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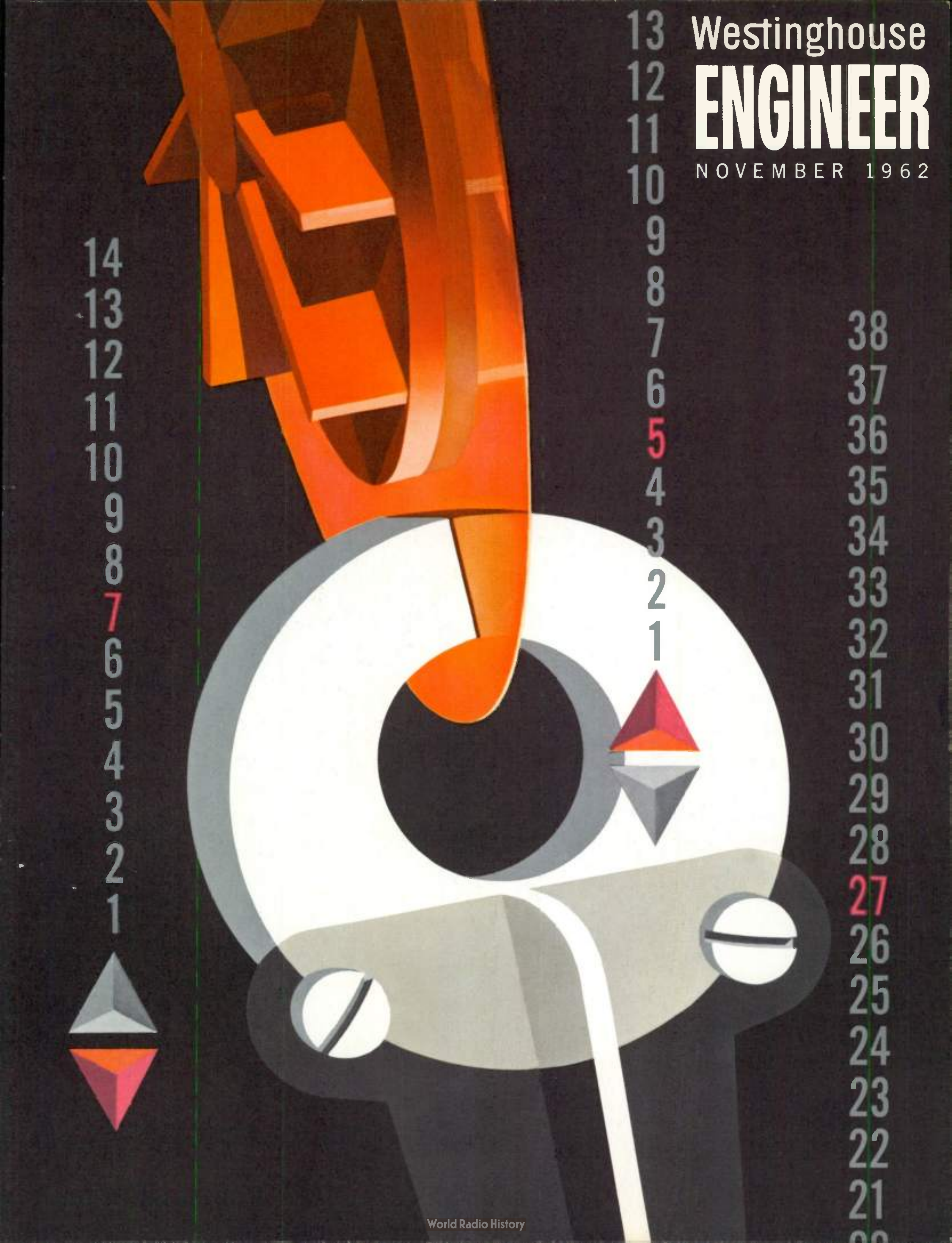

BIG DIPPER

This electrically driven stripping shovel is the largest mobile land machine ever built, and is three times larger in weight and horsepower than any shovel now in existence. The dipper has a capacity of 115 cubic yards. The shovel is 220 feet high to the boom points, and weighs 9000 tons. Twenty-four Westinghouse motors power the main drives of the shovel—sixteen for digging, totaling 9000 hp, and eight for propelling, totaling 2000 hp. The static control system, which uses Trinistor controlled rectifiers, enables the shovel to operate on a 60-second digging cycle. The shovel was built by the Bucyrus Erie Company for the Peabody Coal Company.

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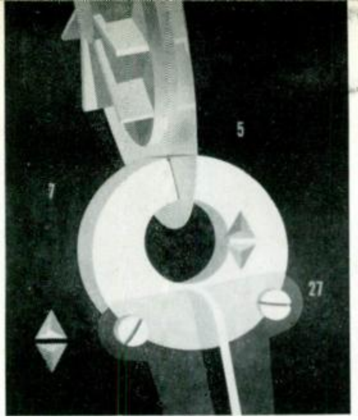

VOLUME 22 • NUMBER 6

Cover Design: The familiar position indicating lights for passenger elevators are combined by artist Dick Marsh with the mechanical elements of a new velocity transducer for a high-speed elevator system (p. 144). This transducer and special acceleration and position transducers provide continuous nonlinear control patterns that give rapid acceleration and deceleration with smooth ride.

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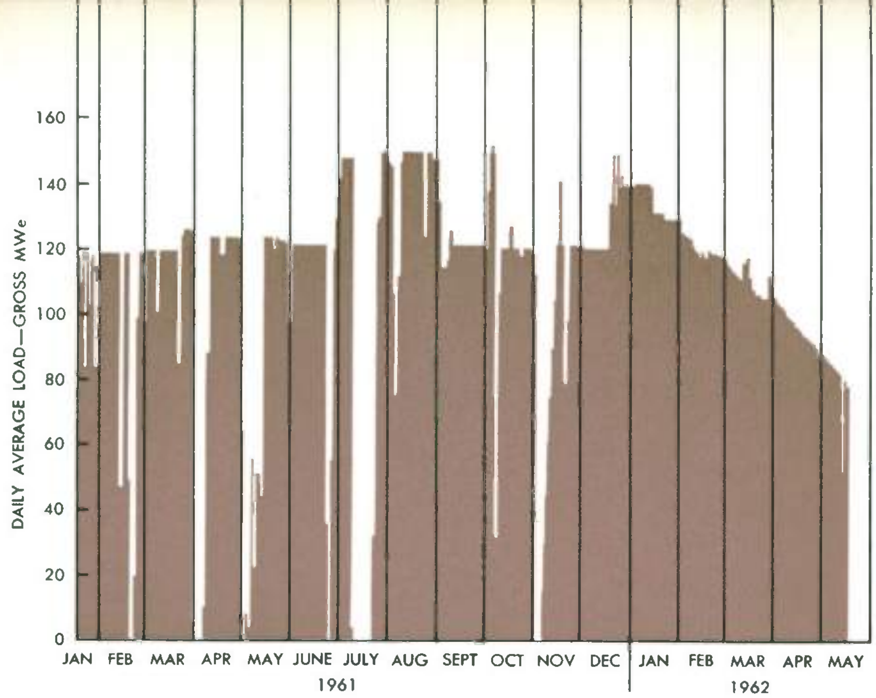

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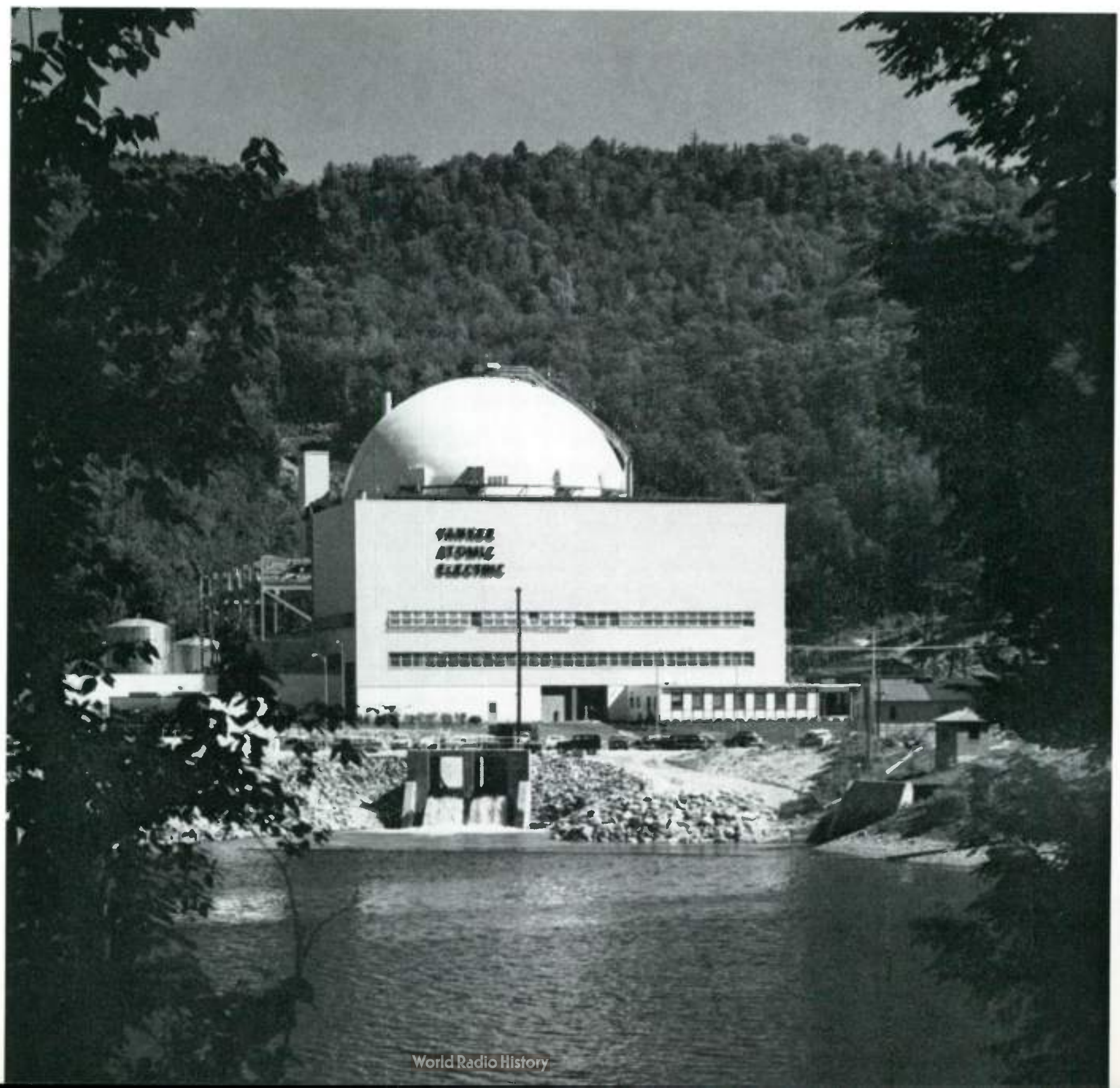
Fig. 1 The operating record for Yankee shows the daily average load in gross megawatts from initial full power operation to shutdown.

Photo The Yankee Atomic Electric Plant went critical in August, 1960, and shut down for refueling nearly two years later, in May 1962.



Yankee Core I Performance

Herewith are some of the operating aspects of the Yankee nuclear plant, plus some details about technical performance.

At 8:19 p.m. August 19, 1960 the Yankee Atomic Electric Company plant at Rowe, Massachusetts achieved its initial criticality on Core I. At 8:00 a.m. on May 18, 1962 the turbine was manually tripped and the Yankee nuclear reactor was automatically scrammed. Thus operation of the Yankee reactor's Core I was terminated after a total electrical generation of 1 229 105 000 kilowatt hours had been delivered to the interconnected transmission system. Several other statistics about the Yankee plant are significant; among them are:

Power Costs	Less than 9.5 mills/kwhr
Average Fuel Burnup	8350 mw-days/tonne
Longest Continuous Run Without Shutdown	147 days
Downtime—From July 23, 1961 to May 18, 1962—(Excluding 5 days for Physics Tests)	34 hours

Now that the reactor has been shut down for refueling, many aspects of its operating record and technical performance can be reviewed. Some of these suggest areas for further improvement.

Operating Record

The operating record for Yankee is summarized in Fig. 1. There were only six shutdowns of a full day or more during this period. Three of these shutdowns (the first, third, and fourth) were made to permit mechanical maintenance and equipment modification; the remaining three (of longer duration) were for physics tests, required by the operating license at 2000, 4000, and 6000 equivalent full power hours of operation.

On September 4 and 5, 1961 the power level was reduced to allow investigation of turbine control valve difficulties. On September 8, plant operation was reduced to 120 mw electrical to conduct a boron shim test with the reactor operating at power. The objective of this test, which began on September 13 and continued to September 21, was to determine the acceptability of operating the primary system at power with up to 400 parts per million of boron, in the form of boric acid, in the primary coolant water.

During the months of October and November, operation at 120 megawatts electrical was scheduled to conserve core life and assure the plant's ability to operate up to 150 mw to meet system peak load demands during the latter part of December and early January.

On December 25, 1961 the control rods were all fully withdrawn from the core and gross generation was 140 mw. In early 1962, a gradual stepwise reduction in plant output was initiated. Plant power level and average temperature of the coolant were progressively adjusted downward as necessary to maintain criticality, although adjustments were not required when turbine valves were wide open. When the core lifetime is extended by power and temperature reduction, the average fuel cost decreases. However, as the power level of the reactor is decreased, the fixed charge contribution to the cost of power rises. The combination of these effects gave Yankee a power level for minimum overall power cost of approximately 85 gross electrical megawatts, corresponding to a reactor power of approximately 280 thermal megawatts. Based on these and other scheduling considerations, May 18 was chosen for Core I shutdown. By that date, production of power from the first core loading had increased by nearly one third during the period after the end of design lifetime at rated conditions in January. The average core burnup was 8350 mwd/mtu (megawatt days per metric ton of uranium); maximum local burnups were about twice that amount.

The cumulative gross output of the Yankee Atomic Electric Plant since initial operation is shown in Fig. 2. Despite periods of reduced power and interruptions necessary for physics tests and mechanical adjustments on plant equipment, the plant factor was better than 70 percent, based on the 392 mw rating up to June 23, 1961 and on the 485 mw licensed rating thereafter. The plant factor from the start of commercial operation July 1, 1961 to May 18, 1962 was 75 percent, in spite of some 5 months of operation at gradually decreasing power levels during the core stretchout period. During the 18 months that have elapsed since electricity was first generated by Core I, the reactor has been at temperature and pressure, ready to produce steam, 95 percent of the time. This high availability of the Yankee nuclear steam generator is one of the exceedingly significant statistics obtained from the Yankee plant.

Results from Primary Loop Components

Yankee is a closed cycle, pressurized water reactor equipped with four parallel primary coolant loops. Each loop has a steam generator, where the primary coolant, circulating at a nominal 514 degrees F under 2000 psig, produces steam on the secondary side at approximately 467 degrees F and at a pressure of 500 psia. Generally speaking, primary loop operation has been satisfactory.

Canned Motor Pumps—The primary coolant is circulated by special canned motor pumps (Fig. 3). The main coolant system is a closed and essentially sealed system.

All four main coolant pumps functioned flawlessly for over 12 000 hours of hot operation after an initial flange leakage problem was overcome. The nickel gaskets originally installed were replaced by more conventional copper gaskets, to provide a more effective seal against leakage. Subsequent minor leakage was attributed to pump flange

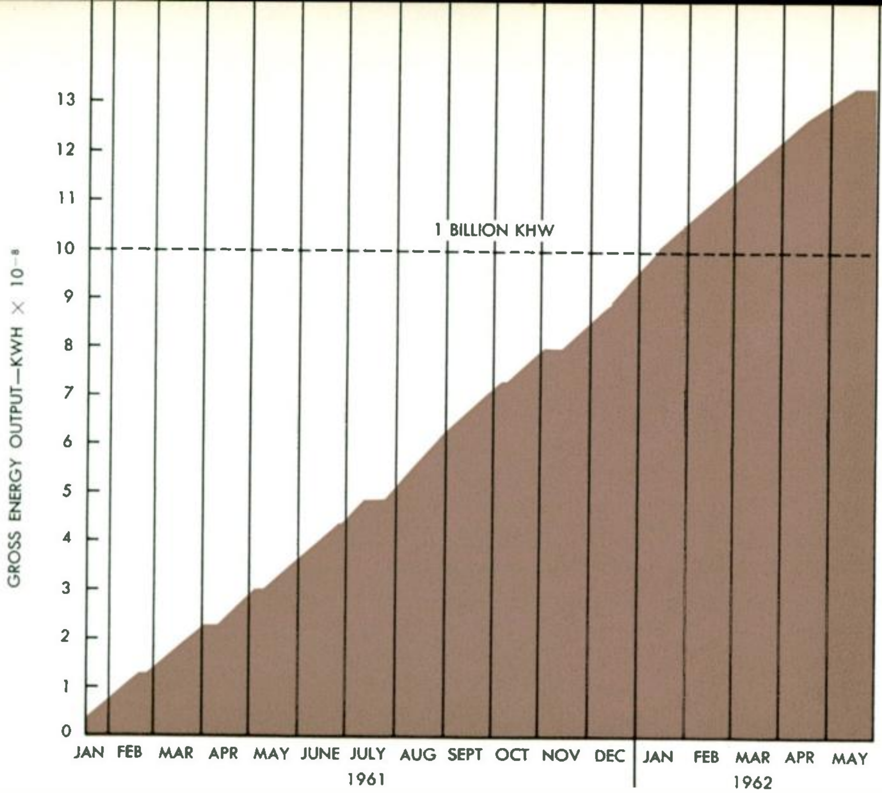
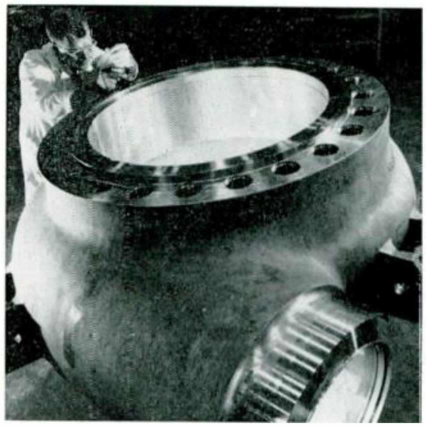


Fig. 2 The cumulative gross output of Yankee since initial operation. In spite of necessary interruptions, the plant factor was better than 70 percent.

Fig. 3 The stainless steel volute for the canned motor pumps. The pump bolts to the top of this volute.



deformation, due to differential expansion between the alloy steel bolts and the stainless steel flange in going from cold to hot operating conditions. Operating procedures were modified so that pressure and temperature of the main coolant were increased simultaneously, rather than going to full pressure at low temperatures.

Other coolant components also posed leakage problems in that seal welding was required for some flanged closures, and revised bolt-up procedures had to be devised for others. Several auxiliary system valves were replaced due to excessive stem leakage and deficiencies in their operating mechanisms.

Steam Generators—Each of the four 100-ton steam generators is of the shell and U-tube type with an integral three-stage moisture separator. All major surfaces in contact with the main coolant are of type 304 stainless steel. The primary side of each generator is designed to operate at 2485 psig at 650 degrees F, with shell side maximum operating conditions of 1035 psig at 600 degrees F.

Significantly, no primary to secondary leakage problems have been encountered with these generators; consequently, there has been no transfer of radioactivity from the primary coolant. Special tests were conducted with two of the four steam generators valved off on their secondary side. The test verified that the moisture separators would perform even better than had been anticipated. With only two steam generators thus functioning, successful plant operation was obtained up to 90 mw electric gross electrical output, indicating that 180 mw could be expected from all four of the units.

Control-Rod Drive Mechanisms—Control-rod drive mechanisms are of the magnetic-jack type. They operated satisfactorily after initial electrical coil troubles were overcome. For the most part, electrical grounds were responsible for early malfunctions, with somewhat inadequate venting and air cooling provisions contributing to the failures. Subsequent coil redesign and modified insulation, venting, and cooling arrangements have resulted in virtually trouble-free operation.

Plant Instrumentation—Instrumentation and control maintenance manhours have been remarkably low. Yankee maintenance records indicate less than 160 manhours per month have been spent on primary plant instrumentation and control; about one-half of this time was devoted to such routine matters as inventory control and preparation for instrumentation changes to accommodate operational or physics experiment requirements.

All plant instrumentation has performed well, with only two spurious scram signals being generated during Core I operation. One signal was initiated by breakdown of a static component, the other by a ground on one of the vital bus feeders.

Plant Control Equipment—A near perfect record for performance and reliability was also achieved by Yankee plant control equipment. The inherent negative temperature coefficient of the reactor proved a most effective stabilizing influence upon the reactor plant. Automatic control rod operation proved even more stable than had been anticipated in the design stages.

Of the 15 plant shutdowns during the initial test period, two were initiated for the scheduled determination and collection of nuclear data. The remaining 13 shutdowns were occasioned by turbine generator testing or were due to operating difficulties of a nonnuclear nature.

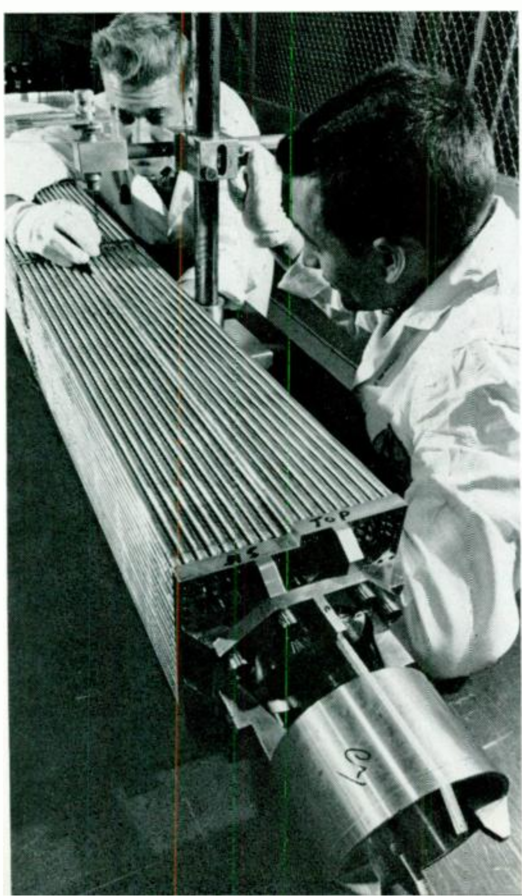
New Systems Perform Well—With few exceptions, newly developed systems and components proved successful. The surge spray portion of the Pressure Control and Relief System that accommodates normal transients has been so consistently effective that no solenoid relief or safety valve operation has been required. Difficulties were encountered, however, in the operation of the stripper-evaporator portion of the Waste Disposal System. Unanticipated gas-producing characteristics of the electrode evaporator caused unwanted oxygen release and persistent carry-over of system solids. The gas-producing difficulties were partially overcome by substituting a steam-heated reboiler for the electrode unit, which was permanently disconnected when the reactor was shutdown for refueling. A slight carry-over of boron will be neutralized by installation of a small "polishing" ion-exchange column.

Other Components

Operational difficulties were encountered in initial testing of the fuel transfer system. For the most part, these troubles were electrical, rather than mechanical. Short-circuited limit switches, for example, caused a cable to jump from grooves in a sheave. A few problems were encountered in mechanical fits, but the operational design concept proved sound after these relatively minor troubles were corrected. Indexing provisions on the manipulator crane, used to handle fuel assemblies, have turned out to be excellent and have retained their initial accuracy for positioning reactor internals. Pit lighting arrangements, however, proved inadequate for refueling operations. Troubles here were chiefly due to short circuits, reflections, and insufficient intensity, so that auxiliary lighting units were necessary for television and visual observations of underwater manipulations. Troubles were also encountered with the television cables. The television-light cooling apparatus developed major leaks, which led to early failure and temporary abandonment of this feature.

Vibration troubles arose from "steam lift" as a result of faulty steam distribution around the turbine rotor after the first impulse stage. This was corrected during a two-week shutdown in January, 1961. Sixteen months later, when the turbine was dismantled for inspection after plant shutdown for reactor refueling, it was in excellent condition. During this inspection shutdown, Stellite was replaced on 15 of the approximately 300 blade tips on the last stage.

Fig. 4 One of the 76 fuel assemblies for the Yankee plant. Each assembly is about eight feet long and eight inches square.



Reactor Core

Fuel Assemblies—The Yankee reactor core is composed of uranium dioxide (UO_2) pellets encased in stainless steel cladding. Seventy-six fuel assemblies—each with 304 or 305 fuel elements—compose a core loading, and contain about 20 900 kilograms of uranium (Fig. 4). Control of fissioning rate is accomplished by twenty-four cruciform control rods, which move vertically between fuel assemblies.

Installed in July and August, 1960, the original core achieved initial criticality August 19, 1960 with first power operation on November 10, 1960.

Theoretical core lifetime ended January 18, 1962. At that time 3 174 031 896 thermal kilowatthours had been produced, providing 939 037 837 net electrical kilowatthours of power for the New England transmission grid.

The useful lifetime of Core I was extended beyond this theoretical date by gradual reduction of reactor power and temperature, thereby taking advantage of the associated negative coefficients of reactivity.

As observed through shielding water in the shield cavity, the general appearance of the spent fuel assemblies was excellent. The surfaces were uniformly dark, which is typical of the finish on stainless steel after submergence in hot oxygen-free water. Subsequent examination through a magnifying periscope verified that there are no physical mars or scratches. Two high burnup fuel assemblies from Core I are to be left in the reactor during Core II operation, and are expected to attain an ultimate burnup of about 18 000 megawatt days per metric ton of contained uranium.

Control Rods—The poison (absorber) sections of the Yankee control elements are fabricated from extruded silver-indium-cadmium alloy (80 percent Ag, 15 percent In, 5 percent Cd) plated with a nominal one-half mil of metallurgically bonded nickel. Although only insignificant amounts of silver have been found in the primary coolant during the life of Core I, there appears to have been some loss and deterioration of the nickel plate. Metallurgical examinations of coupons taken from Core I absorber sections are being carried out to determine the cause and effect of this phenomenon.

Where the control-rod shaft mates with the poison section of the rod, some wear occurred. This wear apparently was caused by relative motion between these parts during the stepping action of the magnetic control-rod drives. The impact from this three-eighths inch step resulted in 30 to 50 thousandths inch wear on each mating surface. Because of this, all control rod drive shaft assemblies and control rods are being replaced by spares of an improved design. These spares, incidentally, had been ordered with just such an eventuality in mind.

The new design prevents the relative motion that caused the wear problem. Stainless steel rubbing straps are also provided on the absorbers to protect the nickel plating against damage while moving through the core. A Zircalloy follower, attached to the bottom of the absorber section, fills the water slot that would otherwise be formed in the core when the control rods are withdrawn. This follower also functions as a guide when the control rod is lowered into the core. Wear similar to that between drive shafts and absorbers was also observed between absorber and follower. This was surprising, since the original fit between these pieces allowed very slight relative motion. The problem was one of material, rather than fit. Apparently the Zircalloy-to-stainless steel joints were not sufficiently effective for long-term service—consequently, the replacement follower sections will have a complete stainless-to-stainless steel joint.

Eight fixed shim control elements are used as auxiliaries to the movable control rods. Visual and television inspection of these shim elements shows only minor evidence of wear or corrosion and a slight normal discoloration of the boron steel section.

Five control-rod drive shafts became temporarily stuck to their associated control rods during dismantling of the reactor internals, but were released without damage by a tool devised on the site. Only one of the 24 guide tubes was difficult to remove, and this problem was readily resolved by exerting an upward pull on the tube while twisting it simultaneously.

Core Instrumentation—Core I operation was monitored by special in-core instrumentation. Installed as a post-design feature, the instrumentation package consists basically of remotely operated flux measurement wires and a group of main coolant exit thermocouples. Each fuel assembly in one quarter of the core was so instrumented, with instrumented assemblies installed in the other quadrants to provide symmetry across the core. Data provided by this instrumentation early in Core I lifetime helped to justify a licensed power increase from 392 to 485 thermal megawatts.

Yankee in-core instrumentation has functioned well after initial operational difficulties were surmounted by field modification. No difficulties were encountered with the thermocouple installations.

Main Coolant Chemistry

The Yankee plant uses boric acid for hot-to-cold reactivity control. As the plant heats up, boric acid is removed first by bleed and feed of pure water, and finally by ion-exchange. At full operating temperature, the coolant is maintained at high purity and neutral pH by a mixed-bed demineralizer.

The formation and transport of magnetic corrosion products of stainless steel (usually referred to as "crud") and activation of the plant surfaces by such corrosion products have not affected plant maintenance. Some concern had been expressed initially about the use of stainless steel cladding, particularly with respect to its Cobalt-59 impurity content. Cobalt-59 is transformed by neutron-gamma reaction into long-lived Co-60. Co-60 activity was expected to cause deposited crud activity in the steam generators. Actually, the major activities in Yankee from core construction materials are Co-58 and Mn-54, derived from nickel and iron respectively by neutron-proton reaction. Yankee experience indicates that commercially available stainless steels are suitable for fuel cladding and do not cause excessive radiation levels.

With essentially no additional complication, boric acid can be used as a chemical shim in the coolant of a reactor during power operation. During Yankee Core I operations, a partial chemical shim test of several days' duration was carried out. Some loss of reactivity was observed over that expected from the boron additions, but the specific cause was not determined. The addition of hydrazine, which is converted to ammonia in the reactor, produced an increase in plant reactivity. This was confirmed by two experimental additions of hydrazine, during reactor operation with all rods out. Here again, the data accumulated did not point to a definite mechanism for the effect. All reactivity changes were slow, and did not present operational problems.

A low level of fission products was observed throughout Core I operation. Main coolant water chemistry showed activity levels of the fission gases krypton and xenon to be only about $10^{-2}\mu c/ml$ (microcuries per milliliter). Iodine-131 has also been detected in the main coolant at about $10^{-4}\mu c/ml$, but this level did not appear particularly responsive to power-level changes during normal operation. The level of fission product release was several orders of magnitude less than that allowed for in the design.

In summary, the chemistry aspects of Yankee Core I operations were quite normal, although some small unexpected reactivity changes were observed.

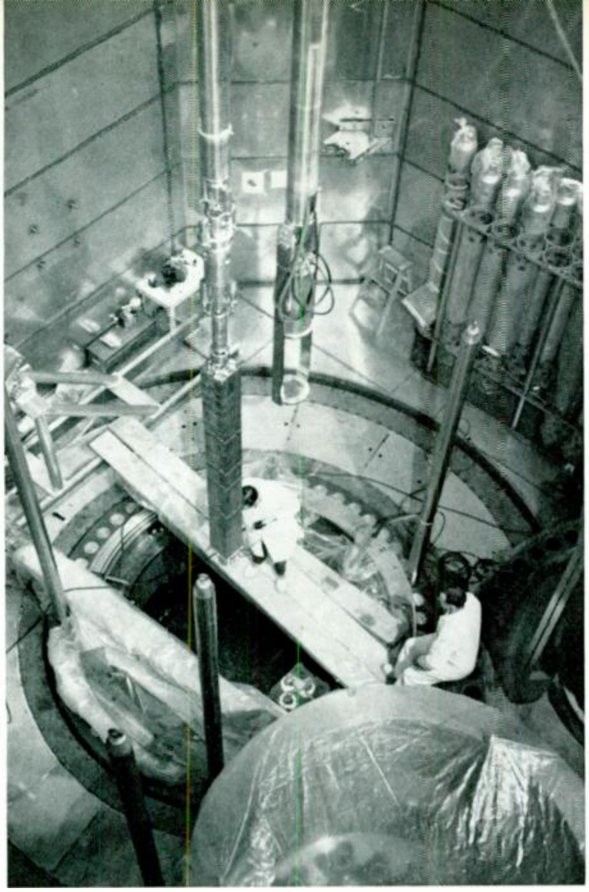
Radiation and Shielding

Initial operations at low power revealed that neutron levels throughout the plant site were higher than anticipated. This excess was traced to intermediate-energy neutron streaming along a narrow path between the reactor vessel flange and the top of the water-filled neutron shield tank. The addition of a permanent Masonite shield over this area reduced the neutron dose rate by a factor of 19. The highest level measured at the top of the vapor container after installation of the Masonite was 7 mrem/hr (milliroentgen equivalent man) at 120 mw electrical (gross). The corresponding neutron dose rate at the equator of the vapor container was reduced to 0.6 mrem/hr.

Gamma radiation levels proved to be well below design estimates. Only a few isolated instances of contamination were observed in the potentially contaminated area; and none were observed in the clean areas. A radiation level of about 7 roentgens per hour from the core was encountered under the reactor vessel head during removal. The head, which had a low activity level, was wrapped in polyethylene and is currently stored dry on a railway car parked on the plant siding. Wet storage of this head had been contemplated originally.

The average gamma radiation level in the steam generator cubicles was about 300 milliroentgens/hr twelve hours after shutdown. As anticipated, this level resulted from the deposition of activated corrosion products.

Typical specific activity of the primary coolant was no higher than $5\times10^{-2}\mu c/ml$, thus indicating excellent integrity of the fuel rod cladding. The typical crud level was 0.15 ppm. Approximately four days after shutdown, the reactor coolant activity was reduced to $7.2\times10^{-4}\mu c/ml$ through operation of the purification system. Subsequent flushing of the crud deposited in the steam generator cubicle by-pass line trap temporarily increased the activity level to $2.2\times10^{-2}\mu c/ml$.



A fuel assembly being lowered into the nuclear reactor during the initial loading.

Economics[1]

The Yankee plant was built at a cost about 23 percent below estimates. The total cost of the project turned out to be $43.7 million, with about $39.4 million of this amount for the plant itself. The balance of about $4.3 million covered the fabrication cost of the first core, working capital, and organization and administrative expenses.

Yankee Atomic Electric Company presently has on file with the AEC a request to authorize an increase in licensed capability from 150 000 to 170 000 gross electrical kilowatts. Dividing the plant costs of $39.4 million by this capability gives a cost per kilowatt of $231.

As has been mentioned, first core power costs amounted to less than 9.5 mills/kwhr. This compares roughly to about 8.0 mills/kwhr for a similar, fossil-fuel plant built at the same time in the same area.

Annual fixed costs based on a twenty-year plant life come to about $6.5 million. Again assuming the higher licensed power level combined with a 90-percent capacity factor, a fixed-cost component of 5.0 mills/kwhr may be possible for the future period. A year ago a 90-percent capacity factor would have been considered unreasonably optimistic, but on the basis of actual plant performance it now seems at least a possibility.

The fuel cost component is much more difficult to predict. In future cores, costs can be reduced by shifting—as Yankee intends to do at the second reloading—from a uniformly enriched, batch core to a two-region cycled core, combined with the use of boric acid to allow increased initial reactivity. Such a core should have associated costs of less than 3.0 mills/kwhr (or less than 3.5 mills if use charges are included).

Actual costs of certain portions of the overall fuel cycle are, as yet, ill-defined. One is the processing of the spent fuel. The earliest a core will actually be chemically reduced to fissionable material and wastes appears to be 1965. Obviously, until this is done a part of core economics is based largely on calculation and predictions, rather than upon experience.

Another area of concern is the developing policy on private ownership of special nuclear material. If put into effect gradually enough to prevent confusion, the effect on economics might be quite small.

A continuing effort exists to reduce costs in those areas where the operator and the manufacturer have control. An eventual nuclear fuel cost as low as 2.5 mills/kwhr is not improbable.

Core I Evaluation

A final assessment of Core I cannot be made until data on the burnup for the fuel and the production of plutonium is obtained. Recognizing the importance of the data to be derived from a destructive examination of Yankee Core I and subsequent evaluation of the data so obtained, the Atomic Energy Commission invited the atomic industry to submit proposals for a Yankee Core I Evaluation. Westinghouse has been selected for this evaluation. The evaluation program, which will continue for two years will contribute substantially to a better understanding of the reactor physics of high burnup cores. It will also make available analytical methods for predicting more accurately the depletion of the fissionable isotope U-235 and the buildup of fissionable and nonfissionable isotopes of plutonium. This data will reduce the present uncertainties with respect to "burnup charge"—the fuel cycle cost associated with depletion of U-235 and buildup of plutonium.

The Core I evaluation program will also include both chemical and materials evaluations. Thus, maximum benefit will be derived from Core I for the entire atomic power industry.

Conclusion

Yankee's overall performance has been outstanding. The operational performance of Core I has been eminently satisfactory, and refueling has not revealed any basic problems or deficiencies in Yankee core design. A number of minor improvements and modifications in mechanical design details of replacement components will improve future performance.

Most significant, Yankee has conclusively demonstrated that a nuclear plant can be constructed and operated in conjunction with other more conventional plants with little or no special treatment. The cost of nuclear power in New England is closer to being competitive than could be anticipated during the design stages. A larger plant of the same type as Yankee, put "on the line" in 1967 or 1968, can be expected to produce substantially competitive power in the New England region of relatively high fossil fuel costs.

[1] Digest of remarks by Mr. Webster at the 1962 Annual Meeting of the American Nuclear Society in Boston, Mass. (Paper 19–1 "Yankee Summary and Evaluation", W. Webster YAEC).

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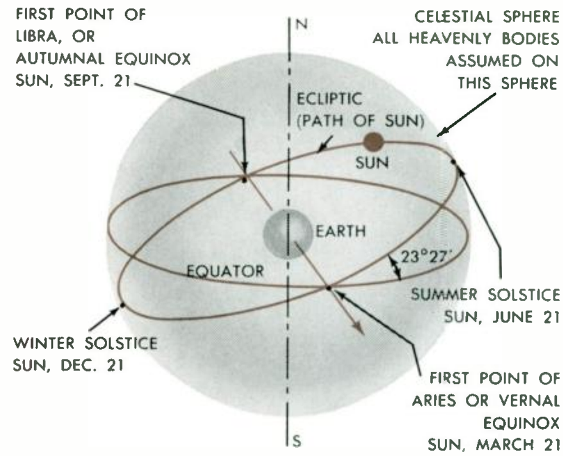
The earth's growing satellite population, result of man's entry into the space age, poses some new problems for radar system designers who are developing methods for keeping the census. Herewith, a general description of the characteristics of satellite orbits, and a discussion of the requirements for satellite surveillance and tracking radars.

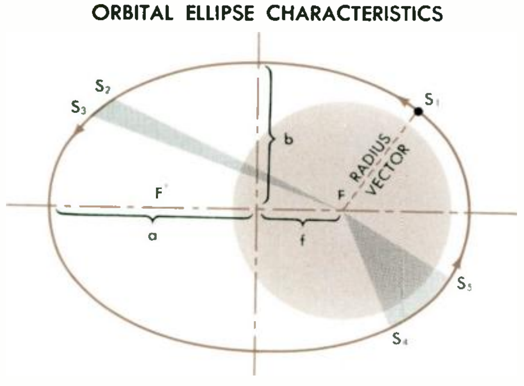
THE CELESTIAL SPHERE



The coordinate system used on this sphere, *Declination* and *Right Ascension* (measured from the first point of ARIES), is to the celestial sphere what the system of *Latitude* and *Longitude* (measured from the Greenwich Meridian) is to the earth. As a matter of interest, the sun in its path over the year appears to pass through the constellations of the Zodiac, each occupying 30 degrees of the ecliptic: ARIES, TAURUS, GEMINI, CANCER, LEO, VIRGO, LIBRA, SCORPIO, SAGITTARIUS, CAPRICORNUS, AQUARIUS, and PISCES.

Satellites and Satellite Observation with Radar

ORBITAL ELLIPSE CHARACTERISTICS



Semimajor axis $= a$
Semiminor axis $= b$, where $a > b$
Focal Length, $f = \sqrt{a^2 - b^2}$
Eccentricity, $e = f/a$
For the ellipse: $SF + SF' = 2a$, where S is point on ellipse.

Kepler's First Law: The center of the main body is at F.
Kepler's Second Law: The areas FS_2S_3 and FS_4S_5, swept in equal times, are equal. (Hence, the velocity at S_4 and S_5 must be greater than at S_2 and S_3.) This law can also be written: $\omega r^2 =$ constant (conservation of angular momentum).
Kepler's Third Law: When comparing orbits of small satellites, $a^3/T^2 =$ constant, where T is the period.

The first man-made satellite, Sputnik I, was placed in orbit October 1957. Since this date, there have been approximately 88 successful launches (as of June 1962), mostly from the United States. Some satellites were deliberately recovered after one or more orbits; others lasted for a few weeks before they came low enough to burn up in the upper atmosphere; still others will remain in space for centuries.

The characteristics of orbital motion were first formalized by Johann Kepler in the early part of the 17th century, when he set down three fundamental laws for the orbital motion of planets (see *Orbital Ellipse Characteristics*):

1. Each planet moves in an ellipse with the sun at one focus.
2. The radius vector of each planet sweeps over equal areas in equal intervals of time.
3. The square of the period of revolution of a planet about the sun is proportional to the cube of the mean distance of the planet from the sun.

These laws were empirically arrived at by Kepler. It can be shown that they can be deduced from Newton's law of gravitation (Kepler died before Newton was born) and are applicable to all satellites.

Characteristics of Satellite Orbits

For a first order approximation, six quantities are required to define a satellite orbit. This assumes that the mass of the main body is symmetrical, that no other disturbing masses are present, and that the mass of the satellite is negligible compared with the mass of the main body. Under these conditions, the orbit is a perfect ellipse.

Two values that are usually used to define the shape of an ellipse are the *eccentricity* (e) and the *semimajor axis* (a). The semimajor axis can be determined from its relationship to the period (T), as stated in Kepler's third law:

$$a^3 = \frac{GM\,T^2}{4\pi^2}$$

where G is the universal gravitational constant, and M is the earth's mass.

The ellipse crosses the equatorial plane at the nodal points (Fig.1), which are referred to as the ascending or descending nodes depending on the direction of travel of the satellite. The nodal points establish the line of nodes, a line of intersection of the orbital plane and the equatorial plane. The angle between the perigee and the ascending node (as seen from the earth's center) is the *argument of the perigee*, and is usually used to specify the orientation of the ellipse in its plane.

Two further quantities are required to orient the satellite's orbital plane. These are usually the *inclination*, or angle between the orbital plane and the equatorial plane, and the *right ascension of the ascending node*, or angle between the line of nodes and the vernal equinox. The vernal equinox (the point of intersection of the ecliptic and the equator where the sun apparently passes from south to north over the earth's equator) is the basic reference direction on the celestial sphere (see *The Celestial Sphere*).

The sixth and last quantity which locates the satellite on its orbit is the *time* of passage through the ascending node or through some other reference point on the orbit.

The six quantities mentioned above are not fixed but vary with time due to second order effects such as the oblateness of the earth, drag, pressure of solar radiation, etc. Some of these effects can be calculated, others are difficult to estimate. For example, the drag at the perigee will depend on whether this occurs on the illuminated or dark side of the earth. Thus, there is a limit to the accuracy with which the future position of satellites can be predicted. Nevertheless, the rate of change of basic characteristics is sometimes given, such as the motion of the ascending node and of the perigee.

A satellite orbit, when plotted on a Mercator's projection (Fig. 2), crosses the equator at an angle equal to the inclination and reaches a maximum latitude equal to this angle. Thus, unless additional thrust is provided to the satellite to change its orbit, it is not possible to inject a satellite in an orbit with an inclination that is *less* than the latitude of the launch site.

To date, therefore, there have been no satellites with very low inclinations, the minimum inclination corresponding to the latitude of the Florida launching sites. However, when the stationary communication satellites appear, they must have an equatorial orbit, obtained

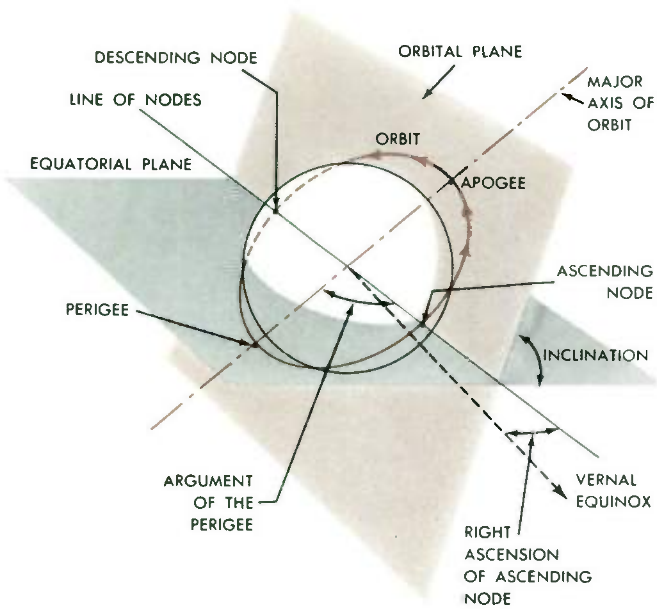


Fig. 1 Satellite orbit characteristics are shown in this three-dimensional view.

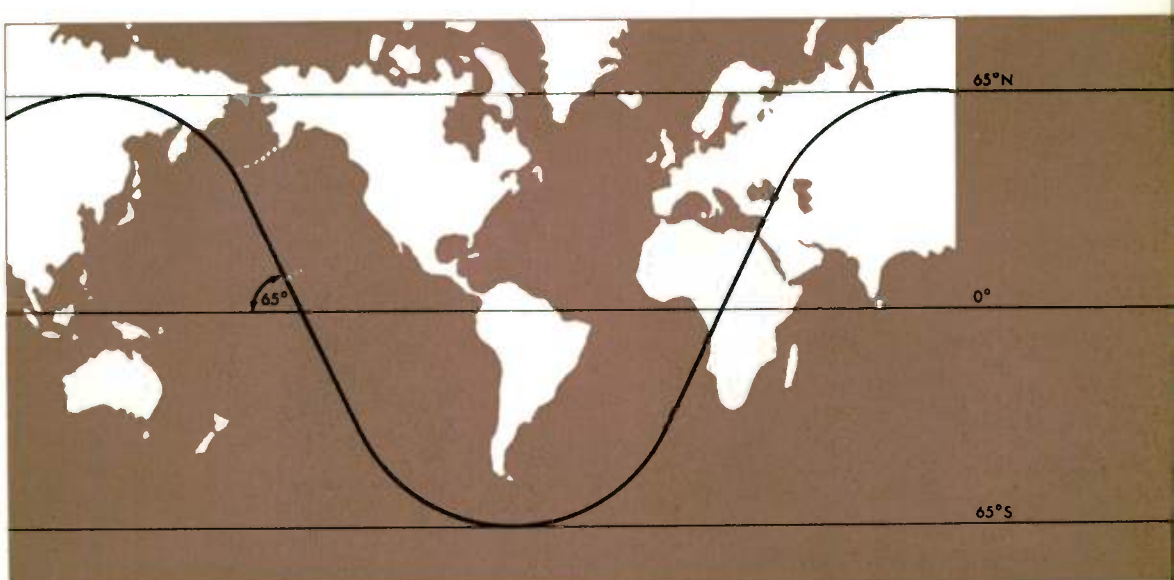


Fig. 2 Orbit with 65-degree inclination (first Russian orbit) shown on a Mercator projection.

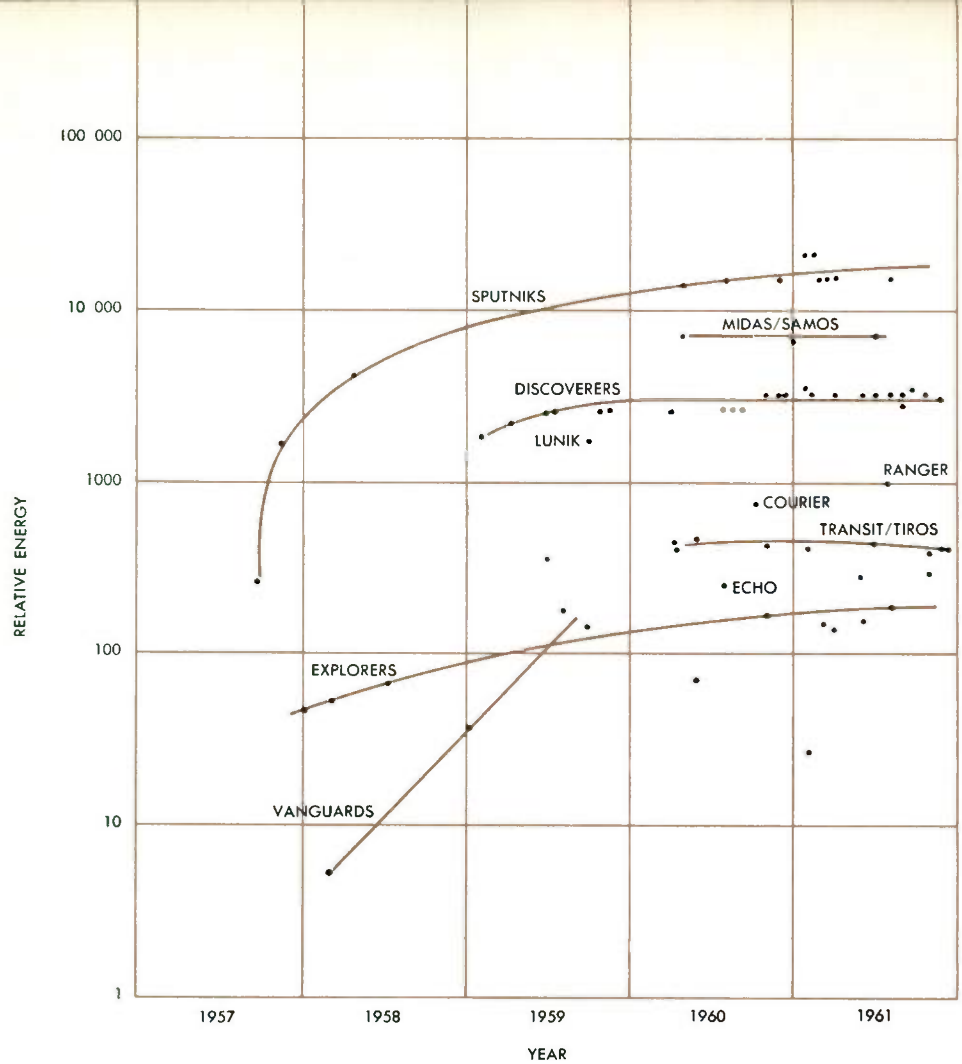


Fig. 3 The relative energy required to place satellites in orbit is shown for various satellite classes.

Fig. 4 The number of objects in orbit has been increasing exponentially by a factor of 2.4 per year.

either by launch from an equatorial site or through an orbital change after launch.

Polar orbits are the only ones that enable a satellite to cover every spot on the globe. Hence, this class of orbits will be favored for reconnaissance satellites such as *Midas*.

Obviously, a certain expenditure of power is required to place a satellite in orbit. Only when it became practical to obtain this power with accurate control was it possible to place an artificial satellite in orbit.

The total energy of a satellite is constant if drag and other second order effects are ignored. From classical mechanics, total energy = kinetic energy + potential energy, or:

$$U = \tfrac{1}{2} mv^2 + \left[-\frac{GmM}{r} \right]^*$$

where m is satellite mass, v is velocity, and r is distance from the earth's center (G and M have been defined).

By bringing in the relationships existing for an elliptical orbit, it can be shown that $U = -\dfrac{GmM}{2a}$ (the negative sign means that this energy is referred to the energy of a body at infinity). This is easily verified for a circular orbit where the velocity is tangential.

The satellite before launch had a potential energy of $PE = -GmM/R$, where R is the radius of the earth. Its kinetic energy due to the earth's rotation was relatively small and can be neglected. Hence, the energy required to place a satellite in orbit is given by:

$$\Delta U = \frac{GmM}{R} - \frac{GmM}{2a} = GmM \left[\frac{1}{R} - \frac{1}{2a} \right]$$

This energy requirement for various satellite classes is plotted in Fig. 3.

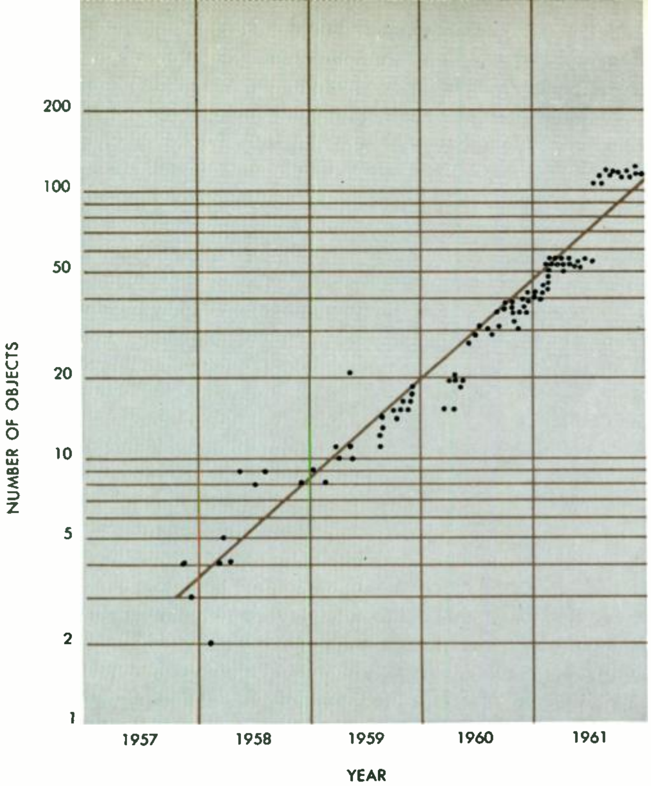
Number of Objects in Orbit

A new satellite may be produced by direct launch or by separation in orbit. A typical launch may place in orbit simultaneously the payload, final stage of the rocket, and a protective cover or nose cone. Once in orbit, a satellite may split by ejecting a capsule for recovery. This has on occasion, due to faulty control, resulted not in recovery of the capsule but in its injection into a different orbit (this occurred for Discoverer XXIII). Sputnik IV apparently exploded in a recovery experiment and generated at least seven additional detectable objects.

Satellites disappear from orbit by gradual loss in altitude due to drag until the object burns up in the upper atmosphere, or by a deliberately controlled re-entry initiated by

*The potential energy is the work required to bring the satellite from infinity to a point at a distance r from the center of the earth:

$$PE = \int_{\infty}^{r} \frac{GmM}{r^2} dr = -\frac{GmM}{r}$$



retrorockets. If the new objects that appear in orbit are balanced against those that disappear, the graph of Fig. 4 is obtained. When plotted on log/linear paper, the points lie very nearly on a straight line, indicating that the growth is exponential, with the number of objects in orbit increasing by a factor of 2.4 every year.

If this rate of growth continues, some 3600 objects will be in orbit by 1966. This may appear to be a rather large number, but the density will still be very low. Assuming that these 3600 satellites are mostly below 1000 miles, the density will still be only one object per 5×10^7 cubic miles (assuming uniform distribution). Therefore, the probability of accidental collision is negligible.

Most satellites lie well below 500 miles for the obvious reason that the amount of work required to place a satellite in orbit (and hence the cost of the operation) increases with the altitude. In addition, when selecting an orbit for a satellite, the mission of a satellite must be taken into account: satellites attempting recovery experiments, such as the *Discoverer* series, will be placed in an orbit just sufficiently high (100 miles) to avoid too short a life through burning up in the atmosphere. Reconnaissance and navigational satellites, such as *Tiros* and *Transit*, will be kept close to the earth to get more accurate data, but high enough (300-500 miles) for a broad field of view. Manned satellites must remain below 500 miles to avoid the Van Allen radiation belt. Communications satellites, such as *Echo I*, are concerned more with coverage than short ranges; therefore, these will be higher (1000 miles); at the limit, some communication satellites will be placed in "stationary" orbits (with respect to the earth's rotation) at 22 000 miles.

Scientific exploration of space at long ranges (as has been done with the *Explorer* satellites) can be achieved most economically with highly eccentric orbits, such as that of *Explorer X* with an apogee of 145 000 miles and a perigee of only 100 miles. Apart from this application, high eccentricities should not be required, and a closely circular orbit actually indicates a high degree of control during the launch phase.

Satellite Surveillance

Eventually, a radar/optical system for keeping the near space under surveillance will be designed and constructed to ensure detection and recognition of new satellites, particularly those with a warlike potential—reconnaissance or bombardment. Present radar state-of-the-art makes such a system possible. Large arrays with wide coverage and tremendous power are required for detection of a one square meter target out to 3000 miles, but are perfectly feasible. The really difficult problem lies not in detection but in identification. This requires high resolution and sophisticated data processing for determining shapes, tumbling rates, and other characteristics. Beyond 3000 miles, satellites are moving relatively slowly and their density is low enough to enable optical systems to take over. These systems have a capability of tracking a suitably illuminated 10-square meter target out to the distance of the moon. An optical system, however, must rely on illumination from the sun; on the other hand it has the advantage of being unjammable.

Surveillance Radars and Tracking Radars

From the point of view of a radar, a satellite may be a very small target (such as *Vanguard I*, a sphere 6 inches in diameter) or comparable in size to small aircraft. Its slant range may be several thousand miles and is never less than 100 miles. Since radar range is proportional to the fourth root of the average radiated power, satellite observation by radar requires an "effective" power (i.e., the combination of RF energy, antenna gain, receiver noise figure, etc.) of about 40 db greater than needed for conventional air search radars.

Before a satellite is detected and tracked, however, it must be "acquired" by the radar and this involves a search around the estimated position of the orbiting object. If the orbit is only known approximately, a high gain antenna with its narrow beam will have some difficulty in picking up the target. If nothing at all about the orbit is known, i.e., if it is a matter of "space surveillance," then the radar must search over a wide zone at a rate such that any satellite passing through is bound to be detected. This requires a relatively wide beamwidth system.

Therefore, two separate situations exist: For tracking a target in space out to very great ranges, the system must be designed with a gain that is as high as possible. The only limits on antenna size will be a matter of practical mechanical design, due consideration being given to the required tolerances. Such radars are usually large parabolic dishes, such as shown in Fig. 5.

For satellite surveillance, the coverage requires a radar with wide beamwidth. Such a radar has little resolution. Wide coverage can be obtained simultaneously with high resolution and high accuracy only by generating a multiplicity of narrow beams. These could be generated as in a stacked-beam radar with a conventional reflector or, preferably, from a phased array that has enormous flexibility from the point of view of capability for generating a number of beams simultaneously and steering them instantaneously from one direction to another.

A complete radar system for satellite surveillance needs to have both a search function and a track function. The search function will detect the object and locate it sufficiently accurately for the tracking function to take over. The highly accurate tracking beam will then enable the orbital parameters of the satellite to be determined. Basically, only one position (including time) and the velocity vector are required to derive all six orbital characteristics of the satellite. In practice, the satellite is tracked over as long an arc as possible and the "data points" fed into a digital computer. A "best curve" is fitted to these points and the orbital constants derived in this fashion. The mathematical processes are quite complex, particularly because the relative accuracy and usefulness of the radar data (range, range rate, azimuth and elevation) will vary with the direction of the target.

Continuous tracking of a target will also enable an analysis of signal amplitude as a function of time to be made. This will indicate whether the target is tumbling, which in turn, will help to identify the object.

Interesting differences exist between a satellite surveillance system and an aircraft detection radar:

1. Because of altitude limitation of aircraft, a long range air search radar has basically a low-angle coverage; to intercept satellites at minimum ranges, a satellite surveillance radar will require high angle coverage (Fig. 6).
2. An air search radar is limited by the radar horizon to ranges of between 200 and 300 miles. The round trip time of the electromagnetic energy (though essential for the measurement of range) does not affect the system design materially. For a satellite surveillance radar, the round trip time becomes appreciable and will affect the mode of operation.
3. Tracks of aircraft, relative to the radar, are independent of the location of the radar site (if one excludes tactical and strategical considerations). On the other hand, satellite tracks, relative to the radar site, are influenced by the latitude of the site: for example, in the Northern Hemisphere, more satellites will pass to the south of the site than to the north of it.
4. Aircraft are basically maneuverable and must be kept under constant surveillance when within radar coverage. On the other hand, the track of a satellite is ballistic. Therefore, a satellite need only be detected and located once on each passage.

The actual coverage and the number of satellite surveillance radars needed will depend on required frequency of satellite observation, or for a new satellite, on how soon (after launch) detection is desired. To have a complete knowledge at all times of what goes on in space, radars would have to be spaced about 1200 miles apart over the whole globe. (This figure is governed by the radar horizon.) This is obviously impossible since, quite apart from the vast expanse of oceans, this country just does not have control over enough territory. The next best thing is to cover 180 degrees of a great circle. Seven or eight sites are required.

A single site with suitable coverage will detect all satellites at least once every 12 hours (except for certain low inclination, low altitude orbits) because the earth's rotation carries it past the satellite orbit (stationary in geometric coordinates) twice every 24 hours.

What the Future Holds

The situation in the near space is somewhat unique in that the results of experiments long past will be floating around for centuries (such as *Vanguard I*) to clutter up the radar screens of future satellite surveillance radars. It is quite possible that to disguise a particular space experiment, a large number of decoys would be placed in orbit simultaneously (such as balloons or unfurlable corner reflectors). This could cause a sudden increase in the number of objects in orbit out of proportion with the effort involved and could well saturate any radar satellite surveillance system at least temporarily until the objects became dispersed. As to identification, there is a practical limit to what can be done from the ground; one way to distinguish between a "dead" satellite and an "active" one may be to take a close look with an "inspection" satellite armed with TV cameras. These "inspection" satellites could also be used to neutralize unfriendly vehicles.

Therefore, the future may see an increase in the efforts to develop systems designed for inspecting and "policing" the near space.

Westinghouse ENGINEER Nov. 1962

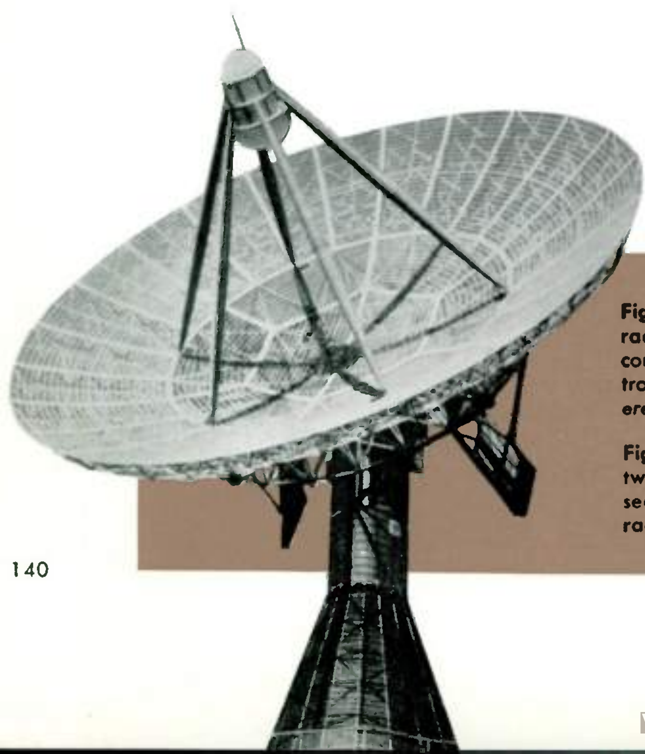


Fig. 5 Sixty-foot dish radar antenna used in the communications and control system of the Discoverer program. (*U. S. Air Force Photo*)

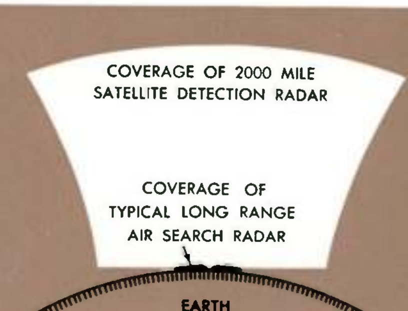


Fig. 6 Comparison between coverage of satellite search and air search radars.

Precise Power Generation for Military Facilities

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Public Works Province Engineering
Industrial Systems
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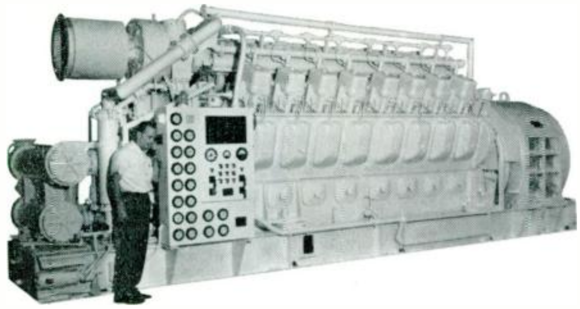

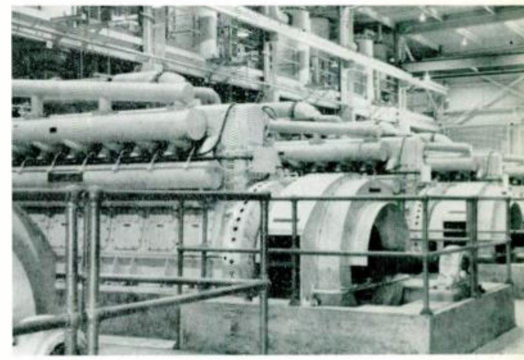

Electric generating and regulating systems for complex military equipment require careful design. Military considerations impose special requirements.

Land-based military facilities have, until recently, been supplied with commercial-quality electric power, and the precise power needed for certain loads has been obtained from secondary regulating devices such as motor-generator sets. However, the number of sophisticated weapons systems that require precise power has increased greatly. As a consequence, the cost of generation equipment for precise power now is offset by the savings resulting from elimination of secondary regulating equipment. Therefore, the trend is to supply an entire facility with precise power.

The term "commercial-quality power," as used in this article, means power of the quality produced by ordinary diesel-electric plants used in commercial applications. The term "precise power" means power having certain characteristics superior to that produced by commercial generation equipment. In general, allowable voltage and frequency transients and waveform deviation are much smaller. (See *Power for Nike-Zeus and Project PRESS.*)

Designers of stationary and portable land military power systems draw heavily on knowledge developed for electric utility systems, but there are some significant differences. Military systems are generally isolated (not part of an extensive network). However, they may be quite large—some systems now in planning could require generating capacities of 100 megawatts continuous with precise power quality. They are generally composed of a relatively small number of loads (less than 100), and several loads may each demand a sizable fraction of the total generating capacity (say up to 30 percent). Finally, military environment or mission considerations may override conventional factors.

Mission considerations are paramount, for example, in defensive weapons systems. Enemy action could easily interrupt public utility power just when it was most needed, so a complete autonomous generation system usually is built at the site to meet the exact needs. The power source must be able to survive in the environment for which the rest of the system is designed. This is achieved by "hardening," which now includes protection against nuclear blast and thermal effects. Electromagnetic pulse, a lightning-like pulse of energy released by nuclear

POWER FOR NIKE-ZEUS AND PROJECT PRESS

The Nike-Zeus antimissile missile system is being developed and evaluated under the direction of the Directorate of Research and Development, a segment of the Army Missile Command. Its primary mission is to defend against long-range ballistic missiles. It is designed to work in an environment of electronic and nuclear countermeasures and decoys and to engage many targets simultaneously. The Zeus missiles are supported by complex detection, tracking, and coordination elements composed of an acquisition radar, discrimination and target track radar, missile track radar, and high-speed computers. Since many targets might be detected simultaneously and many computations (trajectory, predicted impact point, discrimination, intercept point, etc.) must be performed for each target, very fast digital computers are needed to process the radar data.

Project PRESS (Pacific Range Electromagnetic Signature Study) is aimed at determining what effects of missile flight are detectable. It also seeks new means of combating missiles and is being used with the Nike-Zeus test program.

Westinghouse supplied the electrical equipment for two precise power generator installations required for the test program. They are part of the Pacific Missile Range in the Marshall Islands and are operated by the Advanced Research Projects Agency. One powers a Nike-Zeus battery; its six 800-kw generators are driven by engines supplied by White Diesel Engine Division, White Motor Company (see photo, above right). The other, for Project PRESS, has seven 1500-kw generators driven by engines supplied by Alco Products Incorporated (see photo, above left). Military specifications are listed in the table and compared with those for commercial-quality plants of similar size.

COMPARISON OF PRECISE POWER AND COMMERCIAL POWER

	Precise Power		Commercial Power (diesel generator plants)
	Nike-Zeus	Project PRESS	
Rating—kw	800	1500	700–2500
Transient With 25% Stepload			
Voltage			
Drop—%	5	3	5–10
Recovery—seconds	0.5	0.5	1–2
Frequency			
Drop—%	0.8	0.8	5
Recovery—seconds	1.5	1.5	5
Distortion Factor			
Single harmonic	3	2	3–5
All harmonic—%	Not spec.	3	5–7
Deviation Factor—%	4	4	10
Telephone Influence Factor	50	50	125–150

$$AB = 1 - \frac{Z\sqrt{Z^2+2XX_q+X_q^2}}{Z^2+X(X'_d+X_q)+X'_dX_q}$$

where Z = per-unit impedance of suddenly applied load = 1/per-unit load

X = per-unit reactance of suddenly applied load $= Z\sqrt{1-PF^2}$

X_q = per-unit generator quadrature axis synchronous reactance

X'_d = per-unit generator direct axis transient reactance

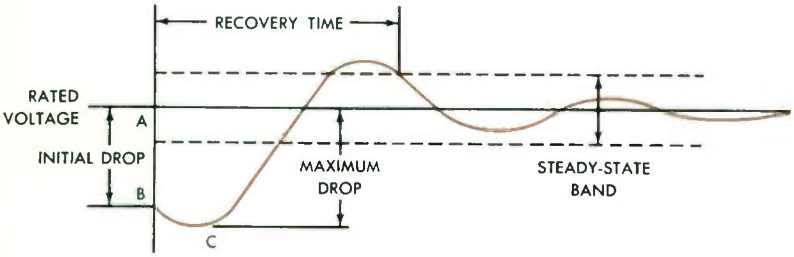

Fig. 1 Generator voltage drop and recovery are the most important characteristics to be predicted for a system. Initial drop *AB* is governed by generator transient reactances and is approximated as shown.

weapons, also is receiving attention, and power plants probably should be protected against it. Radio interference must be eliminated or suppressed.

Radar and computers are two of the specialized loads supplied by modern military power systems. Many high-voltage pulsing radar devices subject the system to instantaneous load changes of 25 percent or more of capacity. These large step loads, if not properly provided for in the system and equipment design, can readily affect performance of voltage- and frequency-sensitive devices that must be fed from the bus at the same time the large load changes take place. For example, a single over-voltage spike can destroy the transistors or diodes in a computer. Voltage pulses also can cause a computer to perform unintentional operations and introduce errors into the memory system.

Planning a System

Systems engineers have developed a number of methods for making quick, accurate, and inexpensive determinations of machine performance characteristics. Transient voltage drop and recovery are the most important characteristics to be predicted, since they largely determine generator and voltage-regulator size, complexity, and cost.

Voltage reaction to a sudden load application is shown in Fig. 1. Because of the short time delays of the magnetic amplifier regulator, the subtransient effect can be neglected in preliminary calculations. Voltage is then assumed to drop transiently from *A* to *B*. It decreases gradually from *B* to *C* (because generator reactances change gradually from transient to synchronous values) and then recovers. The drop from *B* to *C* depends on both the regulator and the generator. It usually averages about 0.75 percent for a 25-percent load change for 60-cycle machines with static excitation systems. Recovery time is difficult to calculate by short methods but easy with an analog computer.

Detailed proof that a proposed power plant's performance will meet all aspects of the specifications is obtained, before actual manufacture and test, with the aid of a digital computer and an electronic differential analyzer. The general analytical representation of a generator, regulator and load combination is shown in Fig. 2. The system is described by differential equations, and the transfer functions shown in the figure are obtained from the operational form of these equations. The system is put into the electronic differential analyzer in the form of amplifiers, resistors, and capacitors that simulate the transfer functions

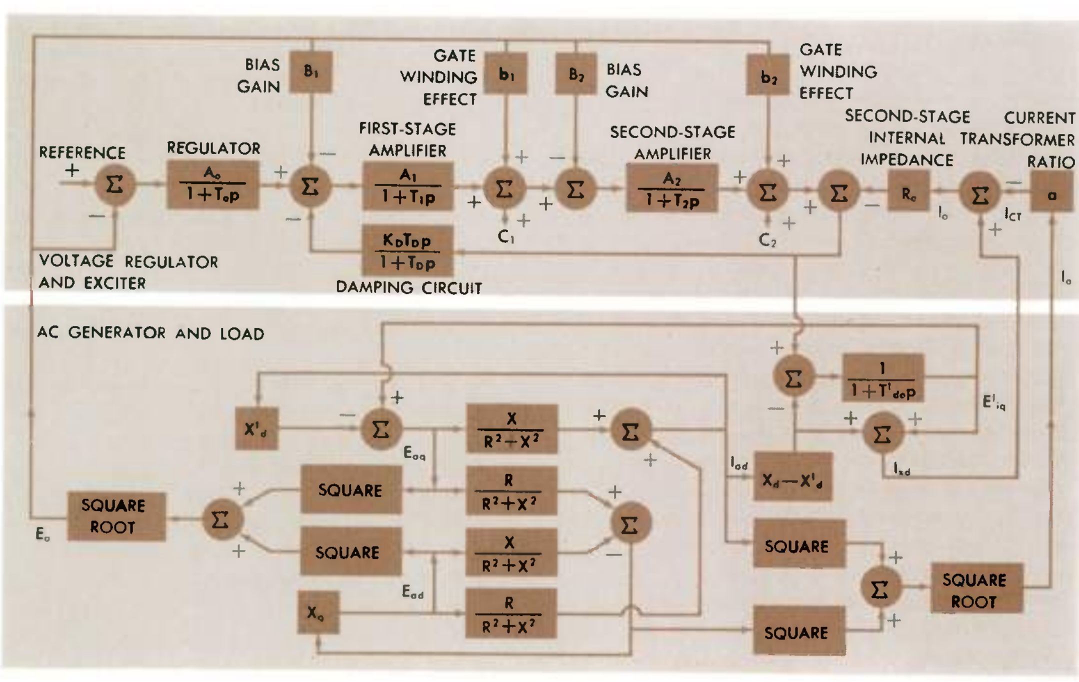

Fig. 2 This block diagram is an analytical model of a generator/regulator/load combination. The transfer functions in the blocks are mathematical representations of system components. When the system is simulated in an electronic differential analyzer, it can be "operated" and components varied to obtain desired system performance.

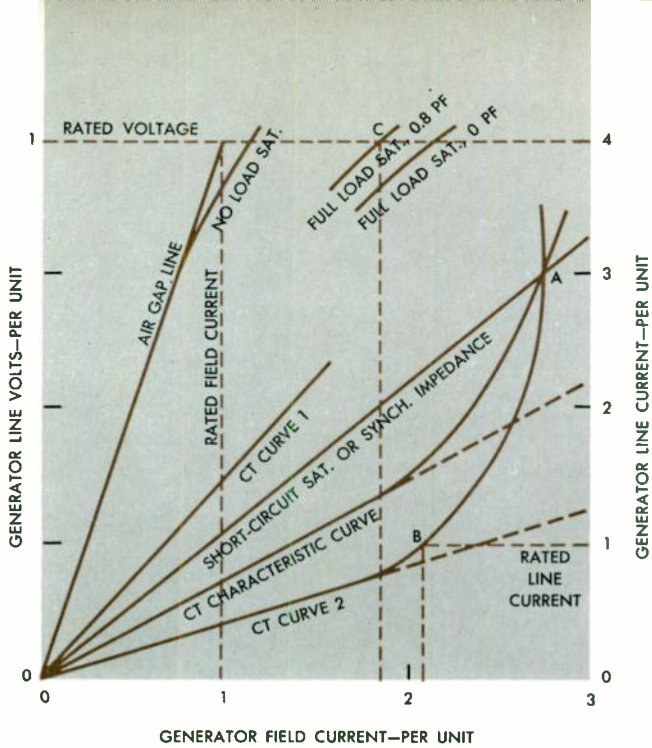

Fig. 3 Saturation curves for exciter current transformer (CT) and generator. Current transformers are designed specifically for each system to match the generator field excitation requirements of that system.

of the actual components. Typical disturbances are then applied to the analog, and the resultant measured reactions bear a scaled relationship to the responses that would be obtained on an actual system. Components are optimized readily by varying the related transfer functions to simulate different components.

With this and other analysis techniques, the designer determines steady voltage stability, transient voltage response, parallel operation performance, short-circuit stresses and heating capacities, mass elastic constants, cyclic speed irregularity, torsional vibrations and stresses, steady-state speed stability, and transient speed response.

Equipment Design Considerations

Generator—Procurement specifications for precise power equipment strongly influence the generator design. Requirements for voltage waveform, harmonic content, telephone influence factor, and voltage drop and recovery with suddenly applied load have the greatest effects.

Low harmonic content and a voltage waveform that closely approaches a sine wave are fundamental requirements, satisfied by several basic techniques. Pole heads are shaped to produce voltage that approaches a fundamental sine wave. (Pole heads of commercial generators are shaped to maximize thermal efficiency; in precise power generation, efficiency is subordinate to good waveform.) Pole-head span is selected to minimize the effective seventh harmonic, stator coil spans are chorded to minimize the fifth harmonic, and stator slots are skewed to minimize higher slot harmonics. Telephone influence factor can also be reduced by skewing. When low harmonic content is required for line-to-line as well as line-to-neutral operation, the third harmonic is reduced by special interconnection of stator windings. Harmonics and telephone influence factor are reduced further by judicious choice of number of stator slots with respect to number of rotor poles.

When a maximum voltage drop for a given step load is specified, the generator and regulator designer must decide on the desired value of generator transient reactance. A fast-acting regulator permits a higher reactance and therefore a less costly generator. However, specified regulator characteristics may limit the design choice.

After the preliminary transient reactance is decided, the designer determines whether this reactance can be obtained with a standard generator frame size. If it appears that an oversize machine would be needed, the designer considers ways to reduce the reactance by fundamental methods, using standard parts where possible. Where other factors are not limiting, wide and shallow stator slots reduce primary reactance. Transient reactance is reduced by adjusting rotor pole shape relative to full pole pitch and by choice of overall pole shape.

Voltage Regulator and Exciter—Static voltage regulator and exciter equipment is usually needed to obtain the specified response speed. From the proposed generator saturation curve and the preliminary calculated generator reactance values, the designer determines the ratings and characteristics for the magnetic amplifiers, power supply transformers, power current transformers, and power rectifiers to be used in the excitation system.

The rating of the exciter components is determined by generator field excitation requirements. Power current transformers must be designed for each system with the following criteria in mind: To sustain all types of short-circuit current for effective relay operation, the current transformer characteristic curve must fall below the generator short-circuit saturation curve for values up to about three per-unit generator line current. If the current transformer characteristic curve has a slope greater than that of the generator short-circuit saturation curve, as indicated by curve 1 in Fig. 3, generator current will not sustain the required field current and the generator current will collapse. To limit generator fault current to a value that the components can withstand, current transformers are designed to saturate at about three per-unit generator current as indicated by point *A*. If the current transformer characteristics are as shown in curve 2, rated generator line current will produce more than the amount of field current (point *B*) required to produce rated generator voltage and field current (point *C*), and regulation will not be possible for this condition.

The required minimum gain of the regulator and exciter is calculated by dividing the difference between generator full-load field voltage and no-load field voltage by the allowable change in line voltage from no-load to full-load. A gain of at least twice the calculated value is used to compensate for thermal drifts and variations in components.

Design Check and Apparatus Manufacture

An analog computer study of the generator-regulator system verifies proper selection of components. This study also establishes the optimum value of system damping, and a circuit is then designed to give the required damping.

Finally, apparatus is manufactured, erected, and tested. The resulting installation meets the needs of the military system it was designed for.

High-Speed Elevator Control

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A. O. Lund
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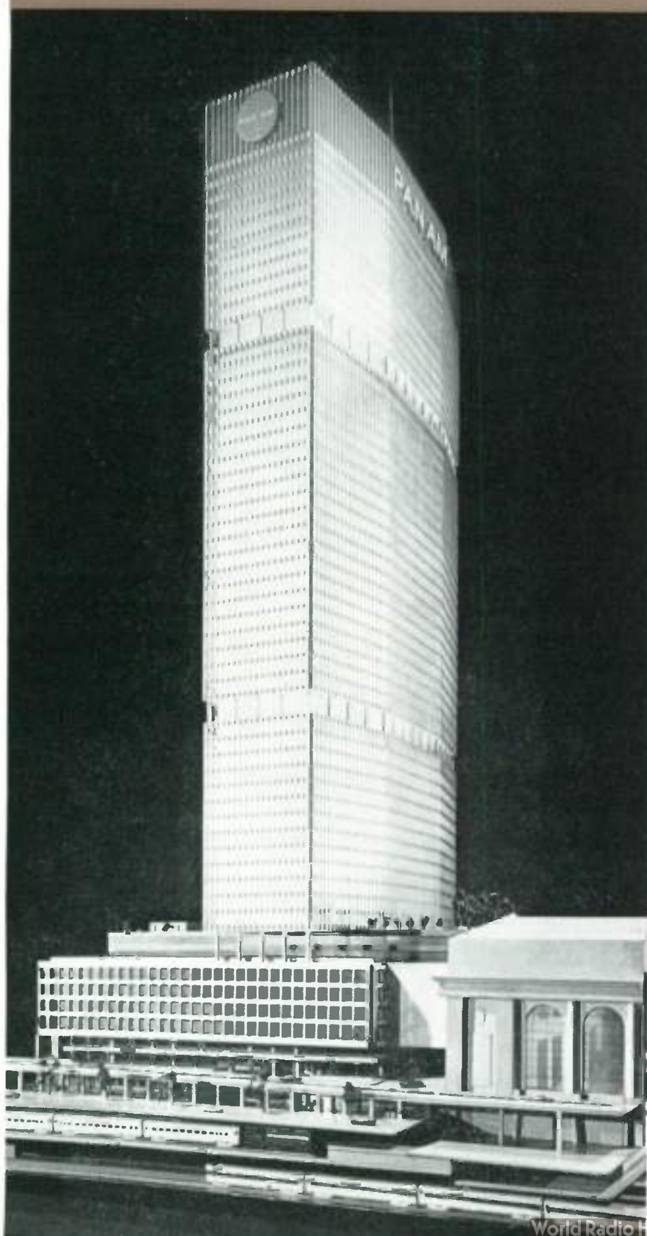
Special velocity and position transducers provide smooth and rapid response in a high-gain feedback control system.



High-speed passenger elevators are a key economic factor in the design and operation of multistory buildings. The economical height of a building (or, for a building of given height, the number of elevators needed) may be determined by the capacity, speed, and efficiency of the elevator control system selected. Safety, riding comfort, and system reliability also affect the value of a building in which elevators are required.

The control loop for a modern high-speed elevator is a high-gain feedback system. It must provide rapid acceleration, rapid deceleration, and smooth operation over a wide speed range. These requirements are best met by a system that uses continuous nonlinear pattern signals to control car velocity and position. The control for the Synchro Glide Mark IV elevator, described in this article, is such a feedback system.

Stepless pattern transducers developed for this application provide the continuous signals needed. They permit operation of the elevators at maximum and minimum speeds without abrupt or uneven changes in acceleration. Conversion from a velocity-regulating to a position-regulating system near the floors provides accurate positioning of the car under all load conditions without use of the mechanical brake.

The system is, in part, an outgrowth of fundamental research on regulating and control methods going back as far as 1936. In one early experimental system, a rate gyroscope was used successfully to regulate low motor speeds (such as occur in an elevator motor during slowdown). Then a new speed transducer was conceived during a seemingly unrelated program—development of a disk and damping-magnet system for watthour meters. This proved even simpler and more reliable than the gyroscopic speed transducer, so it was adopted for the Synchro Glide Mark IV elevator.

Elevator Systems

The basic drive for high-speed passenger elevators is the gearless electric motor with Ward Leonard adjustable voltage control. Auxiliary equipment adds such refinements to the elevator system as attendantless operation, automatic dispatching that adapts to the changing traffic conditions usually encountered, and programmed acceleration and stopping.

A traction-type gearless drive is diagrammed in Fig. 1. The hoisting ropes, usually five to eight in number, lie in parallel grooves in a traction sheave mounted on the shaft of a low-speed dc motor. Friction between ropes and sheave transmits driving torque to move the car and the connected counterweight.

Parts of this article are adapted from a paper (CP 62-70) presented at the 1962 AIEE Winter General Meeting and later published in the March 1962 issue of *Electrical Engineering*.

Photo The 59-story Pan Am Building, nearing completion near Grand Central Terminal in New York City, is illustrated by this model. As the world's largest office building, it will provide work space for 25 000 persons. Its 65 Westinghouse elevators and 21 electric stairways will move an estimated 275 000 persons a day. The elevators will be controlled by the system described in this article; those in the high-rise bank will be capable of traveling at 1600 feet per minute (fpm).

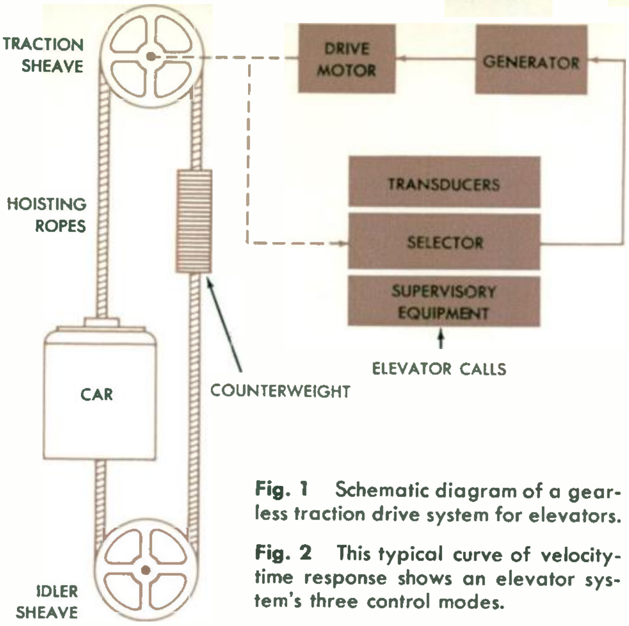
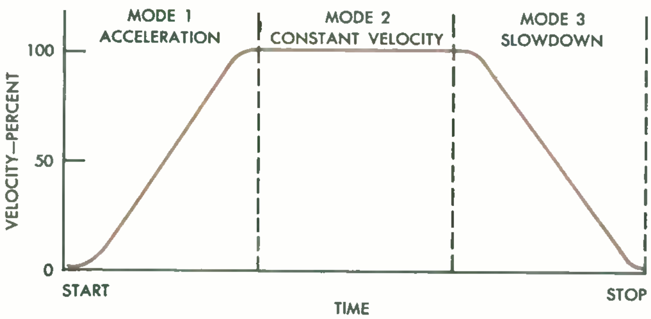


Fig. 1 Schematic diagram of a gearless traction drive system for elevators.

Fig. 2 This typical curve of velocity-time response shows an elevator system's three control modes.



lessly by the special transducers. For slowdown, the signals are made a function of car position by use of a mechanical selector. The selector is, in effect, a miniature elevator driven in synchronism with the elevator car. It includes the relays required to open and close the doors and perform other auxiliary functions.

System Requirements

The principal requirement is for the elevator car to travel between stops in the shortest time possible consistent with passenger comfort. The time to travel in mode 2 can be reduced by increasing the maximum velocity of the car. High constant speeds have little effect on passenger comfort, so the practical time limitation in this mode is usually the rating of the equipment. In modes 1 and 3, passenger comfort is the foremost factor limiting time of travel. Tests show that passengers are sensitive to both acceleration and its rate of change. Because they vary in sensitivity, the optimum response in these modes can be established only by conducting riding tests with a variety of passengers.

Once the optimum velocity-time curve is determined from the standpoint of comfort and minimum time, the quality of the elevator ride can be measured by how well the car follows this curve. To follow a specified pattern input, a high-gain system is needed—one with satisfactory damping and a wide-range velocity transducer of good sensitivity and accuracy. For example, the low velocity required at landing is about two feet per minute (fpm). If maximum car velocity is 1000 fpm, the velocity range

When a call is registered, supervisory equipment directs the car to the correct floor. The motor control provides three distinct modes of travel (Fig. 2). The car first accelerates to its maximum velocity (mode 1) and then travels at constant velocity through mode 2. In mode 3, car velocity decreases to zero. Reverse driving torque is required for overhauling load in mode 2 and for deceleration in mode 3.

Variable-voltage or multivoltage signals on the generator field produce the required motor response. These signals are often applied in steps by cams or relays; in the Synchro Glide Mark IV elevator, however, they are applied step-

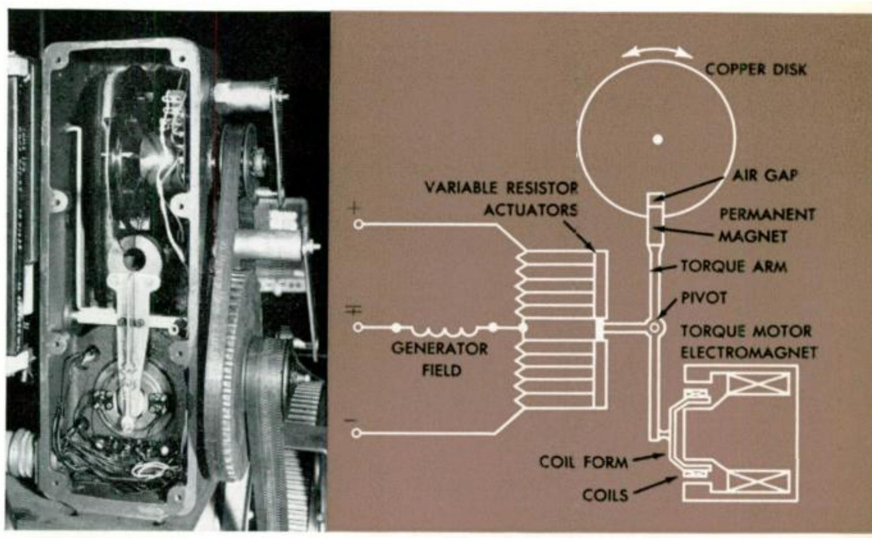
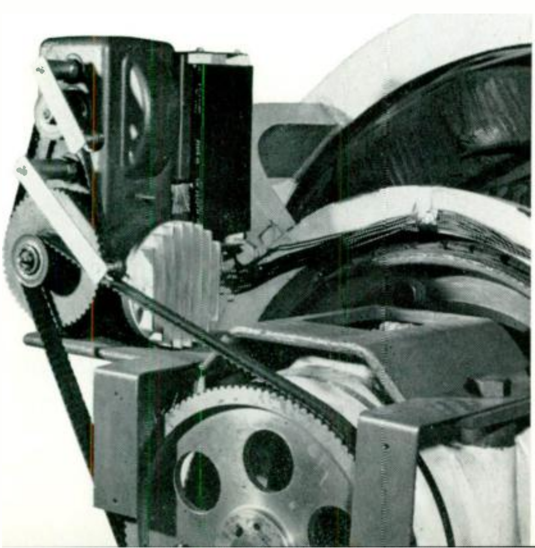


Fig. 4 (Above) Photographic and schematic views of the velocity transducer show the simple torque arm that combines the functions of error measuring, input signal summation, and power amplification. The arm is actuated by a copper disk rotating (in synchronism with the elevator car) in the air gap of a permanent magnet and by a torque motor energized by the control system's pattern and feedback signals.

Fig. 3 (Left) The control system's velocity transducer, with belt guards removed, is shown mounted on the bearing housing of a 60-horsepower 80-rpm elevator drive motor. Two timing belts couple it mechanically to the motor.



is 500 to 1. The corresponding landing speed for a 100-rpm gearless drive motor would be 1/5 rpm.

Velocity Transducer

The velocity transducer designed to meet these requirements is shown in Fig. 3. The functions of error measuring, input signal summation, and power amplification are all included in the basic transducer design to simplify integration of the device into the system. A torque arm in the transducer provides the simple means for combining these functions. Unbalanced torques supply the forces required to actuate variable resistors of sufficient capacity to control directly the maximum field current of most generators.

The torque arm is a vertical beam supported on a horizontal pivot (Fig. 4). Its upper end carries a C-shaped permanent magnet, and the moving coils of a torque motor are attached to the lower end. The entire assembly is gravity balanced around the horizontal axis, and stops limit angular motion to approximately three degrees. An electromagnet supplies a constant field for the moving coil windings. Angular motion of the arm actuates the two variable resistors that change generator field excitation. One end of the generator field is connected to the center of the power supply to allow full excitation of either polarity, depending on the angular position of the transducer torque arm.

Torques proportional to elevator velocity are produced on the arm by driving a copper disk, turning in synchronism with the drive motor, through the air gap of the permanent magnet. Eddy currents generated in the copper react with the field to give "drag" forces proportional to the angular velocity of the disk. (These forces are similar to the familiar damping forces of a watthour meter.) The eddy-current circuit is completed within the disk, so no slip rings are required.

Attempts have been made to calculate drag forces, but difficulties in establishing boundary conditions, and the demagnetizing effects in pole pieces, make the model-test approach more accurate. Drag forces produced on a small permanent-magnet model by rotating a copper disk (6 inches in diameter by 0.044 inch thick) in the air-gap flux are shown in Fig. 5. The force-velocity relation is fairly linear up to a copper velocity of about 2500 fpm. At higher velocities, disk reactance limits the drag force. Use of a thin disk normally improves linearity by increasing the resistance compared to the reactance of the eddy-current

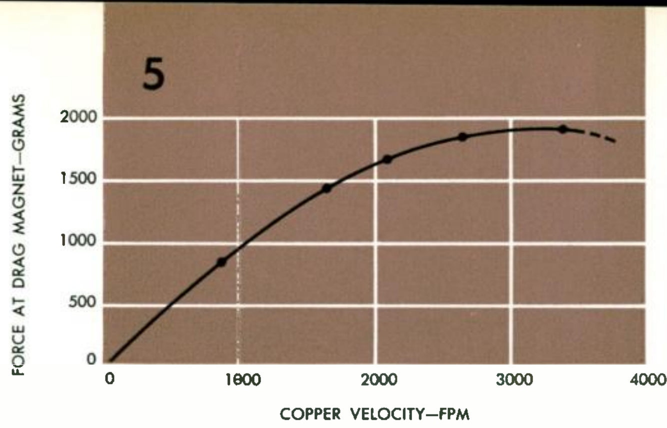
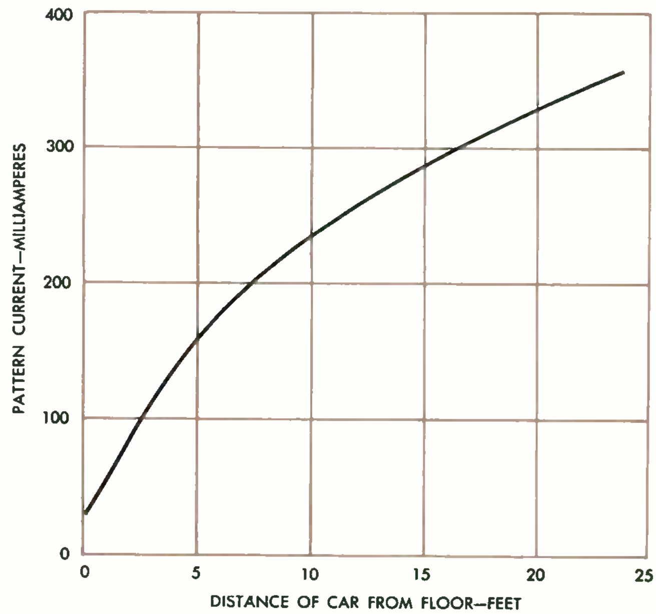
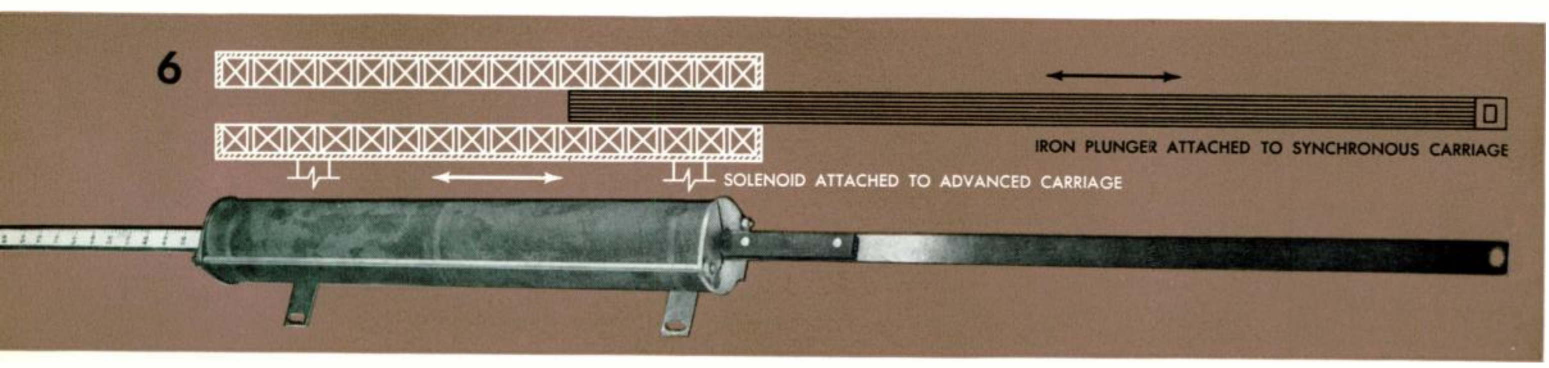


Fig. 5 (Above) Drag forces produced on a permanent magnet by rotating a copper disc in the air gap increase quite linearly with speed up to about 2500 fpm copper velocity. Then, disk reactance limits the drag force.

Fig. 6 (Below) The pattern signal for initial slowdown in approaching a floor is supplied by a selector transducer consisting of a solenoid and a plunger mounted on separate carriages in the selector. Movement of the plunger into the solenoid gives a signal with the current-position curve shown. The photograph shows both members of a transducer for a system with a maximum car velocity of 1600 fpm.

Fig. 7 (Right) The pattern signal for final slowdown and stop is supplied by a hatch transducer with one member on the car and a second member in the hatch at each floor. The parts are shown schematically with the car member at floor level. The shape of the hatch-member plates changes the pattern signal at floor level, as shown in the graph, to increase the system's positional stiffness at that level. The photograph shows the car member assembled with a hatch member.





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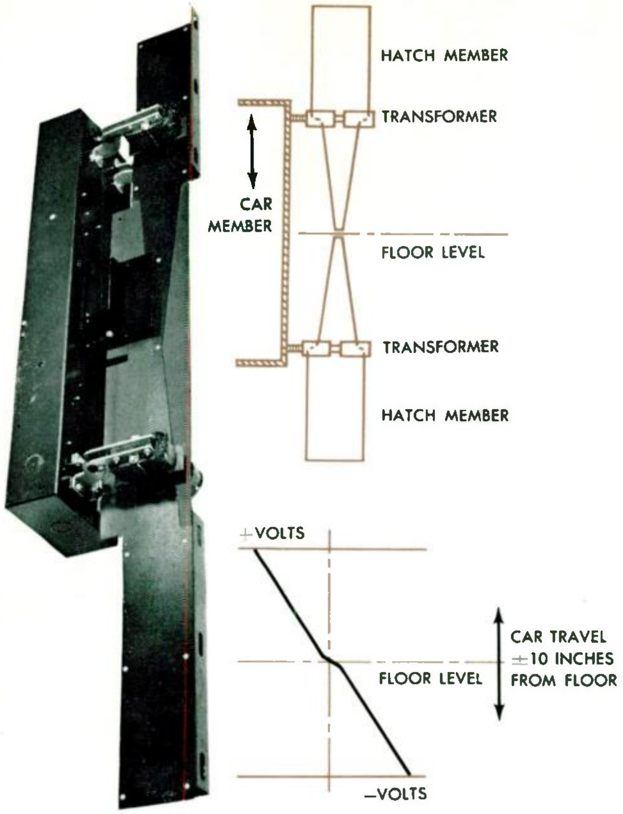


path and thereby minimizing the time constant for the copper disk circuit.

The demagnetizing effect of the disk currents on the permanent magnet reduces the drag forces on the order of 10 to 15 percent. Once the magnet is stabilized by driving the disk at its maximum velocity, no further change in the force-velocity curve occurs at lower velocities. The stability of drag forces in the familiar watthour meter application is well known.

A principal function of the velocity transducer is to compare eddy-current drag torques with the input torques coming from pattern signals applied to the moving coil of the torque motor. If these two torques are not equal and opposing, the arm deflects to change the excitation of the drive system and bring the speed of the elevator car to a value at which the torques balance. When the input torque is constant, as in mode 2, the system regulates automatically for constant car velocity. A variation in car velocity results in unbalanced torques on the transducer. The arm deflects and changes the excitation to return the car to the original velocity. The torques are again balanced in the transducer with the arm in a new angular position corresponding to the change in excitation.

Time delays are principally mechanical and were made small by designing the moving member with a low moment of inertia around its pivot axis. In the design shown in Fig. 4, this inertia in combination with the angular stiffness of the actuator springs has a natural frequency of six cycles per second, about five times the system frequency. The motion of the moving member is critically damped by eddy currents induced in the aluminum coil form of the torque motor. The two 0.03-second time delays represented by this second-order system are unusually small for an electromechanical transducer capable of controlling 300 watts with an input force of only a few grams. When additional output is required, a rotary amplifier is used for power gain. In such cases, the time delay of the added field can be reduced to approximately one-fifth of its normal value by series resistance and the amplifier can still control several kilowatts of output power.

Other input functions are easily combined in the transducer by a summation network connected to the moving coil, which has low impedance and operates at low power level. If the auxiliary functions require circuit isolation, additional coils are provided on the torque motor. The feedback loops described later, used for stabilizing the system, are also summed at the transducer input.

Position Transducers

In early tests with a high-gain velocity system, the conventional steps in pattern signal gave undesirable transient accelerations. It was apparent also that a more precise pattern signal for car position was required during final approach and stop. Two unique transducers were developed to solve these problems. The transducers require ac power excitation and generate output signals that are rectified to supply pattern signals to a coil on the torque motor of the velocity transducer.

One transducer in the mechanical selector supplies a continuous reference pattern for slowdown from high speed to a point 10 inches from the floor. The selector has two carriage members. One is always in synchronism with the car, and the second is initially driven in advance of the first carriage but is stopped when the car starts into mode 3. Now, as the car travels to the floor, the distance between the two carriages is proportional to the distance of the car from the floor. The relative motion between carriages changes the position of an iron plunger with respect to a solenoid (Fig. 6).

As the plunger moves into the solenoid, it changes coil impedance from a minimum to a maximum. The impedance with respect to the core position is shaped by varying the distribution of turns throughout the length of the solenoid to give the current-position curve shown. This pattern shape gives the car the response shown in mode 3, Fig. 3. Scaling is such that a $\frac{1}{8}$-inch movement of the plunger corresponds to 1 foot of elevator travel. For a car running at 800 fpm, the distance traveled in this mode is approximately 25 feet. Inaccuracies introduced by the large scaling factor limit the usefulness of the selector transducer to positions greater than 10 inches from the floor.

A second transducer, with one member on the car and a second member in the hatch at each floor position, supplies the accurate voltage-position pattern needed during the last 10 inches of travel (Fig. 7). The car member consists of two transformers spaced 22 inches apart in the direction of travel. Primary and secondary windings are on core members spaced with a one-inch air gap. Iron pole pieces on the secondary cores are used to increase the coupling between the primary and secondary windings and the output of the transducer. Each hatch member consists of two thin steel plates mounted on laminated plastic. These plates, passing through the air gaps of the core members

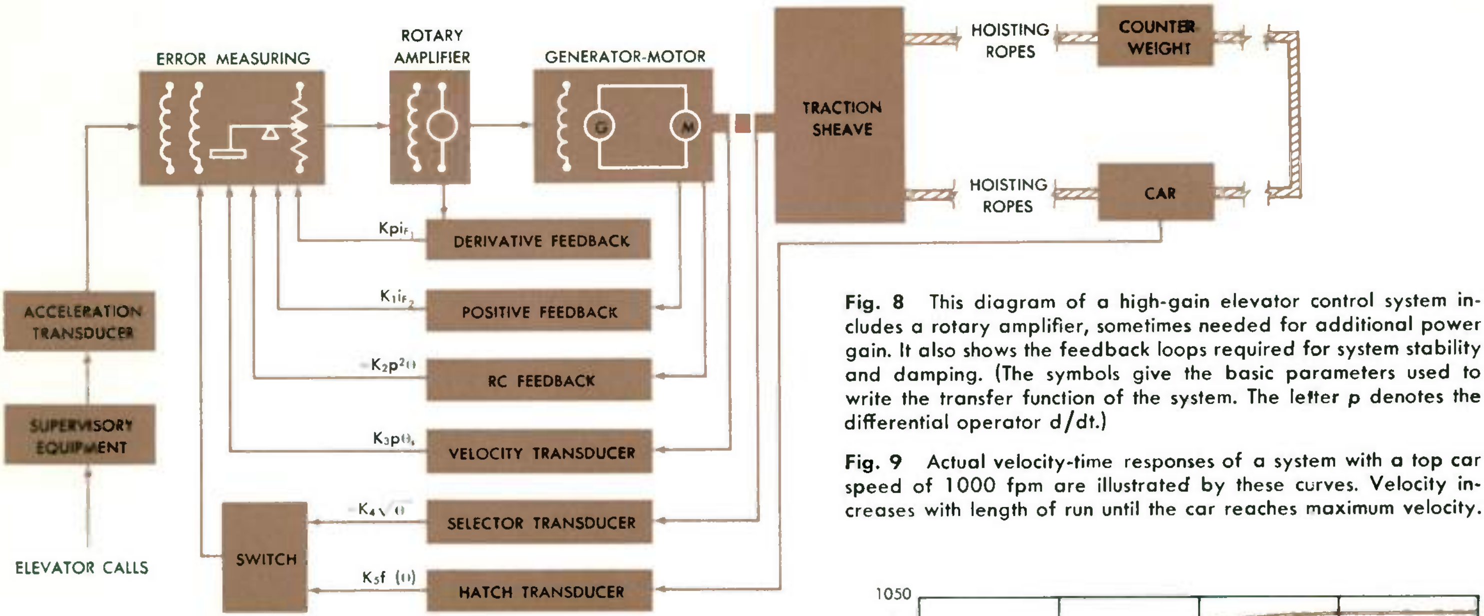
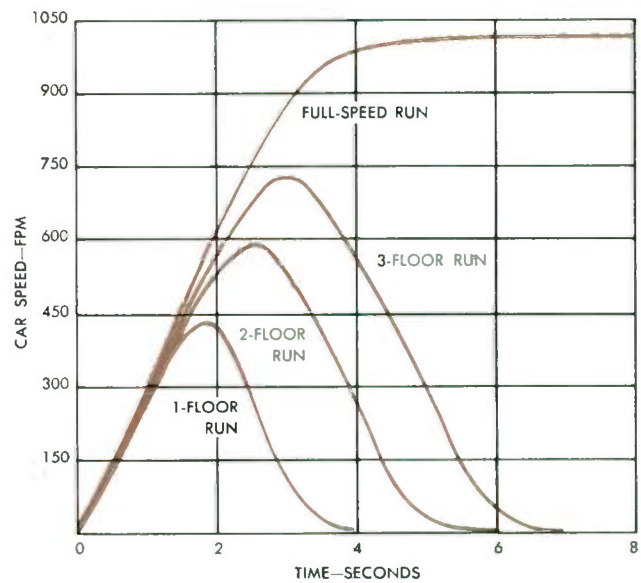


Fig. 8 This diagram of a high-gain elevator control system includes a rotary amplifier, sometimes needed for additional power gain. It also shows the feedback loops required for system stability and damping. (The symbols give the basic parameters used to write the transfer function of the system. The letter *p* denotes the differential operator d/dt.)

Fig. 9 Actual velocity-time responses of a system with a top car speed of 1000 fpm are illustrated by these curves. Velocity increases with length of run until the car reaches maximum velocity.



on the car, reduce the coupling flux to a minimum when the plate width overlaps the poles.

The relatively large air gap provides sufficient mechanical clearance for car movement normal to direction of travel. Changes in coupling from sidewise motions are minimized by the four-pole construction.

The secondary voltages from each core assembly are individually rectified and the two dc outputs connected to a mixing resistor. When the car is at the floor level, the voltages from the top and bottom core assemblies are equal and opposing to give zero pattern voltage across the mixing resistor. When the car departs from the floor position, the contour of the hatch plates produces unequal voltages in the mixing resistor to give the pattern-displacement voltage shown in Fig. 7. Polarity of the pattern voltage is determined by whether the car is above or below the floor. When this pattern signal is applied to the torque motor of the velocity transducer, the elevator car is position-regulated with reference to the floor level.

The general slope of the hatch-transducer pattern is a continuation of the pattern curve of Fig. 6 from the 10-inch point to the floor. One inch from the floor, the slope is changed approximately 2 to 1 by variations in the contour of the hatch plates (Fig. 7). The greater slope increases the positional stiffness at the floor. Since the change occurs at almost zero velocity, it is not noticed by passengers. The system stiffness at the floor is made large so that variations in passenger loading have little effect on car position at the floor level.

Acceleration Transducer

Pattern requirements for the acceleration mode are not so exacting as for the slowdown mode. Positional accuracy is not important because the car is accelerating toward maximum velocity instead of to a position. It is desirable, however, to accelerate at a substantially constant rate, keeping the rates of change within certain limits as discussed later. An acceleration transducer supplies a linear buildup of pattern current (torque) on the transducer arm with respect to time to give the desired result.

The transducer consists of two back-to-back Trinistor controlled rectifiers, in series with the pattern supply, and the control circuits for firing the controlled rectifiers. The rate of buildup of pattern current is compared with an adjustable command signal, and the difference sets the firing angle of the controlled rectifiers. The gate control circuits also provide means for reducing the acceleration at an adjustable point in the acceleration cycle, if this feature is desired.

System Performance

A complete elevator system is shown diagrammatically in Fig. 8. The usual derivative feedback signals are required for stability and satisfactory damping. They are obtained from an RC network in the armature loop with output feeding back to a coil on the torque motor as shown. When the system includes a rotary amplifier for more power gain, other derivative-stabilizing signals are required in a feedback loop around the additional machine. These signals are obtained from extra windings on the rotary amplifier feeding back the rate of change of field flux to the torque motor. A low-gain positive feedback loop is sometimes used to reduce steady-state velocity error. The improvement that can be obtained by this means is limited by the requirements for system stability and damping.

The performances of various machine sizes with different passenger-carrying capacities and speeds have been evaluated in exhaustive tests. Actual velocity-time responses of one system are shown in Fig. 9.

The final pattern shapes needed to give such curves as those of Fig. 9 were determined experimentally because of the difficulty in specifying requirements for passenger comfort any other way. Acceleration from zero to maximum velocity can be as high as 8 feet per second per second with satisfactory comfort, but other considerations such as the life of ropes and machines make it desirable to limit acceleration to a lower value. Sudden application or removal of acceleration is noticeable to passengers, so rates must be changed gradually. Time delays in the system influence the rate at which acceleration can be changed; when these delays are long, the pattern signals must force the system time response.

Time rate of change of acceleration is often used as a measure of riding quality, and "jerk" is the concise name generally given to the unit used to measure this quantity. Ride tests were made with numerous pattern shapes to try to establish a jerk limit, but wide variations in the response of different passengers prevented establishing a practical comfort value. It was also observed that high jerk values are not objectionable if they persist for only a short time, so "jerk-seconds" were examined. Values in the range of 5 to 10 jerk-seconds appear to be satisfactory for passenger comfort.

The final pattern shapes were reached by a program of ride tests. Rates of change of acceleration were made large enough to be noticeable to passengers in the car, and then the rates were lowered until the ride was comfortable. The result is a ride so smooth that it is difficult to tell when the car accelerates and slows down. Once the pattern has been determined it becomes a design constant for the system, requiring no further adjustment.

Floor stops depend entirely on the dynamic braking of the control system, and the conventional mechanical brake on the sheave is applied only after the car has reached zero velocity. The car stop is never felt by the elevator passengers.

Conclusions

The novel transducers described in this article program the dynamic response of a high-gain velocity-regulating system to achieve an elevator control having outstanding performance. The continuous nonlinear pattern shapes give rapid acceleration and slowdown with exceptionally smooth riding qualities. Accurate positioning of the car is secured at each floor under all conditions of passenger loading.

Some of the unique transducer features of the Synchro Glide Mark IV elevator probably will be applied to other control systems.

PRODUCTS FOR INDUSTRY

NEW SILICON DEVICES

Type 109 series of NPN high-power silicon transistors retains electrical characteristics of earlier high-power series but weighs 66 percent less (0.9 ounce). Maximum ratings are 20 amperes collector current, 200 watts power dissipation, 175 degrees C junction temperature.

Type 200 Trinistor controlled rectifier provides high current for industrial and military equipment and permits flexible power control in the 50- to 100-kilowatt range. Device is rated 150 amperes and is available in forward blocking voltages through 400 volts.

O.E.M. power transistors can operate at higher ambient temperatures than germanium transistors but are competitive in price with the germanium devices. Units in the 151 series have current gains of 11 to 46 at 1.5 amperes, and those in the 152 series have current gains of 18 to 75 at 1.5 amperes. Collector-to-base voltage ratings are 80 to 200 volts; collector-to-emitter ratings of the new silicon power transistors are 40 to 100 volts.

Westinghouse Semiconductor Division, Youngwood, Pa.

WET-TRACK TESTER

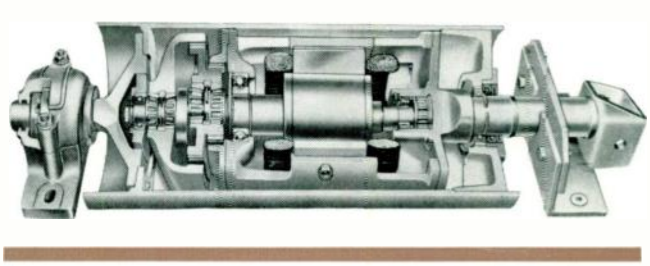
Self-contained instrument evaluates tracking susceptibility of insulating materials by measuring minimum discharge power necessary to produce a track. Internal and external tracking can be distinguished and measured. Any molded, laminated, or cast insulation can be tested, except for thermoplastic materials that flow readily in the heat of an arc. The tester operates from a 130-volt ac supply and draws approximately eight amperes.

Westinghouse Scientific Equipment Division, Research and Development Center, Pittsburgh 35, Pa.

DRUM, MOTOR, AND SPEED REDUCER

Thorite motorized drum powers conveyors, bucket elevators, cranes, hoists, winders, winches, capstans, car pullers, and runout tables. Entire drive is enclosed in the drum. The motor stator is connected to a fixed hollow shaft, and electrical leads pass from it through the shaft to a terminal box. The rotor drives the drum through an epicyclic gear system. A variety of gear ratios, drum sizes, and motor sizes provide many belt speeds, torques, and horsepower ratings. Compact design permits mounting the unit close to the floor or ceiling.

Westinghouse Motor and Gearing Division, Buffalo, N.Y.



TECHNOLOGY IN PROGRESS

Million-Kw Nuclear Plant Studied

Technical feasibility and economic potential of a 1 000 000-kilowatt nuclear power plant using a single closed-cycle water reactor are being studied jointly by the Atomic Energy Commission and Westinghouse. The program's purpose is to determine whether such plants are technically feasible, practical for construction on typical sites, and economically attractive.

A preliminary Westinghouse study indicates that a plant of this size could be in operation by 1970. Moreover, forecasts made in the company's Powercasting program indicate that by 1965 at least 20 percent of the steam generating capacity ordered by utilities in the United States should be in units of more than 1 000 000 kilowatts. While nuclear power economy has always increased with unit ratings, it is expected to be even more pronounced in the 750 000- to 1 000 000-kilowatt range.

The three-phase study program includes conceptual design of a 1 000 000-kilowatt plant for a hypothetical site and preparation of an estimate of capital, fuel, operating, and maintenance costs; review of typical sites in areas where large nuclear plants may be suitable; and establishment of a research and development program necessary to bring the plant to completion.

The design effort will evaluate practicality as well as feasibility. For example, plant requirements may indicate, in the light of existing technology, a need for components that could be built in theory but whose manufacture would require unacceptably expensive modifications to existing manufacturing facilities. Transportation to the site and erection might also be prohibitively expensive. If such situations develop, the study will explore alternate approaches and the research and development efforts needed to prove their feasibility. ■ ■ ■

Hydrogen Purge System

Refineries and chemical plants are making and using more and more hydrogen, and this trend poses safety problems in modern plants that are heavily equipped with electrical devices. Besides the hazard of accidental breakdowns, the gas is so highly diffusive that it is almost impossible to prevent some leakage. Moreover, its high explosion pressure and low ignition temperature often make normal explosion-proofing measures (enclosing electrical equipment in heavy jointless enclosures) too expensive when the equipment is large industrial machinery.

In the South, hydrogen-handling equipment (such as pumps and compressors) simply is located outdoors so that leakage cannot accumulate. In colder climates, however, the equipment has to be inside buildings. One answer then is internal pressurizing of conduits and equipment. An effective new system for accomplishing this has passed its first year of successful operation in a Brockville Chemicals Company ammonia and nitrate fertilizer plant at Maitland, Ontario, Canada.

The complete system that handles hydrogen and other explosive gases is housed in one building. Air under pressure is piped into all conduits and electrical equipment from a safe area outside the building. The pressure keeps the potentially hazardous building atmosphere out of the conduit and equipment, and controlled bleeding of air from the pressurized components continuously purges the system. This controlled bleeding is an advance over earlier pressurized electrical systems, in which no regulated purging occurred.

The pressurized system contains about 14 000 feet of conduit and has a volume of about 500 cubic feet. The components protected include fan motors for the building steam heaters, 4 compressor motors rated at 100 horsepower and 550 volts, and 13 compressor control and annunciation cabinets. The cabinets are gasketed sheet-steel enclosures pressurized with air from the conduits. Air for this system is supplied by a blower discharging at 14 inches water gage pressure. A standby blower starts automatically if normal pressure is not maintained by the running blower. Automatic controls shut down the equipment if air pressure falls below a safe value.

Nine larger compressor motors, rated at 4160 volts, range in size from 350 to 4000 horsepower. Each is pressurized through ducting from its own motor-driven blower.

The plant installation was a joint project of Canadian Westinghouse Company Ltd.; Etudes et Recherches Industrielles S.A. of Belgium; and G. M. Gest Contractors Ltd., Montreal. ■ ■ ■

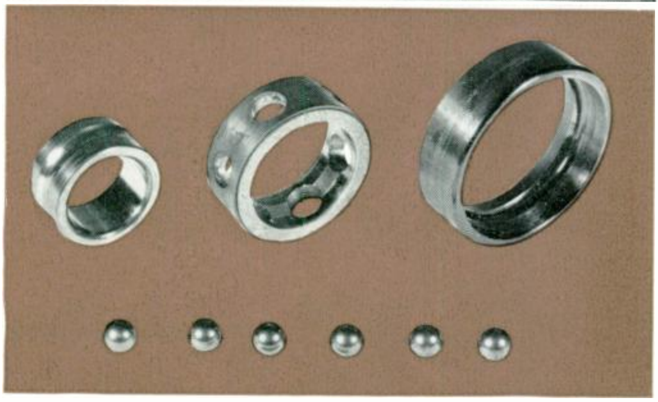
Dry Self-Lubricated Bearings

Dry lubricants and self-lubricating materials are increasingly needed for applications where oil and grease are not satisfactory or will not serve at all. One such application is in bearings for the positioning and actuating equipment of space test chambers, in which space vehicles and components are tested under high vacuum and wide temperature extremes. Conventional lubricants evaporate in vacuum and in high temperatures, and they freeze at low temperatures.

Other potential applications are in vacuum metallurgy facilities and vacuum or inert-gas welding chambers, especially for critical processes in which oil contamination could spoil the work. In the food industries, dry lubricants could prevent oil contamination from processing equipment. They could also serve in unattended machinery and in adverse environments such as radiation and strong oxidizing atmospheres.

To meet these needs, dry lubricants and self-lubricating materials are being screened at the Westinghouse Research Laboratories, and the most promising are being evaluated in ball-bearing tests. The studies have established the effectiveness of a dry lubricating technique called film transfer, in which solid lubricant contained in a bearing component transfers to the other components. At least a year of continuous operation can be achieved, depending on operating conditions.

The approach was based on analysis of the frictional characteristics of ball bearings. Rolling friction between



Above This full-scale model of a central control station is the nerve center of a unified control system for a ship's engine room.

Center Components of a self-lubricated bearing of 20-mm bore size are in excellent condition after 100 hours operation under high vacuum, load, and elevated temperature.

Below A Westinghouse Prodac automatic control system operates the new 56-inch semicontinuous hot strip mill at the Midland, Pennsylvania, works of the Crucible Steel Company of America. Scheduling is initiated by a punched card read into the system. The control system then delivers a slab or ingot to the universal roughing mill seen here. Mill and table speeds, table selection, and screwdown settings are calculated and set by an on-line computer in the system. Mill and table reversal are initiated by signals from hot-metal detectors. The control system operates electrical and mechanical equipment at its optimum capacity and eliminates the effects of human fatigue and error.

Besides operating the roughing mill, the control system displays schedule information to the finishing mill operator. Automatic gauge control maintains accurate strip thickness. Mill operation, from furnace to coil delivery conveyor, is continuously scanned and recorded to provide management with instantaneous data on tonnage, yield, gauge, temperature, downtime, schedule numbers, and order numbers.

balls and races is negligible, even in unlubricated bearings. However, sliding friction occurs between the ball surfaces and the cage, or retainer, that holds the balls in place and also between the cage and other bearing parts. It is this friction that causes heating, wear, and failure.

The most successful way of employing film transfer has been to make the cage itself of a lubricating material. One experimental type of cage is made of a reinforced plastic that has lubricating properties and is also impregnated with a dry lubricant such as molybdenum disulfide. Polytetrafluoroethylene (PTFE) is one of the most successful plastic materials. Another type of cage is formed from a metal matrix impregnated with dry lubricants.

A thin dry lubricating film transfers from the cage to other bearing components, preventing disastrous metal-to-metal contact. The cage maintains this film by metering lubricant to the metal surfaces throughout the bearing's useful life.

Bearings with PTFE-base cages have demonstrated a minimum useful life of 10,000 hours of continuous operation, under a 70-pound load at 6800 rpm and 40 degrees C. Load-carrying capacity is high—bearings have survived 800 hours of operation under a 280-pound load at 600 rpm with no indication of frictional heating or excessive wear. Under high vacuum (10^{-6} mm Hg), these bearings operate for at least 1500 hours at 70 degrees C and a 10-pound load.

Bearings with metal-matrix cages have higher temperature capabilities. One of these, using a silver-matrix cage filled with PTFE and tungsten diselenide, was operated at 200 degrees C and 1800 rpm for 100 hours at a pressure of 10^{-7} mm Hg, 75-pound radial load, and 5-pound axial load. Weight loss from the cage was only 0.05 percent, no wear could be found on other components, and bearing life under these conditions was estimated at 1000 hours. (See photograph at left.)

The film-transfer lubrication technique is applicable to gears, roller bearings, and sleeve bearings as well as to ball bearings. ■ ■ ■

Central Control for Ship's Engine Room

A unified control system for a ship's engine room is being developed by Westinghouse. The system will make power plant operation simpler and more reliable through improved control range and response and provision of central remote control and information display.

The main console and an auxiliary control board at the system's central control station contain startup and operating controls for the main propulsion unit, electric generating system, steam generating system, and selected auxiliary systems. Continuous displays, selective displays, and alarm annunciators monitor important power plant parameters, and operating data are recorded automatically at specified intervals for operator evaluation. A datalogging system periodically scans and logs variables to provide a continuous plant performance record.

Telephones provide communication with the ship's bridge and other areas and electrical ties permit direct control of the propulsion unit from the bridge. Sound monitors permit the operator to listen to selected machinery; closed-circuit television enables him to view engine room areas that are not directly visible from the control station.

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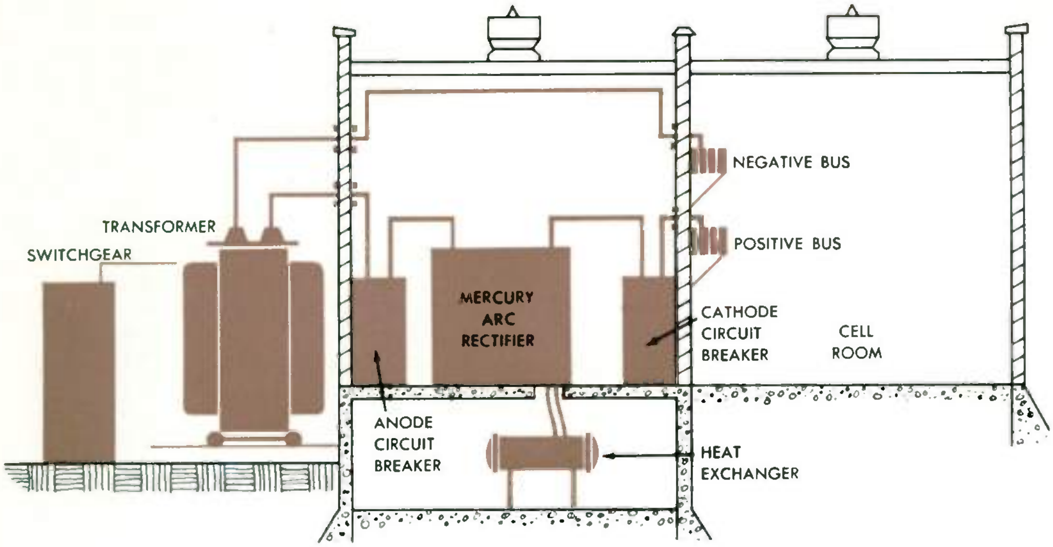

Section view of a mercury-arc rectifier station for electro-chemical service. The need for continuous service and maintenance, considerable switchgear requirements, and liquid cooling requirements for the rectifier made this arrangement the most practical.

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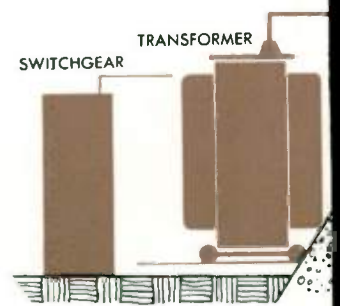

The Rectoformer

A new design approach leads to simpler rectifier installations.

D. K. Barnes Power Transformer Engineering, Westinghouse Electric Corporation, Sharon, Pennsylvania

A. P. Colaiaco Rectifier Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

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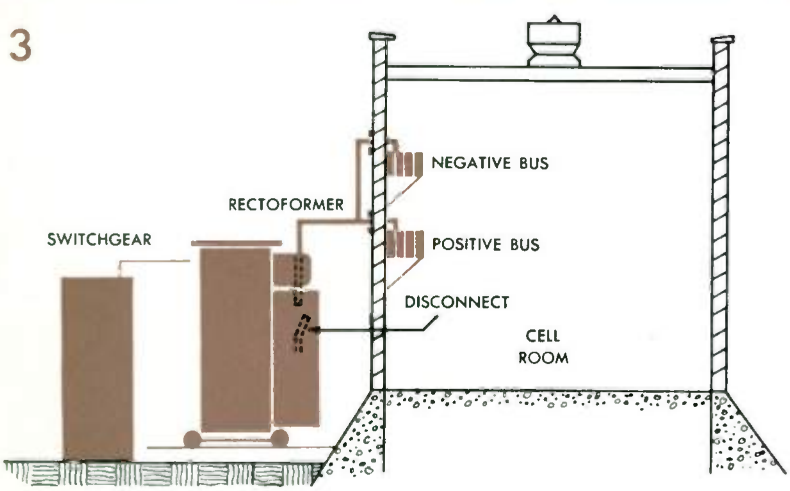


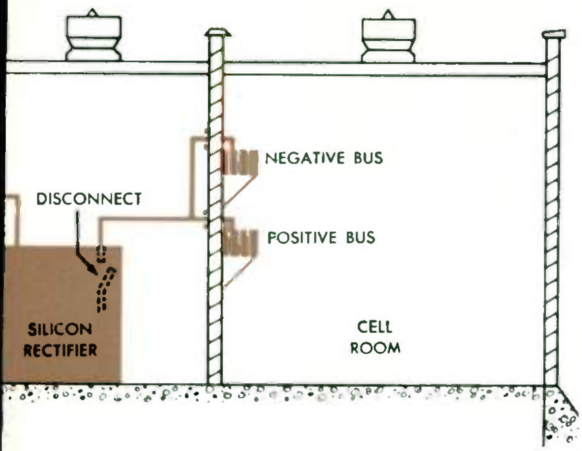
The simplicity of a rectifier station using the Rectoformer is illustrated by this section view.

Historically, large rectifier stations have been designed with ac switchgear and transformers outdoors and the rectifier apparatus and associated switchgear indoors in a building specially provided for that purpose. This arrangement has accommodated many types of basic rectifying elements—motor-generator sets, rotary converters, mercury-arc rectifiers, mechanical rectifiers, germanium and now silicon rectifiers. A typical arrangement (with mercury-arc rectifiers) is shown in Fig. 1.

However, in the past few years, the silicon rectifier has made obsolete all other forms of rectification for large installations and many small ones. The reduced amount of auxiliary equipment needed with silicon rectifiers has resulted in a number of installation innovations, such as shown in Fig. 2. These examples illustrate the flexibility of design permitted by silicon rectifiers, and are indicative of the evolution in cubicle and plant design. The Rectoformer, with transformer and rectifier built as a single unit, is the latest step in this evolution.

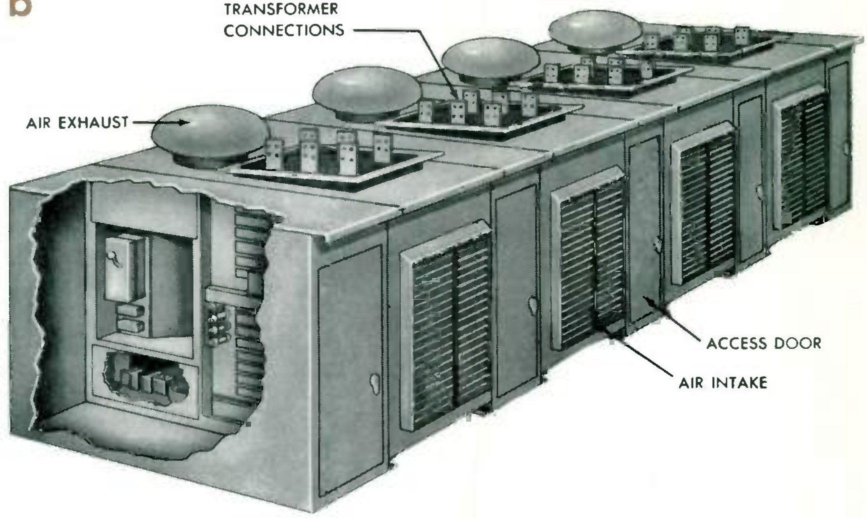
The Rectoformer

The Rectoformer is an engineered merger of rectifier and transformer into a single, self-contained unit. This new approach to large rectifier installations, made practical by the silicon rectifier, provides the user with a



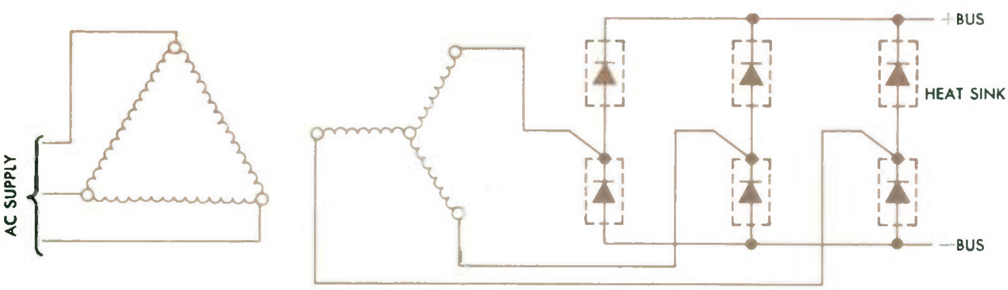
The reduced amount of equipment required by silicon rectifiers is illustrated by a section view of a silicon-rectifier station.

b

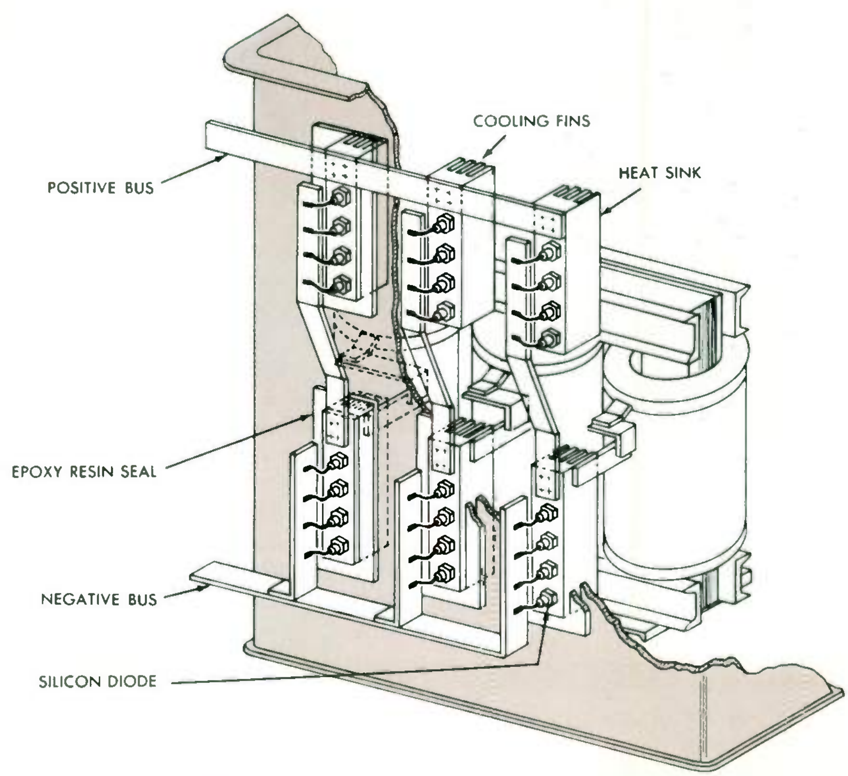


A 500-volt dc silicon rectifier for outdoor service consists of individual air-cooled rectifier cubicles (5000 amperes per cubicle) with enclosed aisle spaces between cubicles.

4a



b



a Diagram of a six-phase, double-way silicon rectifier.

b Physical arrangement of this connection in the Rectoformer (power fuses, balancing reactors, etc., have been omitted).

number of advantages; the rectifier building is eliminated, installation costs are reduced, interconnecting bus between rectifier and transformer is eliminated, and a separate rectifier cooling system is eliminated.

A rectifier station using the Rectoformer approach is shown in Fig. 3. The physical arrangement within the Rectoformer (for a 6-phase, double-way connection) is shown in Fig. 4. The silicon diodes are mounted on six heat sinks, each comprising a leg of a conventional bridge circuit. The heat sinks are mounted on cast epoxy resin frames, which insulate the heat sinks from the transformer tank wall. With this arrangement, diodes and fuses are readily accessible. The heat sinks transmit heat generated in the silicon diodes to the transformer oil, so that a single cooling system serves both transformer and rectifier. The major advantages of a common cooling system for transformer and rectifier are improved reliability and lower maintenance costs.

The transformer oil is cooled with an oil-to-water (Type OW) heat exchanger, which is located directly above the rectifier heat sinks. By mounting the cooler in the region of hot oil, the thermosiphon flow principle can be applied. Oil cooled in the exchanger is directed through internal vertical channels to the bottom of the tank. This oil then rises, passing through the heat sink fins and the transformer windings. On reaching the top section of the Rectoformer, the oil re-enters the heat exchanger and the cycle is repeated.

Water-cooling of the transformer oil permits the Rectoformer to operate several hours in the event of a water supply failure. Unlike conventional air-cooled or water-cooled rectifiers, which must be shut down immediately on loss of cooling, the temperature of the diodes in the Rectoformer is maintained by the large mass of insulating oil, which has a long thermal time constant. Alarm contacts on the oil thermometer and an alarm actuated by thermostats on the heat sinks give an indication of critical diode temperatures when operating either with or without cooling water.

A complete Rectoformer is shown in Fig. 5. All major components, such as diode paralleling reactors, surge suppressors, dc bus, shunt, and dc disconnects are mounted on the tank. The weatherproof housing is also bolted onto a flange on the tank. The two dc disconnect switches are located behind the vertical dc bus seen on the right.

The Rectoformer, made possible by the versatility of silicon diodes, opens the door to a new era in large rectifier installations. It offers advantages in cost, maintenance, and reliability to the plant design engineer for plant expansion and modernization.

Westinghouse ENGINEER Nov. 1962

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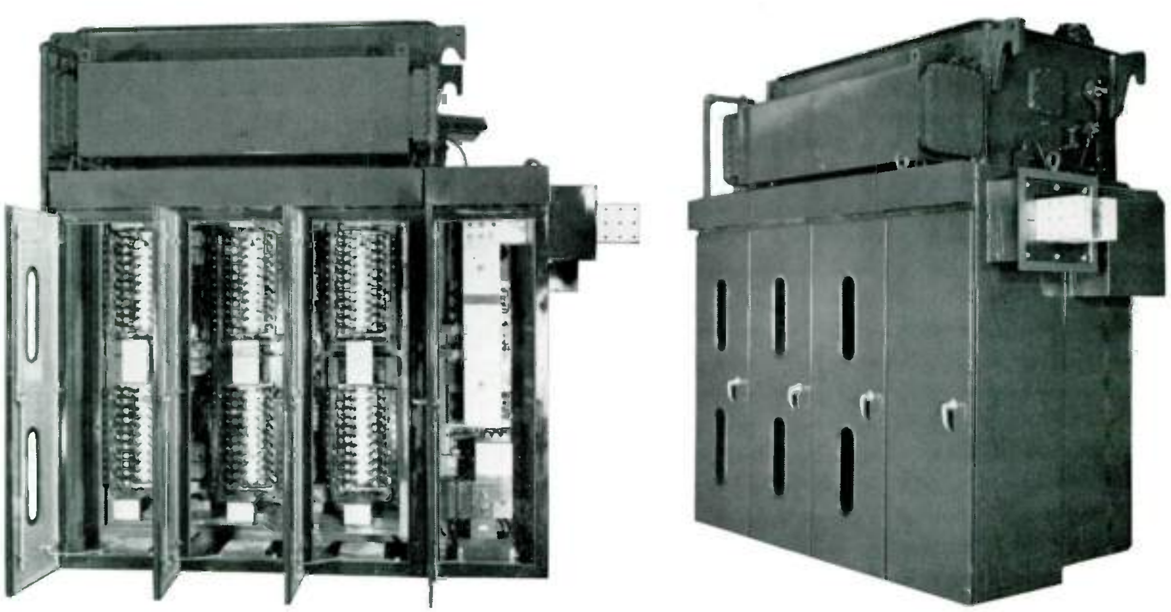

View of Rectoformer, with rectifier compartment open and closed.

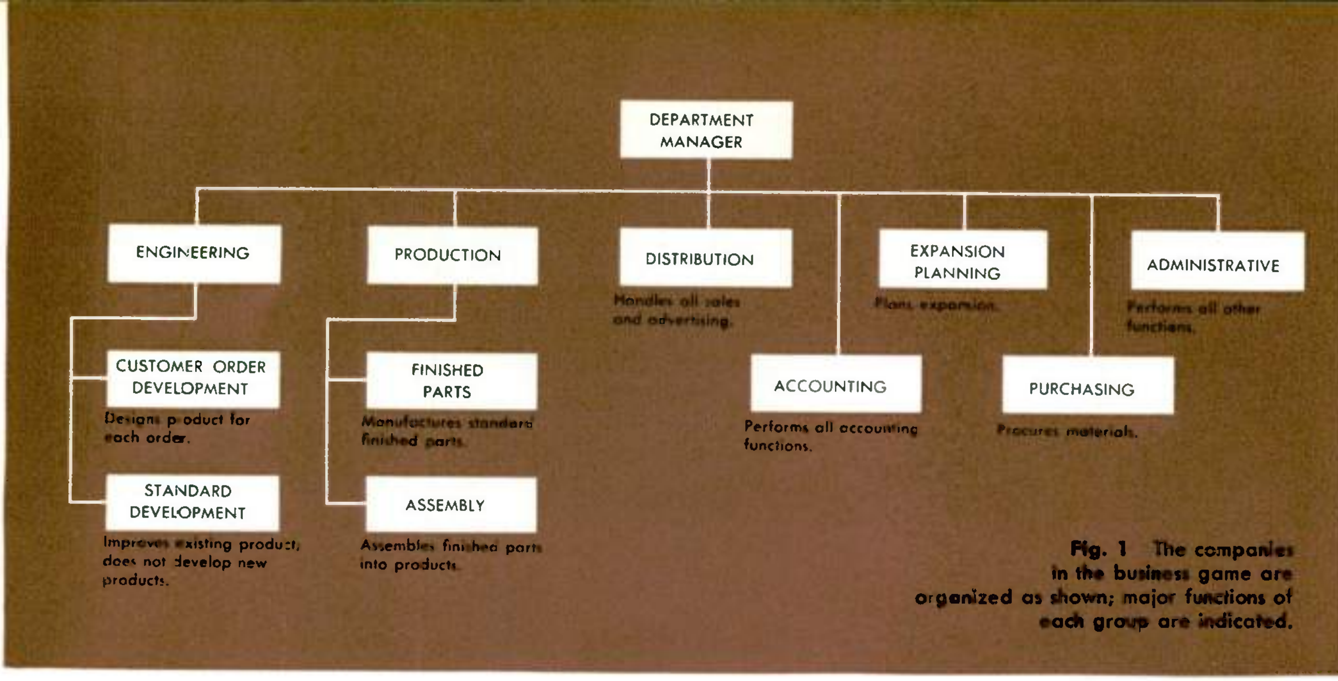

Fig. 1 The companies in the business game are organized as shown; major functions of each group are indicated.

The Business Simulator—A Management Game

Robert H. Davis
Business Systems Department, East Pittsburgh Divisions
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The Business Simulator, used in Westinghouse management training, has proved to be a realistic and useful exercise in management. Several years of operation of a business can be simulated in one day.

Training by simulation is gradually taking a respected place beside more traditional methods. This technique emphasizes active student participation in a realistic situation provided by models of a mechanical, electronic, or pencil-and-paper nature; it is a dynamic case study. Ideally the model responds quickly and appropriately to student actions, providing an excellent situation for learning. During the past few years models have been constructed to simulate business operation. Such models are the bases of business games, which are based on the Game Theory, or the study of strategies.

Business games can be divided into two categories. The first includes games built to teach a specific method for dealing with certain problems such as inventory or production control.

The second category includes games that simulate problem situations for which there are no specific well-defined solutions, but only broad principles of approach. Commonly, games of this type have dealt with top management problems. The Business Simulator is such a game, and has been widely used throughout Westinghouse as a management training tool.

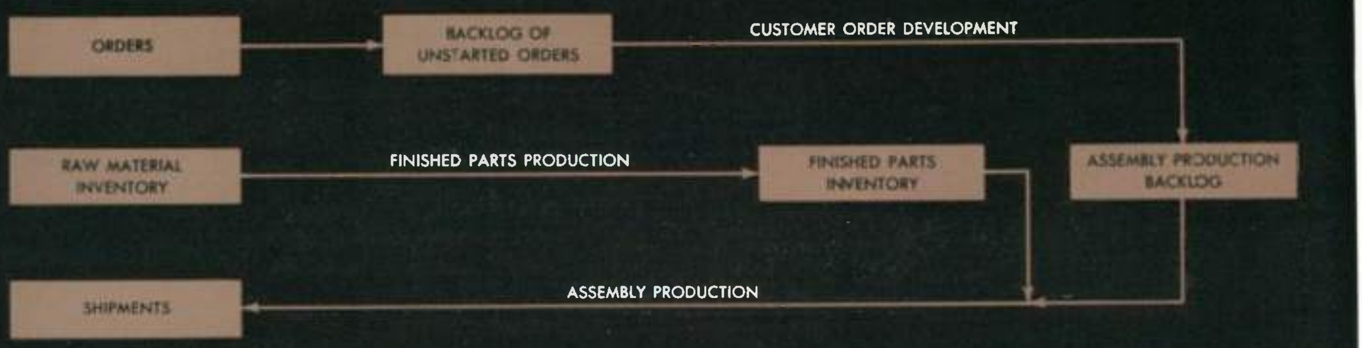
The Business Simulator is a model of a situation in which up to five firms compete in the same capital goods market selling the same fictitious product, "generometers." Each firm is equivalent to a small company, or to a product department of a large company, and produces a single product or product line.

The Business Simulator uses a group of equations which, when given historical data and current operating decisions for each firm, and certain characteristics of the economy, called *quarter constants*, simulates three months of competitive operation. The simulator calculates total industry market, each competitor's share of the market, and the operating details of each firm during the quarter. It updates the historic data and prepares various operating and financial statements for each firm. Teams of players, representing the top managements of the firms, receive these statements at the end of each quarter and make new decisions to control the operation of their firms during the ensuing quarter. This simulation cycle can be repeated as many times as desired.

To provide results quickly, and thereby make it possible to simulate several years of operation in one day, a computer makes all calculations and edits the reports. Results are available about fifteen minutes after operating decisions are made.

The way in which the Business Simulator reacts is determined by 43 control parameters. By using different values of these parameters, different industry segments can be simulated. Different values also can change the emphasis of play without changing the industry segment being simulated; that is, the relative importance of the decision areas may be changed, and the need for some decisions may be removed. This permits the level of play to be adjusted according to the experience of the participants, and to be increased as they become more familiar with the situation.

2



Organization and Operation of the Firms

The firms, although not as detailed as in real life, do include most of the major functions of a real company. Since the Business Simulator is a top management simulation, only major decisions are required of the participants. The Business Simulator automatically handles the minor decisions. The salient functions of the firms are shown in Fig. 1.

Consider now the flow of orders from their origination through shipment, shown in Fig. 2. The orders received each quarter are assumed to arrive evenly throughout the quarter, the same number being received on each of the 65 working days. A typical quarter's sales for a firm is 9000 generometers at an average price of $1800. These orders move into the customer order development section as soon as received. If this section, which can work up to 20 percent overtime if necessary, cannot handle the orders as fast as they are received, a backlog of unstarted orders builds up.

If an increase in plant capacity is planned, the customer order development section will undergo a comparable increase in capacity three months before assembly production; that is, customer order development capacity leads assembly production capacity by one quarter when assembly production capacity increases. Customer order development also leads a decrease in capacity, but cannot cut its staff more than 5 percent per quarter.

The time for completion of engineering work varies among the companies, but runs from 30 to 50 days. The orders are then ready for assembly production, which will be started as soon as possible provided there is a sufficient supply of finished parts. The assembly production section cannot work more than 20 percent overtime, nor can it start production on more than the authorized number of units (a decision) during the quarter. Thus, orders can pile up in the assembly production backlog.

The time required to assemble one product is the manufacturing time, usually from 35 to 55 days. The sum of this and the time required to do the engineering is the processing time. The actual lead time less the processing time is the average time spent in backlogs.

Material is measured throughout in units of finished product, i.e., a unit of raw material is the amount needed to make a unit of finished parts, which is the amount needed to make a unit of finished product. All direct material, (raw material, bought outside, etc.), enters as raw material into the raw material inventory. Material is automatically ordered and the raw material inventory kept at a reasonable level. Material for finished parts production is withdrawn from the raw material inventory as needed and made into standard finished parts. (For simplicity no elapsed time is required to do this.) One sixty-fifth of the quarter's production of finished parts is produced and put into finished parts inventory each day. There the finished parts are stored until withdrawn for assembly into units of finished product. The material is carried as *work in process inventory* until assembly is complete. Then it is immediately shipped, and billed.

Cash is received from sale of product and reduction in plant and equipment. It is expended for raw material, direct labor, factory overhead, standard development, customer order development, distribution, administrative and general costs, and taxes. The terms for purchase and billings are "net in 30 days"; therefore, *accounts payable* and *accounts receivable* are one-third of purchases and billings respectively.

Market Determination

The Business Simulator, when determining the size of the total market available to the firms, considers current economic conditions, and the price, quoted lead time, distribution budget, reliability, and product quality of each of the competitors. The economic conditions are controlled by an umpire; the other factors are controlled by the firms. The total industry market is decreased by an increase in the average industry price or quoted lead time; it is increased by an increase in the average industry distribution budget, reliability, or product quality. Improved economic conditions also increase the total market. The above factors, except current economic conditions, are also used to determine each firm's share of the total market. Reliability is a measure of a firm's past performance in meeting quoted lead times. Product quality is explained under "Standard Development Budget".

Decisions are made by each firm at the start of each quarter to control the operation of the firm during the quarter. The form on which the decisions are entered is shown in Fig. 3. A general discussion of the decisions follows. The interactions of the decisions and other major factors are shown in Fig. 4.

Fig. 2 The key steps in the flow of orders.

Fig. 3 Participants enter their decisions on this form.

Fig. 4 The interactions that take place in the game are indicated here. Players make decisions on those factors shown in black on the diagram.

3

BUSINESS SIMULATOR DECISIONS

Year ________ , Quarter ______

I. Firm Number 0 0 ☐
Standard development budget this quarter ($) 1
Distribution budget this quarter ($)
Desired cost reduction this quarter (%) 0 2
Desired expense reduction this quarter (%)
Plant expansion (% of Plant Capacity)
Plant decrease (% of Plant Capacity)
Maximum authorized assembly production this quarter (units) 3
Maximum authorized finished parts production this quarter (units)
Desired ending finished parts inventory (units) 4
Price of product ($ per unit)
Quoted lead time (working days) 5

II. Production levels for determination of next year's standards. (Enter in fourth quarter only.)
Normal finished parts production (units)
Minimum finished parts production (units) 6
Normal assembly production (units)
Minimum assembly production (units) 7

III. Multipliers to adjust ensuing year's standards. (Enter in first quarter decisions only)
Finished parts production labor rate
Assembly production labor rate
Raw material unit cost
Finished parts production expense rate 6
Assembly production expense rate (ZF) 7

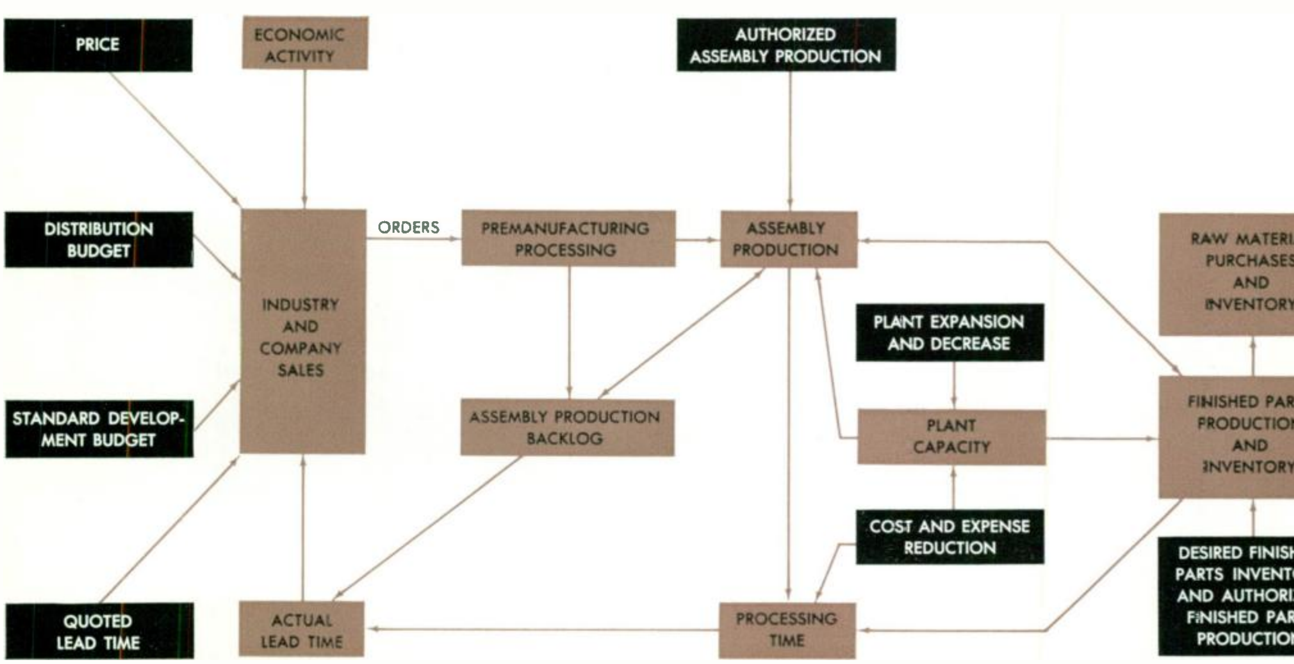
Decisions Made Each Quarter

Standard Development Budget is the amount to be spent on standard development during the quarter. Standard development improves the product. This improvement is not felt immediately; because of the developmental time required there is a lag of one or more quarters.

Distribution Budget is the total amount to be spent during the quarter on advertising and sales promotion. It has a diminishing return effect on sales volume so that doubling the distribution budget will not double sales, other factors remaining unchanged. Past distribution budgets also affect sales, but to a lesser degree.

Desired Cost Reduction is the percentage reduction in costs desired by the end of the quarter. Cost reductions are made in direct labor and material. The reductions actually obtained will vary throughout the organization and will depend on the amount of slack which has crept in since reductions were last made, and on the amount of reduction requested.

Desired Expense Reduction is the percentage reduction in expense desired by the end of the quarter. Expense reductions are made in factory overhead, customer order development, and administrative expenses. The actual reductions vary in a manner similar to cost reductions.



4

BUSINESS SIMULATOR — BALANCE SHEET — FIRM 1, 1958, QUARTER 4

CURRENT ASSETS:				
CASH		$	7,489,000	
ACCOUNTS RECEIVABLE			4,824,000	
INVENTORY (AT WDC)	12,427,000			
LESS LIFO RESERVE $	14,000		12,413,000	24,726,000
FIXED ASSETS:				
PLANT AND EQUIPMENT		$	12,800,000	
LESS: RESERVE FOR DEPRECIATION			8,320,000	4,480,000
TOTAL ASSETS			$	29,206,000

CURRENT LIABILITIES:			
ACCOUNTS PAYABLE	$	2,124,600	
NOTE PAYABLE		---	
ACCRUED TAX LIABILITY		1,608,300	3,732,900
CAPITAL:			
CAPITAL STOCK	$	25,473,000	
EARNED SURPLUS		---	25,473,000
TOTAL LIABILITIES PLUS CAPITAL		$	29,206,000

STATEMENT OF OPERATIONS

				UNITS OR $ PER UNIT
ORDERS ENTERED	$	16,140,000	U	9,000
ORDERS UNFILLED		22,774,000		12,699
GROSS SALES BILLED	$	14,472,000		8,070
MANUFACTURING COST		10,183,000	$/U	1,261.80
ENGINEERING COST		1,499,400		185.80
DISTRIBUTION COST		1,300,000		161.09
ADMINISTRATIVE & GENERAL COST		489,610		60.67
OPERATING PROFIT	$	1,000,000		123.92
TAXES		558,600		
NET PROFIT	$	441,400		54.70

COST BREAKDOWN

PROD. LABOR AT STANDARD	$	1,434,700	
DIRECT MATL. AT STANDARD		6,276,600	
FACTORY EXPENSE AT STANDARD		2,134,000	
TOTAL W.D.C.	$	9,845,300	1,220.00
VARIANCE-PRODUCTIVE LABOR		23,737	
-DIRECT MATERIAL	-	2,541	
-FACTORY EXP-BUDGET		11,700	
-VOLUME		144,300	
DEPRECIATION		160,000	
TOTAL MANUFACTURING COST	$	10,183,000	
CUSTOMER ORDER DEVELOPMENT	$	1,299,400	
STANDARD DEVELOPMENT		200,000	
TOTAL ENGINEERING COST	$	1,499,400	
ADMINISTRATIVE EXPENSE	$	489,610	
EXPANSION PLANNING EXPENSE		---	
INTEREST EXPENSE		---	
TOTAL ADMIN. & GENERAL COST	$	489,610	

NEXT YEAR'S STANDARD UNIT COST

		FIN. P. PROD.	ASSEM. PROD.
DIRECT LABOR	$	88.86	88.86
FACTORY EXPENSE		132.91	134.23
STANDARD RAW MATL. UNIT COST		777.47	

INDUSTRY DATA

FIRM	PRICE	QLT	%MKT	FIRM	PRICE	QLT	%MKT
1	1,793	85	20	2	1,793	85	20
3	1,793	85	20	4	1,793	85	20
5	1,793	85	20				

TOTAL INDUSTRY MARKET 45,000 POT. % OF MARKET 20

CASH FLOW STATEMENT

	CASH SOURCE	CASH APPLICATION
CASH		2,807,000
ACCOUNTS RECEIVABLE	2,301,900	
INVENTORY		182,000
PLANT AND EQUIPMENT		---
RESERVE FOR DEPRECIATION	160,000	
ACCOUNTS PAYABLE	330,600	
NOTE PAYABLE		---
ACCRUED TAX LIABILITY		245,600
CAPITAL STOCK		---
EARNED SURPLUS	442,100	

PRODUCTION STATEMENT

	UNITS	DIRECT LABOR $ PER UNIT	FACTORY EXP $ PER UNIT
FINISHED PARTS PROD.	8,318	90.21	140.25
ASSEMBLY PRODUCTION	8,070	90.45	143.10
PLANT CAPACITY NEXT QTR.	9,000		
ACTUAL LEAD TIME (DAYS)	96		
PROCESSING TIME (DAYS)	96		
RAW MATL. PURC. (UNITS)	8,198	(AT $/UNIT)	777.47

INVENTORY STATEMENT

	DOLLAR VALUE	UNITS	MONTHS SUP.
RAW MATERIAL	2,239,300	2,880	1.04
FINISHED PARTS	2,997,400	3,000	1.08
WORK IN PROCESS	7,190,700	6,473	

COST AND EXPENSE REDUCTIONS

COST REDUCTION IN DIRECT LABOR	$	---
COST REDUCTION IN DIRECT MATERIAL		---
EXPENSE REDUCTION IN FACTORY EXPENSE		---
EXPENSE REDUCTION IN CUSTOMER ORDER DEVEL.		---
EXPENSE REDUCTION IN ADMINISTRATIVE EXPENSE		---

BACKLOG ANALYSIS

UNSTARTED ORDERS	---
ORDERS IN PRE-MANUFACTURING PROCESSING	6,226
ASSEMBLY PRODUCTION BACKLOG	---

ESTIMATED CAPITAL REQUIRED FOR A 1% EXPANSION	$	128,000
MAXIMUM DISCRETIONARY BUDGET		8,739,000
INVENTORY CARRYING COST		493,100

There is no central cost and expense reduction function; the reductions are made by the sections concerned. Therefore, a cost reduction in direct labor or an expense reduction in factory overhead expense will cause an increase in factory overhead expense during the quarter in which the reduction was obtained. This is caused by the additional effort required to obtain the reduction. As larger and larger reductions are requested, the cost of obtaining them increases more rapidly than the reductions.

Cost and expense reductions, since they result in a more efficient operation, decrease processing time and increase plant capacity, although there is no change in the physical plant.

Plant Expansion and Decrease are the ordered changes in plant capacity in percent. They result in a proportionate change in the customer order development, production, and administrative facilities in the one existing plant; there is no change in the number of plants. In the case of expansion, the additional facilities, except customer order development, will be available for use six months after the expansion is ordered. Planning expenses occur in the same quarter as the order, and capital expenditures in the following quarter.

As was mentioned previously, the customer order development section's capacity increases three months earlier than that of the other functions.

When a decrease is ordered it does not become effective until the end of the quarter in which it was ordered; the portion being eliminated is available for use during the quarter. The capital recovery is less than the portion of book value represented by the decrease, thus resulting in a net loss. Both expansion and decrease may be ordered in the same quarter.

Maximum Authorized Assembly Production is the maximum number of units that can be started in assembly production during the quarter.

The number actually started is limited by the 20 percent overtime restriction, the number of orders whose engineering will be completed by the end of the quarter, and the finished parts inventory plus finished parts production. Assembly production starts are assumed to be distributed evenly throughout the quarter.

Maximum Authorized Finished Parts Production and Desired Finished Parts Inventory. Finished parts production (measured in units of finished product) is adjusted to yield the desired finished parts inventory at the end of the quarter, considering withdrawals for assembly production. However, it can be no greater than maximum authorized finished parts production, nor require more than 20 percent overtime.

Price and Quoted Lead Time. Any values may be selected for price and quoted lead time. They both affect sales; high values decrease sales and low values increase them. All the sales obtained in a quarter are billed at that quarter's price, even though they may not be billed until some future quarter. Quoting short lead times to boost sales and then failing to meet them results in a lower reliability, which reduces future sales. Quoted lead time is measured in working days (65 working days per quarter).

Section II of Fig. 3 lists those decisions made only at the beginning of the fourth quarter of each year. They are the *production levels* to be used in determining the following year's standard costs.

The first and third entries should be the normal or average production levels per quarter expected during the next year in the respective production sections. The second and fourth entries are the minimum anticipated production levels, in any quarter of the next year. These entries should not be more than 90 percent of their respective normal production levels.

The four levels chosen have no effect on actual costs. They are used by the firm's accounting section in determining the next year's per unit standard costs for labor, material, and factory overhead. These equal actual costs at normal production, providing wage and material rates don't change.

Each fourth quarter report contains the *standard costs* calculated on the basis of the production levels in Section II of the fourth quarter decisions. These standards are in dollars per unit of finished product and apply, as altered below, for the ensuing four quarters. Since these standards are based on costs during the quarter just completed, they can be changed if anticipated costs during the next year are different from those on which the standards were based. This is done by entering multipliers on the appropriate lines of Section III. To increase a standard cost by 15 percent, a multiplier of 1.15 is used; to decrease it by 10 percent, a multiplier of .90; to leave it unchanged, 1.00. The maximum decrease is 10 percent.

Output Statements

A sample of the output is included as Fig. 5. The first of the output statements is the *Balance Sheet*. Most of the entries are self-explanatory, but some warrant comment. It is assumed that payment for all orders is received one month after shipment, so that accounts receivable is one-third of gross sales billed. If, despite careful planning, a firm has insufficient cash to cover its obligations, the bank issues a 90-day, 1½ percent note for the needed amount. Accrued tax liability is approximately the tax due for the past six months, since taxes are paid six months after they are incurred. Capital stock does not change and there are no dividends. Profits accumulate in earned surplus.

The *Statement of Operations* follows the usual profit and loss form.

The *Production Statement* shows the quarter's output of the finished parts and assembly production sections in units, and the actual per unit labor and overhead costs. Actual lead time, in working days, is the average for all orders entered during the quarter. Processing time is the time actually required to complete an order, and equals actual lead time if there are no backlogs. The last line shows the raw material purchases during the quarter and the actual raw material unit cost.

The *Inventory Statement* shows, in addition to dollar value and volume for each inventory, the month's supply at current usage.

Fig. 5 The results of each firm's decisions are given in the form of an output statement, such as the one shown at left. Most parts of this statement are similar to those in most businesses, but further explanation of some of them is given in the text. During the operation of the management course, at the end of each year each firm receives the balance sheets of all other firms in the business game.

HOW WILL ANOTHER DOLLAR SPENT ON DISTRIBUTION AFFECT MY SALES?

This is one of the many questions Business Simulator participants ask themselves because, just as in real life, the relation between distribution expenditures and sales is not specifically known. The participant does, however, have some ideas about the relation. For example, an increase in distribution expenditures usually causes some increase in sales, the amount depending on how much effort was previously being applied.

The Business Simulator is not intended to represent any individual firms or specific markets, but to include the general relationships common to most capital goods, firms, and markets. The Business Simulator relation between sales and distribution expenditures includes both the effect of delay and saturation. Curve *1A* shows the delay. Money spent during one quarter affects sales not only during that quarter, but, to a lesser degree, during future quarters. If the umpire wishes to simulate customers with short memories, he can, by changing a control parameter, get a steeper curve such as *B*. Current sales will then be more dependent on current distribution expenditures. By changing the control parameter in the other direction, the umpire can produce a flatter curve such as C. With this curve, participants would notice less dependence of sales on current distribution expenditures. In all cases the total effect on sales, the area under the curves, is the same; the only difference is the time over which it is spread.

The second effect, saturation, assumes that each additional dollar spent on advertising and sales promotion will contribute less than the previous one. Curve 2 shows this. By changing a second control parameter the umpire can select different members of this family of curves and, in effect, simulate industries whose normal distribution expenditures are higher or lower. A third control parameter permits the umpire to change the sensitivity of sales to distribution expenditures; that is, he can make sales more or less dependent on the distribution expenditures after correction for delay and saturation.

Many other such nonlinear relations are included in the model. Several examples are the effect of standard development expenditures on product quality, the effect of past delivery performance on reliability, and the effect of the level of finished parts inventory on time required for assembly production.

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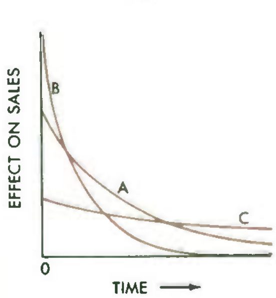

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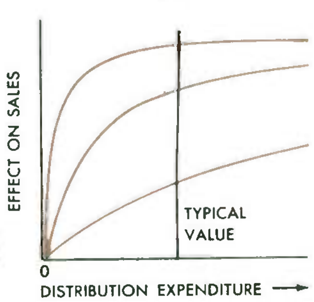


Cost and expense reductions are those obtained during the past quarter. The expense of obtaining the reductions is not deducted; it is included in factory overhead, administrative, and customer order development expenses. The reductions are permanent, but as time passes costs and expenses tend to increase.

Estimated capital required for a one percent expansion is included as an aid in planning expansion, which must be financed from cash.

The maximum discretionary budget is the maximum amount which may be spent on distribution and standard development during the next quarter. It is developed from estimated receipts and expenditures for the next quarter, and is based on the fact that a firm may not intentionally borrow.

Inventory carrying costs, for accounting purposes, are included in factory overhead expense. For the sake of information they are also shown separately.

The *Backlog Analysis* shows the distribution of unfilled orders, i.e., all orders received but not billed.

The *Industry Data* report shows the price and lead time (QLT) quoted during the past quarter by each firm. At the end of the fourth quarter it also shows the percent of the year's sales made by each firm. The last line shows the total market available during the quarter and the firm's sales in percent.

At the end of each year each firm receives the balance sheets of the other firms.

Application

Generally all five firms are used in an exercise. When small teams are desired in a large group, two games are run simultaneously. In this case one game usually has a rising economy and the other a falling one.

A typical exercise is conducted as follows. In preparation each student is given a booklet explaining the model, but not the specific internal relations, which he studies prior to the start of the course that the game is being used in conjunction with. On the evening before the start of the exercise two to three hours are devoted to review and clarification of the model, assignment of teams, and distribution and discussion of specific information on the characteristics of the firms.

On the day of the exercise approximately forty-five minutes are allowed for preparation of the first set of decisions. As the exercise progresses the time allotted for preparation of decisions is gradually decreased to about twenty minutes. Approximately fifteen minutes are required to process the input information, make the computer run, prepare the output reports, and return them to the participants. Six to eight quarters are usually simulated. Finally, after a short preparation period a critique is held in which each team explains to the other teams its approach to the operation of its firm and the results of this approach, and appraises its performance.

In the past three years approximately 900 members of Westinghouse management have participated in Business Simulator exercises. Six hundred and thirty have participated as part of the two continuing middle management programs; special corporate programs and divisional programs have accounted for the remainder of the participants.

ABOUT THE AUTHORS

Roger J. Coe and **R. J. Creagan**, the coauthors of the article about the Yankee plant, represent long experience in their respective fields, Coe in the electric utility field and Creagan in nuclear engineering.

Coe is an electrical engineering graduate of Cornell University, in 1925, and joined the New England Electric System in 1926. Since that time he has served with affiliated companies of that system in various engineering and operating positions. He was named a vice president of the New England Power Company in 1955, and a vice president of Yankee Atomic Power Company in 1956. He has been in charge of Yankee's technical and engineering activities since the beginning of the project. In addition, Coe also plays a role in atomic studies and programs for the New England Electric System.

Creagan, who appeared in these pages in the March issue as author of an article on water reactors, is engineering manager for the Westinghouse Atomic Power Division. A graduate of Illinois Institute of Technology in 1942, Creagan worked at the Argonne National Laboratory, earned his Ph.D. from Yale, then joined Westinghouse. He has participated in several major nuclear projects, including the *Nautilus*.

K. A. Oplinger has been working with control systems, and their components and transducers, ever since he joined the Research Laboratories in 1928. One of his first assignments was development of electromechanical components for recording and reproducing sound on 35-mm motion picture film. He has also conducted fundamental work in feedback control systems, gyro stabilization, watthour meters, inertial guidance systems and other gyroscopic devices, and elevator control systems. He supervised development and flight tests of the first automatic pilot using three rate gyros to permit unlimited maneuvering.

Oplinger received his B.S. degree in electrical engineering at Purdue University in 1922. He then served on the Purdue faculty while doing graduate work, and he received his E.E. degree in 1927. He is now an advisory engineer in the Control Systems Department at the Research Laboratories. He is an AIEE Fellow and a member of the American Physical Society.

L. A. Bobula earned his B.S. degree in electrical engineering at Case Institute of Technology in 1940 and immediately joined Westinghouse on the Graduate Student Course. He was assigned to the Research Laboratories and is now a fellow engineer in the Control Systems Department. He has contributed to the development of servo generators, shipboard stable-element electronic apparatus, an accelerometer for elevator measurements, transducers for elevator control, boiler level controls, an infrared length gauge for steel mills, and other special sensing devices.

A. O. Lund graduated from the University of Wisconsin in 1934 with a B.S. degree in electrical engineering and then took graduate work at Stevens Institute of Technology. He joined Westinghouse on the Graduate Student Course in 1936 and was assigned to the Westinghouse Electric Elevator Company (now the Elevator Division) in the mechanical design section. He served later in electrical design and is now a fellow engineer engaged in development of motor control systems. Lund's primary interests are in feedback control and solid-state components, and he helped develop the elevator control system described in this issue.

W. M. Ostrander joined Westinghouse on the graduate student course in 1940 after graduation from the Polytechnic Institute of Brooklyn with a B.E.E. degree. He was assigned to the Lighting Division and then served in the U. S. Navy from 1942 to 1945. After the war, he transferred to the Elevator Division. Ostrander has contributed to development of improved Rototrol systems for geared elevators, controlled stopping for single-speed ac elevators, and other elevator control systems including the one described in this issue. He is presently a senior engineer in the electrical development section.

W. L. Wright has worked with powerplant designs ranging from turbojet aircraft engines to the precise-power generating equipment described in this issue. He joined Westinghouse on the Graduate Student Course in 1947 after receiving his B.S. in mechanical engineering from the University of California. His first assignment was as a design engineer in the Transportation Engineering Department, where he worked with diesel, electric, and gas-turbine locomotives. He moved to the Engineering and Service Department in 1951, working with the experimental Westinghouse gas-turbine locomotive and diesel-electric locomotives.

Wright transferred to the Aviation Gas Turbine Division in 1954, where he helped design and develop turbojet engines. He served for a year as Westinghouse resident representative at Rolls-Royce Ltd., Derby, England, coordinating interchange of technical information under an agreement between the two companies. Since 1960, he has been a senior engineer in the Public Works Province, Industrial Systems. He is responsible for systems engineering projects in precise-power diesel, turbine, and atomic generating systems.

P. R. Dax was born in England in 1921, educated in France until 1940, when he went on a six-year tour of duty with the British Navy. He obtained a B.Sc. (Engineering) degree from London University in 1949. After seven years service with the Admiralty in Royal Naval Scientific Service, Dax joined the Westinghouse Electronics Division in 1957 as a Fellow Engineer in the radar subdivision. In 1960, he was made an Advisory Engineer in charge of the system development and analytical section in the radar subdivision. Dax recently obtained a one-year leave of absence from Westinghouse to serve with MITRE in Europe.

A. P. Colaiaco makes his third appearance on these pages, for the second time to discuss the silicon rectifier. A graduate of Penn State (BSEE, 1942), Colaiaco came with Westinghouse on the Graduate Student Course. He began working with silicon rectifiers in 1952 when the semiconductor first appeared suitable for power devices. Colaiaco is presently manager of the Rectifier Engineering Section, which includes both semiconductor and mercury arc rectifiers.

D. K. Barnes, who joins Colaiaco in describing the Rectoformer, is a graduate of Lehigh University (BSEE, 1951). Barnes came with Westinghouse on the Graduate Student Course, and in 1952, was assigned to the Transformer Division. He has worked primarily on the design of core form power transformers and rectifier transformers. His transformer design work was temporarily interrupted from 1954 until 1957 while he served in the U. S. Navy.

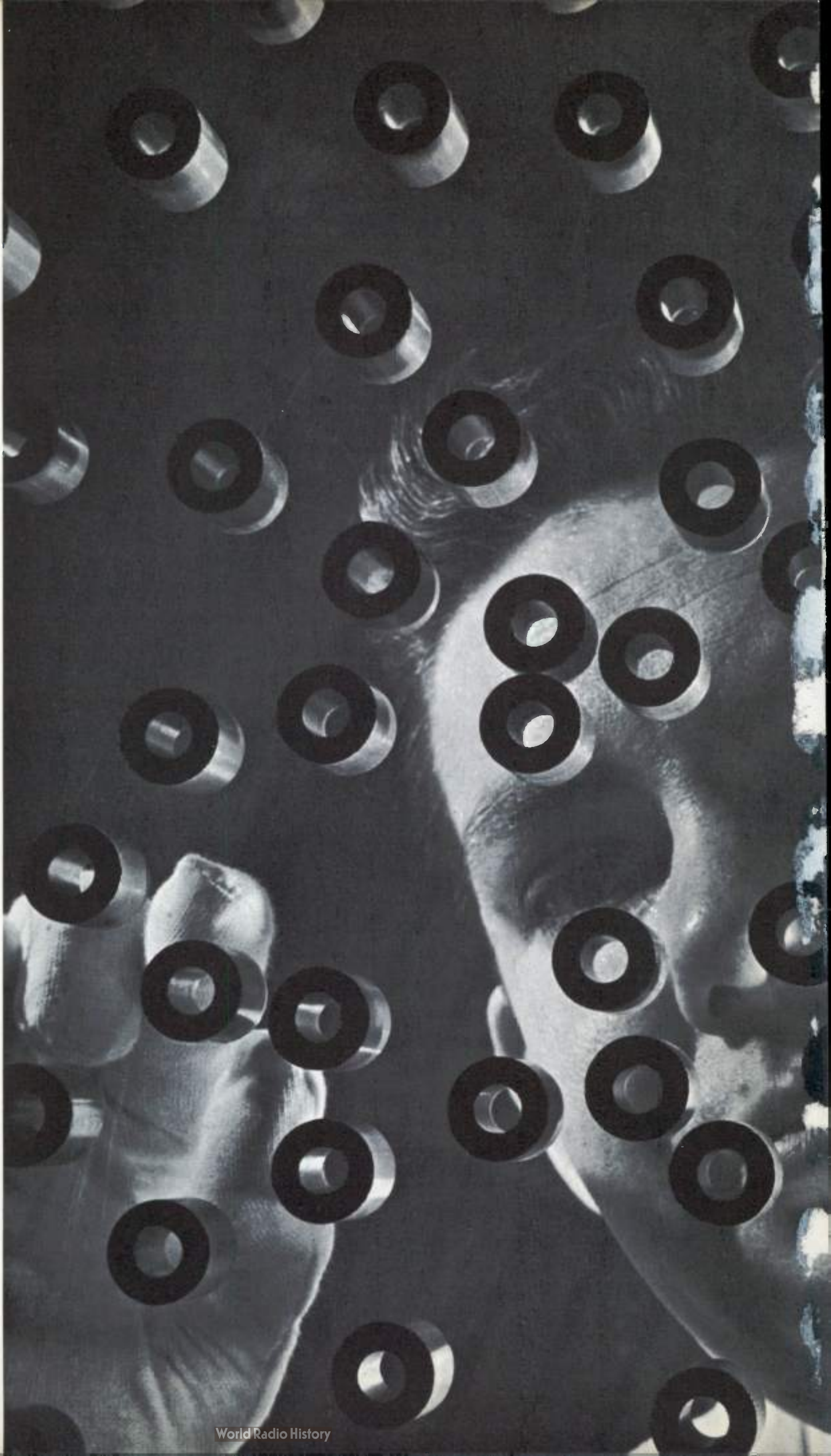
Robert H. Davis has concentrated on computers since he first joined Westinghouse in 1955. A graduate of the University of Pittsburgh, where he earned his BS in electrical engineering, he had hardly settled in his job when the call to military service came along. He spent the next two years as a Lieutenant in the Corps of Engineers, and returned to Westinghouse in 1957 in the Operations Research Group in East Pittsburgh. Here he developed the business simulator, described in this issue.

In 1959 Davis became staff assistant to the Director of Engineering. In this capacity he advised engineering staffs on the application of computers in engineering, and helped train engineers in the use of computers.

Early this year, Davis rejoined the Business Systems Department, where he works in Advanced Business Systems. Here his work involves helping product divisions plan business systems, developing systems analysis and planning techniques and similar tasks.

Uranium Pellets

These uranium pellets are for the fuel assemblies that will go into the Atomic Energy Commission's Experimental Gas Cooled Reactor at Oak Ridge Tennessee. Almost 400 000 of these pellets will be encased in stainless steel tubes and fabricated into assemblies. Westinghouse is manufacturing these fuel assemblies for the Union Carbide Corporation.



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