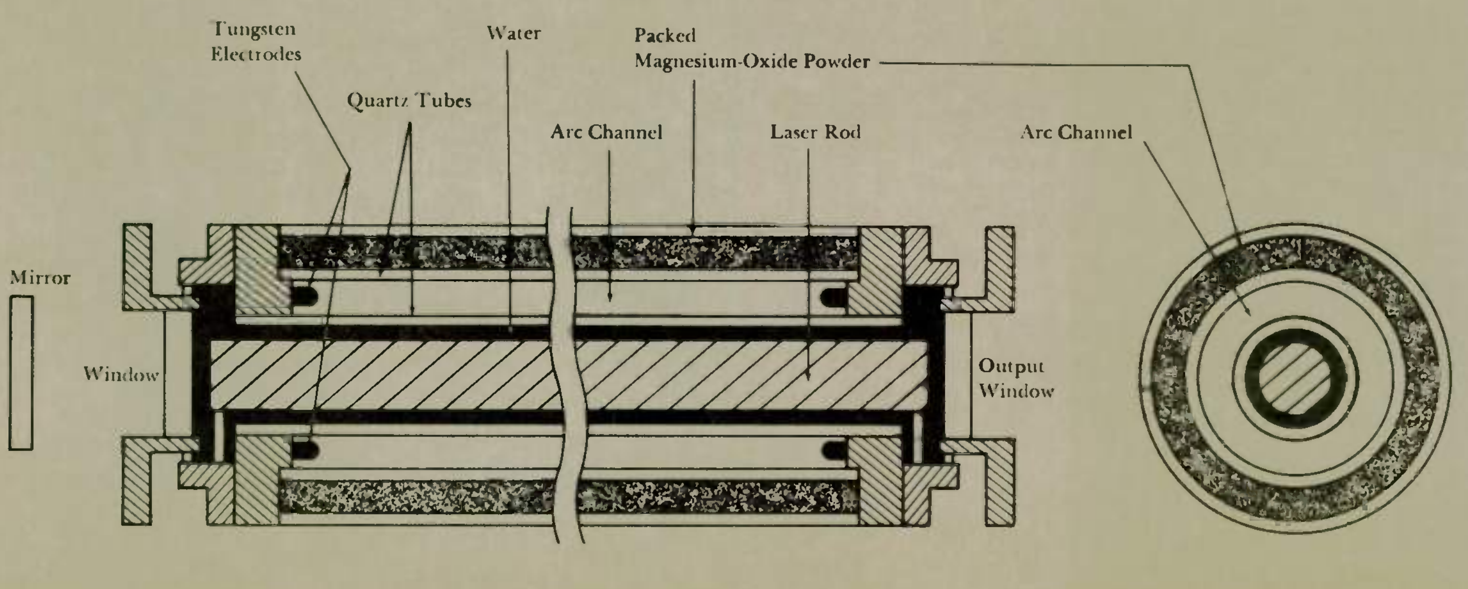
One limit to the beam energy obtainable from an optically pumped laser is the intensity of the light available from the flash lamp that "pumps" it, and this intensity in turn is limited by the efficiency of the lamp and the amount of electrical energy that can safely be put into it. Recent development of a flash lamp that accepts more energy input and is more efficient than earlier lamp arrangements has pushed back this limit. The lamp is a new coaxial type that completely surrounds the laser rod.

The high-energy pump should increase the usefulness of laser systems by providing higher energy outputs than have been possible. In two of the more important industrial laser applications, for example, drilling and welding, the smaller amount of beam energy that has been available until now has severely limited the thickness of material that can be drilled or welded and the diameter of the holes or spot welds that can be made. The unique characteristics of lasers also open potential applications in optical measurement, optical "radar," photography, and long-range communication in deep space. Again, higher energy output is needed to realize the laser's potential.

The new pump is used with glass laser rods. These rods contain a small percentage of neodymium; in operation, some of the neodymium ions are energized, or "pumped," to a higher energy state by a short brilliant flash of light (typically a few thousandths of a second in duration) from a flash lamp. Then, a fraction of a second later, these ions return to their original condition of lower energy, and the pulse of excess energy that they release is emitted from the end of the rod as a narrow coherent light beam millions of times brighter than the pumping light.

Some pulsed laser systems, designed for a "giant-spike" pulse, develop high peak *power* but in such a brief time period that total *energy content* is low. (Peak power, for example, may be a thousand megawatts but energy content only 20 joules or less.) The new pumping system is designed primarily for high energy (although it can also be used for high peak power). With a glass laser rod, it can provide laser output energy of 900 joules and more per pulse. Part of the development work on the new lamp was carried out under contract with the U.S. Army Missile Command, Huntsville, Alabama.

Coaxial laser pump is a flash lamp that completely surrounds the laser rod for high efficiency. The construction also is inherently stronger than that of other lamps, so more energy can be put in. Both effects increase laser output. The space between the two outer walls is packed with magnesium-oxide powder to reflect light onto the rod.



Conventional pumps for high-energy lasers usually have consisted of one or more flash lamps placed alongside the laser rod, or of a flash lamp wound spirally around the rod. Flash brightness, and therefore laser output, varies directly with the amount of energy in the electrical pulse that fires the lamp. However, because the electrical pulse creates shock waves that tend to shatter the lamp, the amount of energy that can be put into a conventional lamp is limited by the strength of the glass or quartz tube.

The new pump is inherently much stronger than the other types. It consists essentially of concentric tubes held together at each end by metal electrodes. (See illustration.) The laser rod fits inside the transparent quartz inner tube, and the annular space between this tube and the outer wall is filled with rare gas to form the flash lamp's arc channel. An electrical discharge in this annular channel forms a hollow cylinder of light that completely surrounds the laser rod. Water circulates around the rod to minimize damage from pump radiation and laser emission, and also to cool it. Typical laser rods used are 18 millimeters in diameter and about a meter long. Electrical pumping energy is supplied by a bank of capacitors.

The inner quartz tube undergoes only compression forces from the shock waves, which tend to push it together instead of tending to tear it apart. Moreover, the water inside the inner tube tends to damp resonance vibrations. Since the pumping light from the coaxial lamp is reflected inward, the outer tube can be reinforced with high-strength opaque materials. The result of this construction is an exceptionally strong structure that permits higher energy input than the other types of flash lamp can stand. Moreover, efficiency is higher because of the close coupling between pump and laser rod and the high reflectivity of the outer wall. Including a diffuse reflector such as magnesium oxide in the outer wall also does away with the bulky and expensive reflecting cavities needed by conventional flash lamps to focus the light onto the laser rod.

An efficiency of 5.1 percent in converting input electrical energy to laser output energy has been achieved. With an input of 23,000 joules of electrical energy, for example, an output of more than 900 joules of coherent radiation is obtained. (About 5000 joules of the input is required to raise the material of the laser rod to the excited state.) This efficiency is significantly higher than the 4.6 percent attained with other pump types and the same laser rod.

Moreover, the coaxial flash lamps operate at much lower current density because of their large plasma area. Since high current densities tend to shorten lamp life, the coaxial lamp should have longer life expectancy than other comparable flash lamps.

The lamps with double-walled quartz outer tubes have been fired repeatedly at 70,000 joules without breaking. If higher energy input is needed, the outer tubes can readily be reinforced by several means. One filament-wound unit, for example, has been test-fired repeatedly at 150,000 joules.

High-Speed Data Processor for Antisubmarine Hydrofoil

A central data processor will be the "brains" for the action information center of the Royal Canadian Navy's new high-speed antisubmarine hydrofoil. The unit, designated DPS-2402, will provide split-second information processing for the complex electronic equipment controlling the ship's weapons system. The 200-ton FHE-400 hydrofoil, which could be the forerunner of a squadron of such craft that could rise above choppy waters and pursue submarines at high speeds, will use advanced electronic techniques to detect, track, and destroy enemy submarines.

The data processor will be capable of withstanding shock and vibration, extreme temperatures, salt spray, and humidity. It will process data in real time; that is, as fast as it occurs. Built with tiny molecular-electronic components, the unit is capable of retaining from 4000 to 32,000 words in memory and has a cycle time of two microseconds.

The hydrofoil is designed for operation in the roughest seas and will be capable of attack at high speeds. Its weapons system will include a variable-depth sonar, torpedoes, radar, and communications and navigation equipment. It is scheduled for completion and sea trials in 1968.

Large Reversing Mill Has Thyristor Power

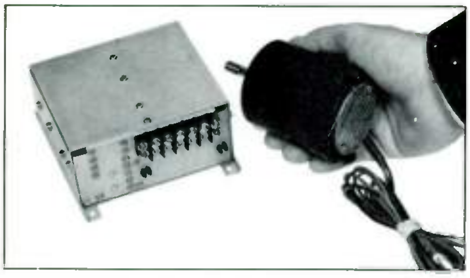
A thyristor power supply system, the first such system for a large reversing cold mill, is being installed to provide static conversion of ac power to variable-voltage dc power for the mill motors. The mill, a four-high unit, is designed to roll steel strip with entry thickness up to 0.187 inch; finished strip will range down to 0.0125 inch thick, and maximum strip width is 68 inches. The two 3000-horsepower mill drive motors are directly connected to the backup rolls and provide full power at 70 to 210 rpm.

A thyristor ac-to-dc dual converter rated at 4800 kilowatts provides the power to drive the mill motors for full motoring and regeneration in both the forward and reverse directions. A similar 1600-kw dual converter powers each of the two double-armature reel motors, which develop 2000 horsepower and operate at 175 to 700 rpm. Another converter powers the 75-horsepower screwdown motors. The complete screwdown, conversion, and regulating system is housed in one floor-mounted structure.

A card programmer determines the setting of various operating parameters from input data stored on punched cards. These parameters include mill top speed, entry and delivery reel current, entry and delivery x-ray gauge thickness setting, draft compensation, x-ray gauge cycling in and out of mill pass lines, screw position at beginning of the pass, automatic slowdown and stop of the payoff reel, and automatic mill reversal and acceleration. Operation is partly manual during the first pass and then completely automatic. As the mill accelerates, an automatic gauge control system takes over and makes changes in tension and screwdown settings to maintain average gauge accuracy.

Products for Industry

Three-phase inverter and matched induction motor form a brushless dc drive that is simple, compact, and reliable. Efficiency is as high as or higher than corresponding brush-type wound-field dc motors; weight of inverter and motor is approximately equal to that of a brush-type motor. Several motors can be used with a single high-capacity inverter if they are started in a programmed sequence; advantages are greater starting torque and economy in weight and cost. Combinations with ratings as high as one horsepower can be supplied. *Westinghouse Aerospace Electrical Division, P. O. Box 989, Lima, Ohio 45802.*



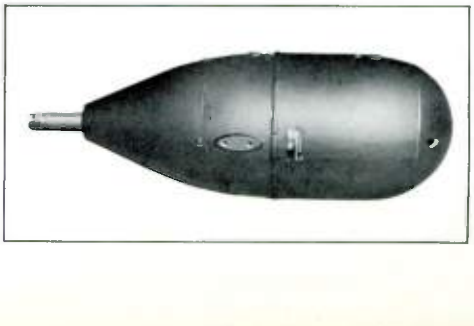
Hipernom thin-gauge alloy is a foil material for magnetic shielding. Efficiency is as much as 30 percent greater than that of conventional foils because of the material's high initial permeability—approximately 30,000 at 40 gauss. Greater efficiency permits less material to be used for a given shielding level. Applications include wrap-around shielding for transformers, tubes, cathode-ray tubes, cables, and other electronic elements. Material is available from stock in 0.004-inch and 0.006-inch thicknesses and in widths up to 15 inches. *Westinghouse Materials Manufacturing Division, Blairsville, Pa. 15717.*

Current-limiting fuse (Type CLT) for transformer protection meets the need for new protective devices with larger interrupting current ratings and high voltage ratings, a need brought about by lower system impedances and higher voltages. (In a direct line fault where high fault currents are available due to low impedances and high voltages, the ordinary protective link may be incapable of safely clearing the fault.) The CLT is a 15-kv fuse designed to interrupt fault currents up to 20,000 amperes rms. It is coordinated with the high-voltage protective link and the low-voltage breaker so that the lower-cost high-voltage link, rather than the CLT fuse, will interrupt low fault currents or clear secondary faults. Fuse and protective link are both mounted inside the high-voltage bushing. The single CLT current rating is coordinated with all completely self-protecting transformer ratings from 5 through 100 kva at primary voltages of 12 through 14.4 kv. *Westinghouse Distribution Transformer Division, Sharpsville Avenue, Sharon, Pa. 16146.*

Capacitor potential device, type PCM, is for revenue metering in EHV interties. It also provides normal functions of relaying and voltage indication, and carrier accessories can be added to make it suitable for broad-band carrier coupling to the high-voltage line. The potential device is available for transmission systems of 115 kv and higher. Its three secondary windings are each nominally rated 115/66.4 volts. The "X" and "Y" windings maintain the 0.3 accuracy class up to a total burden of 400 va, while the "W" winding provides zero sequence voltage if desired. *Westinghouse Distribution Apparatus Division, P. O. Box 341, Bloomington, Ind. 47402*

Safety handle mechanism, Type SM, prevents tampering with circuit breakers and switches. It can be applied to units with current capacities up to 200 amperes. Double interlocking with cover and door hardware is provided, and the handle can be locked with as many as three padlocks. *Westinghouse Standard Control Division, Beaver, Pa. 15009.*

Submersible electric motor operates under deep-water pressures while flooded with fresh or salt water. Key features are "wet" windings and water-lubricated bearings, which make the water environment an unlimited supply of coolant and lubricant. The motor is available in many sizes for driving pumps, gears, or propellers. Bearing construction allows the motor to be used in any position. For high-thrust applications, special thrust bearings that can withstand pressures of over 4000 pounds per square inch of bearing surface can be incorporated. *Westinghouse Marine Division, Hendy Avenue, Sunnyvale, Calif. 94088.*



About the Authors

Arthur T. Monheit earned his BSEE from City College of New York (1950) and his MS from Harvard University (1951). He came directly to the Westinghouse Aerospace Division (then the Air Arm Division) from Harvard to work on designing autopilot systems. In 1954, he was made project engineer responsible for the Bomarc Missile radar seeker system design, which involved radar stabilization and tracking.

Monheit was transferred to the space systems group in 1959 to direct studies in the area of satellite interception and rendezvous. This work was the base for an article that he coauthored on satellite rendezvous (July 1962 *Westinghouse ENGINEER*). In 1963, Monheit was made director of a navigation satellite program, and the following year became manager of advanced control data systems, responsible for systems development activities for aerospace control systems and for systems requirements and software for aerospace computers.

Arthur G. Buckingham graduated from Clarkson College of Technology in 1950 with a BSEE degree. He joined Westinghouse on the graduate student program and was assigned to the Special Products Development Division in East Pittsburgh to work on the development of control systems for the USS *Nautilus*. From 1952 to 1957, he was engaged in the development of fire and flight control systems at the Aerospace Division. Since 1957, he has been engaged in the inception, development, and design of guidance and control systems for spacecraft. He is presently in the control and data systems section of the Aerospace Division.

Since 1928, **Frank C. Rushing** has been designing and developing electromechanical devices and machines—for applications ranging from underseas to outer space.

Rushing came with Westinghouse on the graduate student course from the University of Texas with a BSME. He attended the company's mechanical design school, and obtained his MSME degree from the University of Pittsburgh. After a year of industrial motor design, he was awarded the Lamme Memorial Scholarship in 1931, and given a leave of absence to study electric machine design at Techniche Hochscule zu Charlottenburg, Berlin, Germany.

Rushing returned to the Westinghouse Research Laboratories in 1933 to work on a wide variety of problems in specialized machine design and development. Among his accomplishments were high-speed motors to rotate the unbalanced rotors used in rayon spinning, dynamic balancing machines, and vibration instruments. He led the development of an ultra-high-speed centrifuge for uranium isotope separation. During the war years, he served as chairman of the Navy-Industry Coordinating Committee assigned to write U.S. Navy shock specifications and develop the necessary testing instruments and equipment.

In 1945, Rushing was appointed Engineering Manager of the Motor Division (later the Motor and Gearing Division) where he was responsible for the development of motors (1 to 500 hp) for industrial and military application.

Rushing's move to the Space Age came in 1964 when he was asked to join the Westinghouse Defense and Space Center to put his talent for machine design and development to work on the increasingly complex mechanical and electromechanical problems of defense and space equipment. Here, he has led or assisted with such varied developments as satellite attitude control by gravity gradient, nutators for electro-optical rocket guidance, tape transports for programmed fault indication, motors for torpedos and deep submersibles, manipulators for deep submerged vessels, large space erectable antennas and reflectors, electrical connectors for space, and long space erectable booms and antennas. The development that Rushing describes in this issue is an excellent example of the attention he will give to a design problem, even to such a common device as an electrical connector.

F. S. Tarneja has worked with solar cells since he joined the Westinghouse Semiconductor Division in 1959. He has been one of the leading contributors to the development of the large-area silicon cells described in this issue.

Tarneja graduated from Delhi University, India, in 1952 with a BSc degree in physics and then went on to take his BSc in mechanical engineering at Benares Hindu University in 1956. He came to the United States the following year to enter Carnegie Institute of Technology, where he earned his MS in mechanical engineering in 1958. Tarneja has since done graduate work in metallurgy there, and last year he received a master's degree in business administration from Duquesne University.

Edwin G. Noyes, manager of the steam turbine control engineering section, is making his second appearance on these pages as a coauthor describing developments in steam turbine control. This time, he is joined by **Manny Birnbaum**, who has headed up the development and application of the new electro-hydraulic control system.

Noyes, a Texas A & M University graduate in ME (1948) came with Westinghouse on the graduate student course and was assigned to the Steam Division, where he became a steam turbine design engineer. In 1957, he was made a supervisory engineer in charge of steam turbine controls. In late 1961, Noyes was appointed to his present position where he is responsible for the design, development, and application of control systems for large and medium sized turbines.

Birnbaum joined Westinghouse in 1956 after graduation from the Polytechnic Institute of Brooklyn with a BME. His first assignment was in the Steam Division's medium turbine control section to assist in the design and application of automatic extraction control. In 1959, he was assigned to a company automatic steam plant study team to investigate steam turbine integral automatic control, supplemented by a digital computer control of power plants. Following this assignment, he returned to the control engineering section to develop the electro-hydraulic control system. He has been responsible for the coordination of system analysis, hardware evaluation, interface, interlock design, and packaging. He is presently in the control section of customer order engineering, responsible for turbine control systems application.

The design of the high-speed trip mechanism for circuit breakers, described in this issue, was a joint effort by **Walter V. Bratkowski, William H. Fischer**, and **Raymond J. Radus**. Bratkowski and Radus are in the Westinghouse Research Laboratories, and Fischer is in the Power Circuit Breaker Engineering Department.

Bratkowski is a graduate of the Carnegie Institute of Technology, with a BS in Mechanical-Aeronautical Engineering (1952) and an MS in Mechanical Engineering (1957). He joined Westinghouse in 1952 to work in the Materials Engineering Department. Bratkowski is presently in the materials testing and evaluation laboratory of the Research Laboratories, with responsibilities in the field of applied mechanics—primarily in the areas of shock, vibration, and stress analysis.

Fischer graduated from the University of Pittsburgh with a BSME in 1950, and obtained his MSME from Pittsburgh in 1958. He joined Westinghouse on the graduate student course in 1952.

His major responsibilities have been in the development of advanced methods of circuit interruption—using air, gas, and vacuum techniques—and in the development of mechanical operators for circuit breakers. He is presently working on advanced methods of operating circuit breakers.

Radus came with Westinghouse on the graduate student program from the University of Pittsburgh with a BSEE in 1951. He has spent most of his time designing magnetic devices for a variety of purposes. He has developed a variety of control techniques using the flux-transfer principle for controlling a permanent magnet field. The high speed of the circuit breaker trip mechanism is made possible by a magnetic circuit developed by Radus.

Hot Steel Strip at Over 3000 FPM

This six-stand finishing train at Wheeling Steel Corporation's Steubenville South plant reduces 32-ton slabs, 10 inches thick, to thin strip. The 80-inch mill will be under complete computer control.