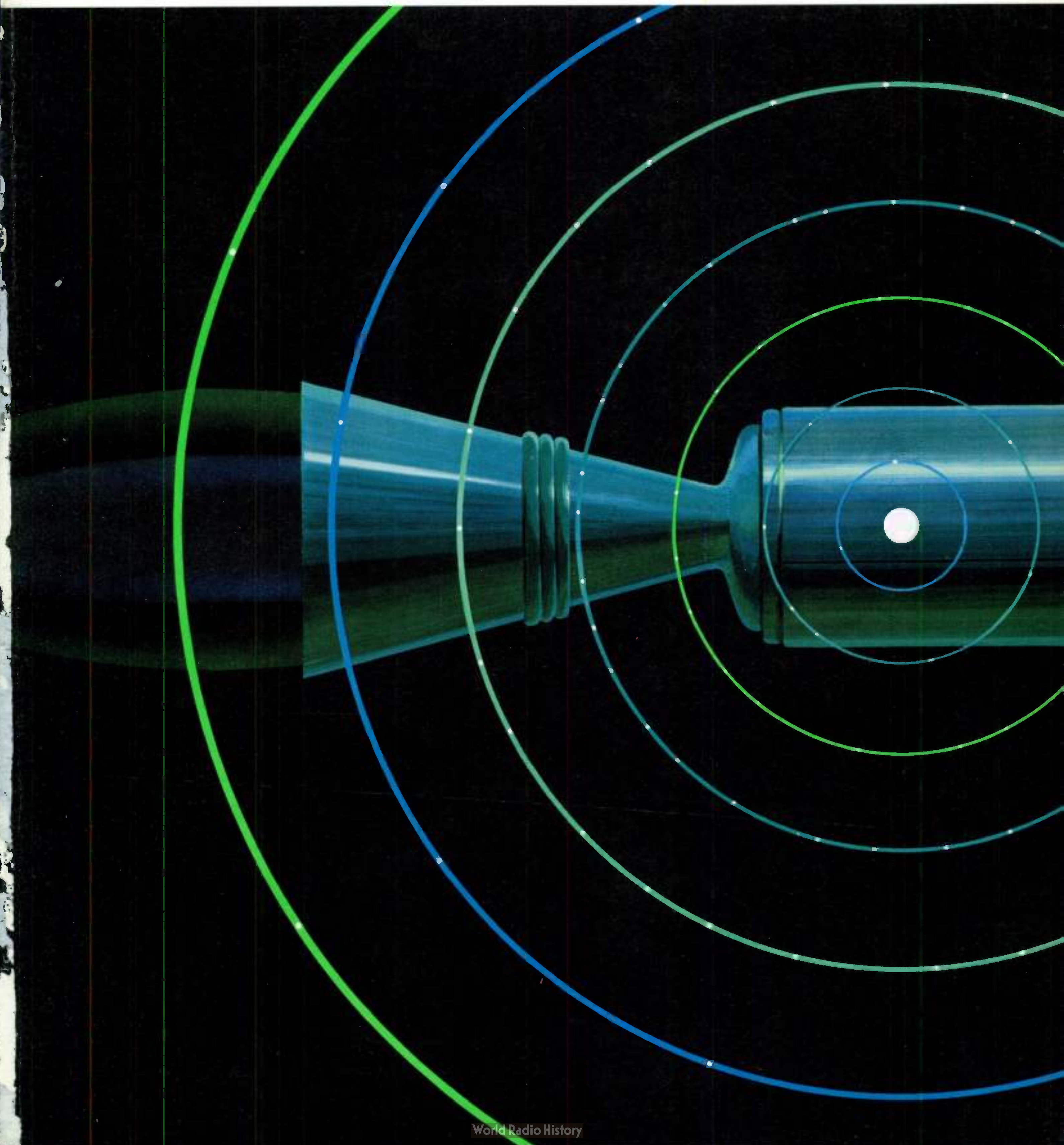
# Westinghouse ENGINEER

May 1965



**Westinghouse ENGINEER**
**May 1965, Volume 25, Number 3**

*Left:* This wintertime view of a section of the steel superstructure for the Westinghouse Transit Expressway in South Park, Pittsburgh, was taken in February, shortly before our copy went to the printer. Bethlehem Steel Company had just completed the fabrication and erection of the steel superstructure for the 9340-foot roadway loop. The concrete roadway runners on which the rubber-tired vehicles will operate are now being poured.

The three lightweight automated vehicles that will operate on the roadway are scheduled for delivery to South Park this month. Once the vehicles are installed, Westinghouse engineers will spend several months gathering engineering data on the new transit system and evaluating its performance.

The purpose of the $5-million project is to determine whether the Transit Expressway can meet the mass transportation needs of urban areas with medium population density throughout the United States. It is being financed by grants of $2,872,000 from the Federal Housing and Home Finance Agency, $886,000 from the Port Authority of Allegheny County, $200,000 from the Pennsylvania State Department of Commerce, and $1,042,000 from Westinghouse and other companies in the area.

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**Cover Design:** Nuclear propulsion in space is the message conveyed by artist Thomas Ruddy on this month's cover, using the now familiar rocket nozzle and a symbolic representation of a uranium atom.

# The NERVA Nuclear Rocket Reactor Program

by W. H. Esselman

*With nuclear rockets, man will have the capability of much longer range space exploration, because of their inherent superiority over chemical rockets. The NERVA program has demonstrated the feasibility of such nuclear rockets.*

While the attention of the nation is now focused on the Apollo first manned lunar landing program, this mission should be envisioned as only the first step in the exploration of space. As the next round of space exploration crystallizes, the high performance of the nuclear rocket engine will assure its application in the advanced missions of the coming decade. Its first use will undoubtedly be as an upper stage of a chemical rocket. A nuclear rocket engine achieves twice as efficient use of each pound of propellant as can be attained with chemical combustion processes. Therefore, if it is substituted for a final stage chemical rocket, it can substantially increase the payloads that can be landed on the moon. In addition, a nuclear rocket engine using existing or planned boosters will permit planetary exploration that would be possible only with very much larger rockets if they were all-chemical. The development of the technology for the first of these nuclear rocket engines is making significant and rapid progress in both the Rover and the NERVA programs. Some of this progress is outlined here.

**Project Rover Reactor Development Chronology**

**1955 to 1959:** Research phase of the program conducted by the Los Alamos Scientific Laboratory.

**1959 to 1961:** Period of full reactor exploratory testing by Los Alamos during which general design methods were established, controls data and materials information were accumulated, fuel element fabrication methods were developed and initial reactor operation was conducted.

**June 1961:** NERVA development team of Aerojet-General Corporation and Westinghouse Electric Corporation selected.

**1962:** Kiwi power test series demonstrated successful reactor startup with liquid hydrogen. In November, tests of the Kiwi B4A, which was the favored design for the NERVA engine, led to the identification of fuel element vibration and structural problems.

**1963:** Year of redesign, analysis, component and subsystem testing, and cold flow tests of Kiwi B4A and Kiwi B4B reactors that demonstrated cause of the vibration and indicated that revised design approaches of Los Alamos and Westinghouse would lead to a stable design.

**Early 1964:** Cold flow tests conducted by Los Alamos on Kiwi B4D and Westinghouse on NRX-A1 indicated that the redesigns avoided the vibration problems.

**May to Sept. 1964:** Major milestones achieved by Los Alamos by the successful power operation of Kiwi B4D and Kiwi B4E which included a restart.

**Sept. to Oct. 1964:** Major milestone achieved in NERVA program by operation of the Westinghouse NRX-A2 reactor at full power and temperature conditions. Restart tests were also conducted.

The unfolding of the U. S. nuclear rocket program, Project Rover, is charted at left from its beginnings at the Los Alamos Scientific Laboratory in 1955, through the entry of industry, to the present successful hot firing phase. Rapid progress was achieved by Los Alamos on the conceptual reactor design and fuel-element development. By 1959, the Kiwi[1] series of reactor tests demonstrated the significant performance and potential of the nuclear rockets and stimulated interest in the development of a flight-type engine. The NERVA (Nuclear Engine for Rocket Vehicle Applications) program was initiated in 1961. This effort, under the direction of the Space Nuclear Propulsion Office of NASA and the AEC, is being performed by the Aerojet-General Corporation as the prime contractor and Westinghouse Electric Corporation as the principal subcontractor with responsibility for the development of the nuclear subsystem, which includes the reactor, shielding, and reactor controls. The Kiwi program was intended to demonstrate feasibility and proof-of-principle of the nuclear rocket reactor. This it has successfully accomplished. Over the past several years, the Kiwi and NERVA reactor programs have been closely coordinated to provide a continuing, logical development program.

In November 1962, progress was interrupted by a vibration problem in the Kiwi B4A test, which required a detailed analysis and component test program to overcome. Recent successes in 1964 have, however, surpassed all objectives, and the understanding of nuclear-rocket technology is now increasing at an accelerated rate.

The present status of the development is amply summarized in the following statement by Harold B. Finger, Manager of the NASA Space Nuclear Propulsion Office, following the successful NRX-A2 test:

"Combined with the Kiwi B4E test run earlier this year by the Los Alamos Scientific Laboratory, this NERVA reactor test is further clear proof that this country has achieved a major advance in rocket propulsion—nuclear rocketry. These tests prove that the nuclear reactor concept is sound and that nuclear rockets can achieve the previously predicted high performance that will be required for future space missions."

The task assigned by the Space Nuclear Propulsion Office (SNPO) to the Westinghouse Astronuclear Laboratory was the development of a reactor system capable of flight operation. These efforts began with a review of the various Los Alamos designs to select the concept most adaptable to the flight environments. A design based on the Kiwi B4A was chosen. The development then proceeded, aimed at achieving a high-performance reactor capable of meeting the high reliability requirements of a flight engine. To accomplish this purpose, concentrated effort was required on the:

1) Structural design of a reactor capable of operating at near liquid hydrogen inlet temperatures and with outlet temperatures of several thousand degrees, coupled with the capa-

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Dr. W. H. Esselman is Deputy Manager, NERVA Project, Astronuclear Laboratories, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

bility of withstanding booster type vibration and shock environments:

2) Fuel-element development to meet the high-temperature corrosion resistance and structural needs of the reactor;

3) Development of a reactor and fuel-element design capable of multiple restarts;

4) Development of nuclear and thermal design procedures that can precisely predict the flow and temperature conditions over this range of conditions;

5) Development of a control system and suitable instrumentation for controlling the reactor;

6) Development of a flight-type engine shield to reduce radiation dosage and heating in the key engine and stage components;

7) Development of facilities and capabilities required to produce fuel elements, assemble reactors, and test both component and full-scale reactors.

Some of these problems were part of the Kiwi development, but special attention was needed for the flight reactor. Before discussing the program aimed at these problems, consider the general operation of a nuclear rocket engine.

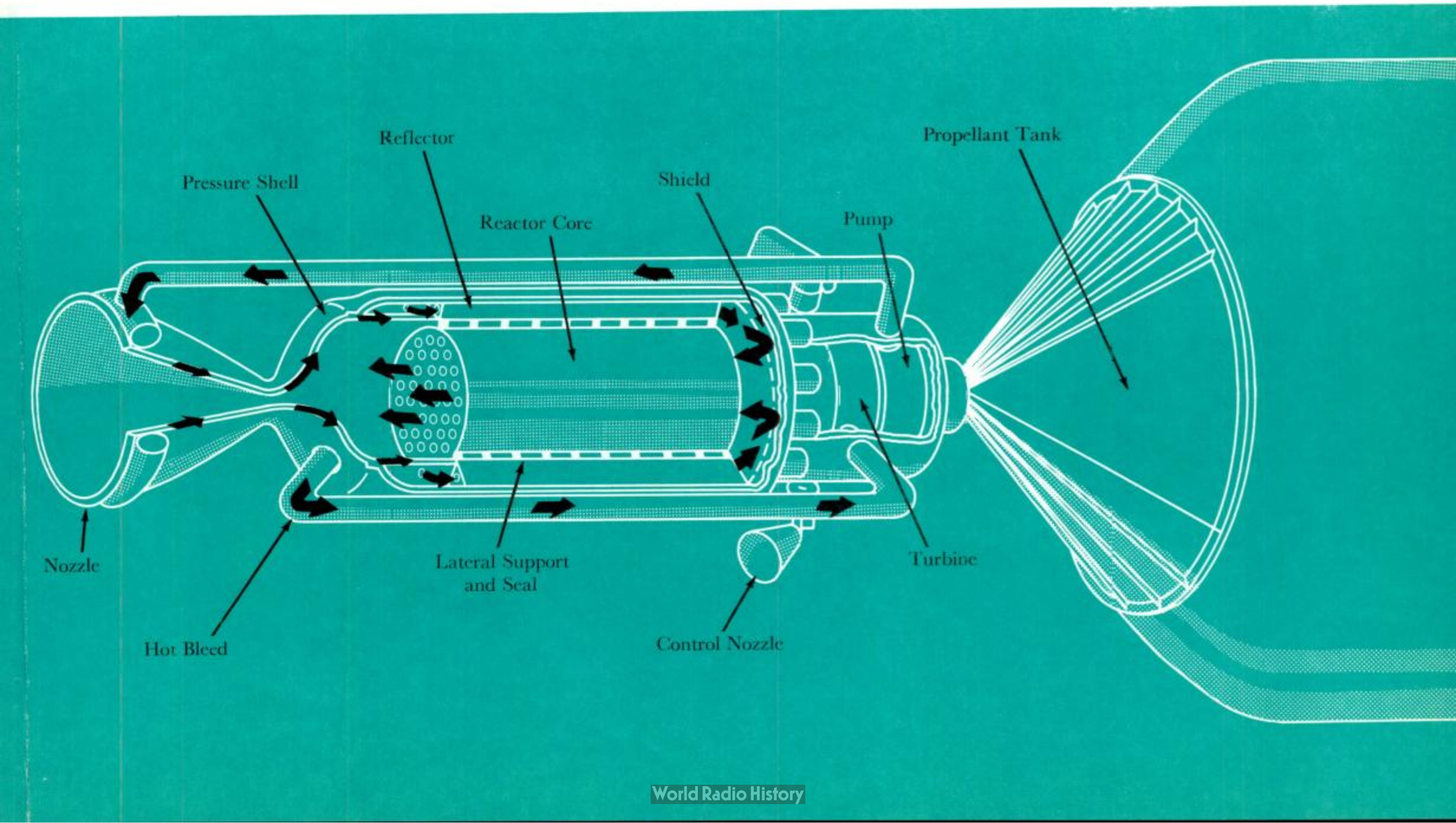
### *How It Works*

A nuclear rocket engine achieves its thrust by heating hydrogen to temperatures in the 3000 to 4000 degree F range and expanding this gas through a nozzle. The operating cycle of a typical nuclear rocket engine is shown in the schematic diagram (Fig. 1).

Liquid hydrogen in the vehicle tank stored at −420 degrees F is pumped to engine operating pressures by a turbopump. The hydrogen then passes through the tubes of a regeneratively cooled nozzle into the core, where it is heated to outlet temperatures. Passing through the nozzle, the hydrogen expands and accelerates to supply the engine thrust needed to push the rocket into space.

The "hot bleed" cycle shown is one in which hot gas from the nozzle is mixed with cold hydrogen, bringing the mixture to a temperature suitable for the turbine drive.

A mockup of the NERVA engine is shown in Fig. 2. The engine, which is 22 feet high from the top flange to the exhaust exit of the nozzle, has a performance goal to provide 50,000 pounds of thrust. The reactor, which is a right circular cylinder approximately 3 feet in diameter by 4 feet high enclosed within the pressure vessel, produces a thermal power of about 1000 mw. The annulus between the reactor core and the pressure vessel is occupied by a beryllium neutron reflector, which contains the reactor control drums. Directly above the inlet end of the reactor is a radiation shield that shadows the engine



**1—Operating cycle of a typical nuclear rocket engine** is shown in this schematic diagram. Thrust is achieved by heating hydrogen to temperatures in the 3000 to 4000 degree F range and expanding this gas through a nozzle.

components, vehicle, and payload, and protects them from excessive radiation doses and heat deposition. Liquid hydrogen passes through the turbopump into the propellant piping and into the regenerative cooling tubes of the nozzle. The spherical tanks supply actuator gas for engine startup.

The hydrogen extracts the heat generated in the reflector by neutron and gamma absorption and attenuation and cools the various parts of the reflector, so that the hydrogen is gaseous when it enters the shield region. After passing through the shield, the hydrogen enters the core. In the core, uranium fuel is dispersed in graphite elements that are pierced by circular propellant channels. The flow through the channels is controlled by orifices to obtain uniform temperature rise across the reactor. The heat generated by the fissioning of the uranium heats the hydrogen to an exit temperature significantly in excess of 3000 degrees F.

A primary measure of the performance of a rocket engine is given by its specific impulse ($I_{SP}$). Specific impulse is defined as the pounds of thrust delivered per pound per second of propellant flow. Greater specific impulse reduces the amount of propellant required for a given mission and makes possible heavier payloads. The big advantage of the nuclear rocket is in its ability to produce a higher specific impulse.

Most of today's chemical engines have a specific impulse of about 300 seconds while advanced engines burning hydrogen and oxygen will provide a specific impulse of 425 seconds. Specific impulse ($I_{SP}$) is related to exhaust temperature ($T$) and propellant molecular weight ($M$) by the proportionality:

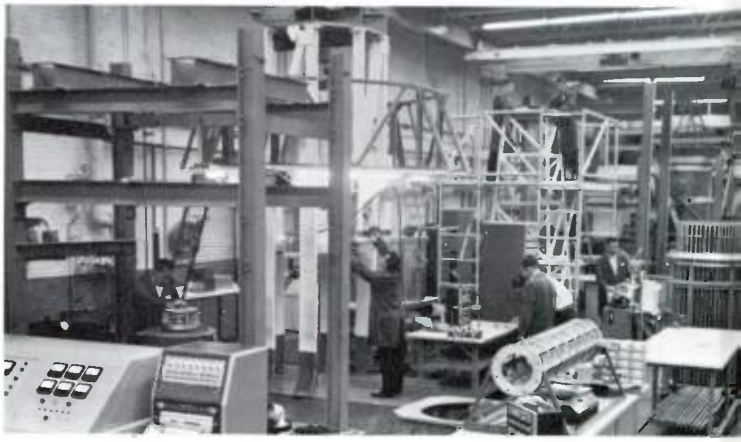
$$I_{SP} \sim \sqrt{\frac{T}{M}}.$$

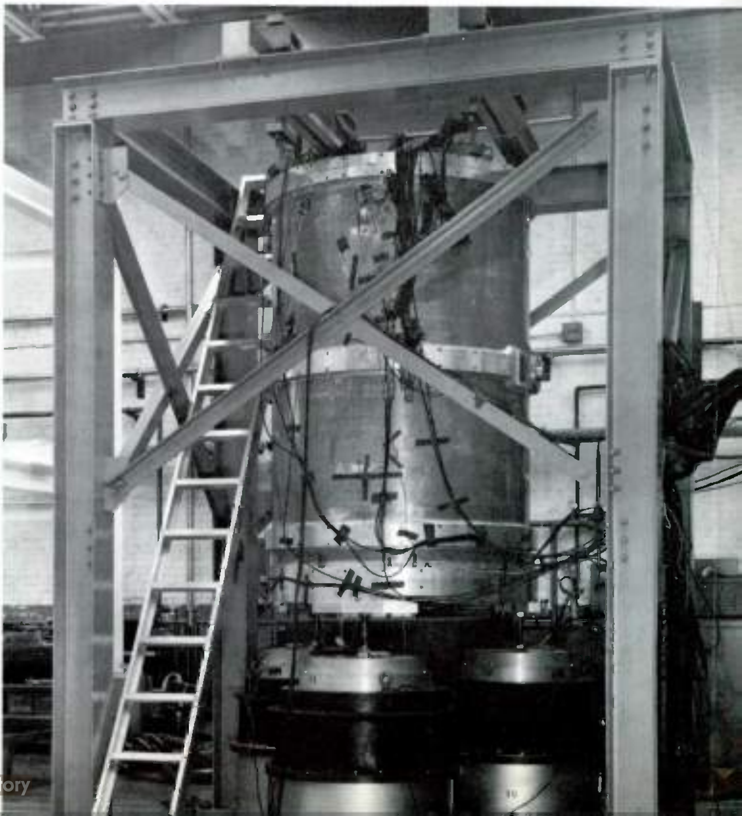
Since the specific impulse of an engine is inversely proportional to the square root of the molecular weight of the propellant gas, the nuclear rocket engine using hydrogen has a distinct advantage. Specific impulses in the range of 800 to 900 are attainable.

The evident potential performance of the nuclear rocket engine introduces the question of why they are not in use today. The answer lies in the status and unusual requirements of the development program. To illustrate this point, consider some difficult problems of the NERVA reactor program.

### *Difficult Problems in the NERVA Reactor Design*

While the Westinghouse background in reactor development was a solid base for the NERVA development, it was immediately evident that many new technological problems required solution. High operating temperatures in a potentially





**2—This mockup of the NERVA engine,** *(top)* which would contain the nuclear reactor, is about 22 feet high from the top flange to the exhaust exit of the nozzle.

**3—Component tests** *(center)* were conducted in this laboratory. Included were tests on core parts and the complete core.

**4—Reactor was vibrated** *(bottom)* in an axial position in this test arrangement. Extensive vibration tests were conducted under anticipated conditions of operation.

corrosive atmosphere, extreme variations in temperature across the reactor, and rapid temperature transients make this reactor design a formidable task. The interplay of fuel-material temperature capabilities and nuclear and thermal design taxed the capabilities of metallurgists and reactor designers.

The nominal values of power density and heat fluxes in nuclear rocket reactors are in the range of ten times higher than in conventional nuclear reactors. These factors, coupled with the closeness of the fuel-material operating temperature to its physical limits, require much attention to the detailed thermal and nuclear design.

Effects that would be relatively insignificant in other designs have a major influence in the NERVA reactor. For example, a five-percent difference in fission density results in at least a 200 degree F change in coolant temperature leaving the channel. The effect of this small change in power generation on the hot-spot temperature is even further accentuated by the higher resulting film and material temperature drops.

To ease the fuel-element and reactor-design requirements, a highly sophisticated nuclear and thermal analysis was developed to obtain the precision required for the NERVA core design. This procedure supplies a three-dimensional heat generation prediction throughout the core. Statistical variation in fuel-element dimensions and fabrication variables are then introduced into the calculation of the hot-spot temperature. To reduce the maximum temperatures, each channel is carefully orificed to compensate for the variations in radial power generation and actual coolant channel impedance.

While the thermal and nuclear design problems were solvable by the extension and careful application of known analytical techniques, two problems were not so easily resolved. The high-temperature fuel-element development and the reactor mechanical design problems required proceeding with a reactor design based on a paucity of experimental information and much judgment in the selection of the proper design approaches. Imagine, for example, the problem of supporting a bundle of white-hot fuel elements in a stream of flowing hydrogen with the cold hydrogen that enters the reactor passing within inches of these hot elements! Clearly, the fuel-element development and the mechanical design are intricately related. A material with excellent high-temperature properties could greatly ease the structural design. Conversely, the invention of an ingenious reactor design can reduce the need for high fuel strength at the operating temperatures. As with all designs, the NERVA is a compromise based on the best material properties available today.

The many requirements of a satisfactory fuel element eliminate most of the known materials. In addition to being capable of containing the fissionable element, a satisfactory material must possess:

1) Suitable nuclear and radiation resistance properties;

2) Mechanical properties at operating temperatures to withstand the temperature gradients and pressure differences imposed by the energy production and fluid flow conditions;

3) Capability to withstand the rapid changes in temperatures required by the rapid startup requirements of a nuclear rocket engine;

4) Suitable low-temperature physical properties to withstand the shock and the vibration loads caused by the booster operation;

5) Sufficient corrosion resistance to hydrogen to maintain its structural integrity and contain the fissionable materials for the required engine operating times.

The temperature requirements eliminate all the elemental materials except graphite, tungsten, rhenium, tantalum, molybdenum, and niobium. The only temperature-compatible compounds are some of the metallic carbides, nitrates, and borides. While needed physical data is lacking on most of these materials, the choices rapidly narrow to a few possible materials.

Graphite was chosen for the NERVA fuel element. It has excellent high-temperature properties, with a sublimation temperature of 6700 degrees R, and relatively high tensile strengths at operating temperature (~2000 psi). While the mechanical design was simplified by the choice of graphite as the fuel element material, the design of the reactor remained a formidable task. The relatively good low-temperature characteristics of graphite with respect to vibrational and shock loadings eased the problem of mounting the core so that it can resist booster induced vibration damage.

Graphite's ability to withstand thermal shock has allowed a design which can be subjected to rapid thermal transients. The high operating temperatures cause a more subtle problem of accommodation for the expansion of the core and the sealing between the cryogenic regions of the reactor and the high operating temperature regions. The design of this seal is one of the more formidable tasks of the NERVA program.

In the fall of 1962, extensive damage occurred to the Kiwi-B4A reactor during a power test. The cause of this damage was not immediately evident, and considerable concern developed over the adequacy of the basic reactor principle. Critical evaluation of the evidence, however, identified the most probable cause of the reactor damage as a severe hydrodynamic vibration. A concentrated analytical and test program confirmed the vibration premise and guided design changes to prevent the condition.

The overall result is a rugged reactor design shown schematically in Fig. 1, capable of coping with all the postulated environmental conditions of booster and flight operation and maintaining its integrity during the severe high-temperature operation.

### *Experimental Program*

Before a reactor could be committed to a full-scale test, an intensive experimental program was required to verify the adequacy of the key components. From an economical or schedular standpoint, it was impractical to test each of the components under all of its environmental conditions—in general, combined environmental testing (such as vibratory tests under high-temperature radiation conditions) could not be performed. Instead, several classes of component tests (Fig. 3) were conducted on core parts and the complete core. Some of these tests are still in progress to qualify the reactor for more strenuous operations or for flight service.

A few examples can indicate the scope of the component test program. In Fig. 4, for example, the reactor is shown being vibrated in an axial position. Extensive vibration tests were conducted under all of the anticipated booster vibrations, plus any vibrations expected from nozzle-induced or two-phase vibration-induced conditions.

Fluid flow tests on the many parts of this reactor were performed in a hydrogen flow facility constructed at the Westinghouse Waltz Mill Test Site. This facility was used primarily for checking the liquid and gaseous hydrogen flow-distribution conditions within the reflector and the core. In addition, experiments were performed to study the stability of the various parts under the many unusual operating conditions. This facility was designed to perform experiments with liquid hydrogen flow rates up to about four pounds per second.

At the other end of the temperature spectrum, many electrically heated furnaces were developed to test the fuel elements and other key parts at high-temperature operating conditions. Perhaps the most significant of these installations is the furnace used to check the quality and capabilities of the fuel elements. In this unit, single elements are electrically heated to reactor operating temperatures and are subjected to hydrogen flow rates simulating reactor operating conditions.

### *Reactor Control*

In addition to the reactor developmental problems, the control of the reactor also encompasses many questions.

One problem is to achieve sufficient reactivity control to safely vary the reactor power level through all desired transients. Because control is obtained only from the reflector drums, the available reactivity adjustments are limited. This limited control span must be sufficient to compensate for the operating effects of hydrogen and temperature, and to allow adequate margins for shutdown and excess reactivity. Since information on the reactivity effects of temperature and hydrogen in the core and reflector can only be obtained by full-scale reactor tests, great emphasis (and dependence) was placed on the use of proper analytical approaches for predicting the nuclear characteristics of the reactor. This work has proceeded well, and initial results show close agreement between predictions and full-scale experiments.

The other control problem arises in the kinetics or dynamics of the system during startup and power operation. Particularly important are predictions of temperatures and pressures within the system and the reactor during the startup flow transient. The liquid-to-gas change in the hydrogen entering the engine introduces a two-phase flow problem—accompanied by all the uncertainties associated with this phenomenon. The two-phase flow condition first exists in the piping, then passes on to the nozzle. As pressure of the turbopump rises to 195 psia, the hydrogen becomes supercritical, thereby ending the two-phase flow condition. Effects of hydrogen on the system have been adequately predicted, and initial runs agree closely with the results obtained by analog computer analysis.

The stability of the reactor when subjected to flow conditions approaching liquid hydrogen entering the core is of major significance. Concern has been expressed during past years about postulated instability problems caused by the high positive reactivity worth of liquid hydrogen. Very low core inlet temperature conditions have been avoided to prevent this potential difficulty. Recent tests, however, have demonstrated stability.

### *Reactor Testing*

The most significant experiments and the culmination of the foregoing efforts are the full-scale tests. Each of these tests is a major undertaking and, therefore, only a limited number can be included in the program. Since essential information must be learned from each full-scale test, the prime prerequisite for a successful program is the organization, planning, and training which precedes the actual run day. In the NERVA Project, the planning for a specific reactor experiment begins almost two years before the actual test date. After much discussion and compromise, precise objectives are established and the experimental plans are carefully designed. The experimental plan must incorporate the maximum amount of the reactor designer's desires without compromising the main objective.

The first specifications to be established following the design of the experiment are the measurements and instrumentation requirements. Six to nine months before a test, firm commitments are made on the 200 to 300 instruments to be mounted on the reactor. Detailed revisions are required to the basic reactor design to accommodate these thermocouples, pressure and differential pressure probes, accelerometers, displacement transducers, and strain gauges. Instrumentation external to the pressure vessel can be altered more easily, but it too must be established at least six months before the test. A total of 500 to 700 instruments are required.

These requirements highlight another basic development problem in that the majority of these instruments must function in a severe radiation environment. Besides being tolerant to the total radiation dosage, some of the instruments must be designed to operate with gamma heating rates as high as 30 watts per gram. This heating problem is the more difficult one, requiring that the internal instrument design be such that heat is conducted to surfaces that can be cooled by hydrogen.

In addition to the development and design required to properly instrument a reactor test, plans must be made to accumulate and rapidly prepare the data for analysis. The adequacy of the data acquisition system used in the NERVA program can be judged by the fact that a complete set of plotted data is issued three days following a test. This may present of the order of 100,000 bits of plotted information.

Other plans and analysis that must be prepared prior to a reactor test are: (1) Predictions report of each of the variables to be measured; (2) detailed test specification, operating procedures and check-off lists; (3) detailed handling assembly and disassembly procedures for the test article; and (4) safety analysis of the particular experiment. As these plans are completed, the reactor is being assembled for the tests.

The full-scale tests are performed at the Nuclear Rocket Development Station at Jackass Flats, Nevada. This 90,000-acre site about 90 miles northwest of Las Vegas was established in February 1962, by agreement between the AEC and NASA, and includes the part of the AEC's Nevada Test Site, which had been used for the ground tests of the Kiwi reactors. Operations at this site are controlled by the SNPO Nevada Office.

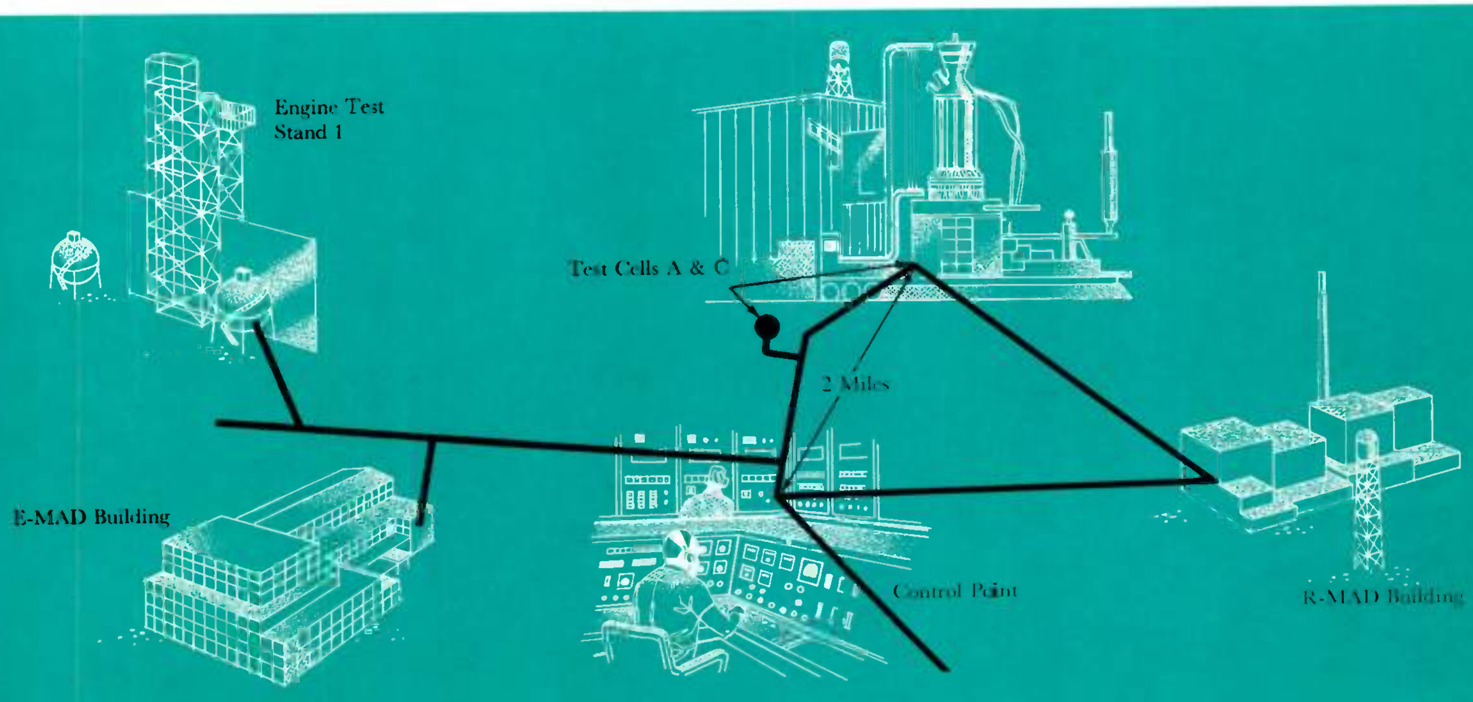
The principal facilities at NRDS are shown in Fig. 5. Test Cells A and C and the R-MAD (Reactor-Maintenance, Assembly, and Disassembly) building were developed and are being used for the Kiwi and NRX test programs. The R-MAD building is used for assembly and remote disassembly of the reactors. Other facilities shown on the map are the ETS-1 test stand and the E-MAD (Engine-Maintenance, Assembly, and Disassembly) buildings, which were developed as a part of the NERVA program. The NERVA engine will be assembled and disassembled in the E-MAD building and tested in the down-firing position in ETS-1. This test stand includes a cooled duct to direct the exhaust gas from the stand. The design of this duct represents a complex fluid flow and material cooling problem.

The NERVA reactor, which is shipped from the Astronuclear Laboratory in Pittsburgh, is assembled with a nozzle and pressure vessel on a test car (Fig. 7) in an assembly and disassembly building. The test car is a railroad car modified to provide a shielded region for the control actuators and electrical equipment. It also contains the coolant, purge and hydraulic lines and instrumentation leads required for the test. The nuclear reactor assembly is mounted with the nozzle pointing up. Subsequent to these operations, the test assembly is transported to the test cell, about two miles away.

The NRX-A1 reactor mated to the test cell is shown in Fig. 6. Piping and electrical connections are made through the test cell wall, by means of a shielding plug carried on the end of the car. This plug is designed to allow remote disconnection following the reactor test.

The test cell used for the NRX testing is Test Cell A, which has one 100,000-gallon and two 28,000-gallon liquid hydrogen dewars and 700 instrument channels for data acquisition. The liquid hydrogen is pumped to the reactor by a facility turbopump, and the turbine is driven by high-pressure hydrogen gas from the gas storage farm. The test cell includes a gas manifolding room, a flow control room, and a reactor hook-up room. An aerial view of the test cell is shown in Fig. 8.

A room adjacent to the cell contains the data acquisition equipment, which collects instrumentation signals from the reactor. All reactor test operations are controlled from a Control Point about two miles from the test cell, thereby eliminat-



5—**Principal facilities** at the Nuclear Rocket Development Station are shown here in diagrammatic form. R-MAD and E-MAD buildings are for maintenance, assembly, and disassembly of the reactor and engine, respectively.

ing direct radiation hazards to control personnel during the test. Control signals are transmitted to the reactor through an underground cable. The data is transmitted to the Control Point by a hard wire FM multiplexing system.

The tests are performed by a joint test organization called NTO (Nevada Test Organization), composed of Aerojet-General Corporation and Westinghouse personnel. The tests are under the direction of a Test Director, who has full responsibility for the conduction of the test. A Test Review Board representing the technical disciplines, and SNPO, are present throughout the final days of the preparation for the run and during the testing to approve any last minute revisions to the test specification. Starting two days prior to the test, called R-2 day, each of the operations proceed according to a prescribed check-off list. Checks are made of the test piping and valving systems and the controls of each of the operational units. An end-to-end check is performed on each of the instrumentation channels. Inputs are introduced as close to each of the detectors as possible, and a calibration check is made at the Control Point two miles away.

These operations continue through R-1 day during which another set of check-offs must be accomplished. On run day, the final check-offs are accomplished and, at about 0600, the status of the check-off board at the cell is reviewed. When all local operations are completed, the cell is evacuated and road blocks are established about two miles from the cell. Following this time, no one can enter the evacuated area except the re-entry team, who must be instructed by the Test Director.

The Control Point check-off begins at about 0730. In addition to the instruments at the Control Point, complete television coverage of the test cell and test article is maintained.

The control room personnel consist of about twenty operators (shown in Fig. 9) under the direction of a Chief Test Operator (CTO), who receives his direction from the Test Director. Other key operating personnel present during the test include the data acquisition team, the television and photographic monitoring team, test-cell monitoring team, radiation and safety personnel, and sufficient personnel to repair any malfunction. During the test, a team of design personnel are observing some one hundred key variables that are being recorded on strip chart recorders. If any variable exceeds a red line value, they notify the Test Director.

A data review team is available to review the quick-look data immediately following the run. Final safety approval to

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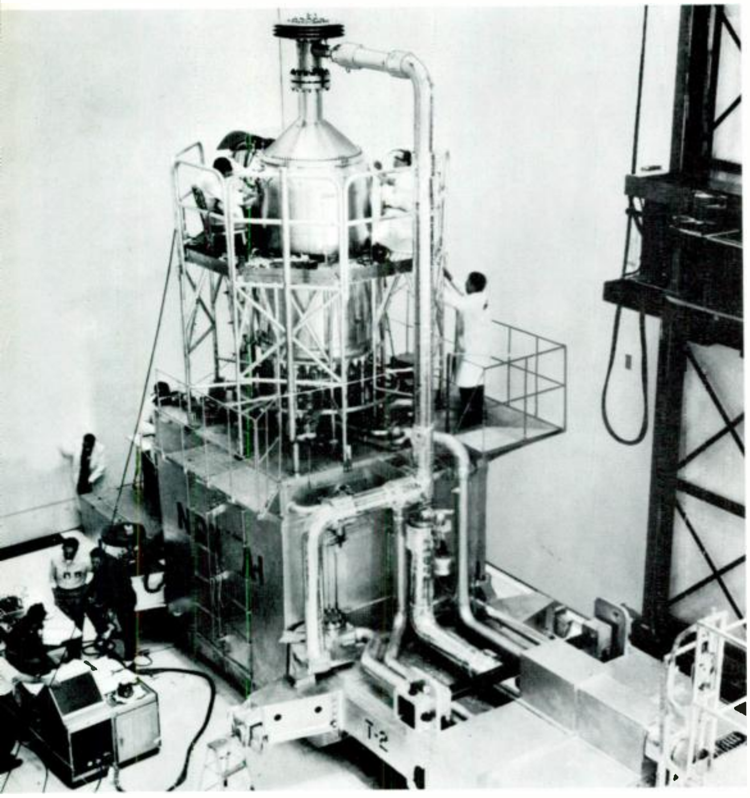
**6—The NRX-A1 reactor** mated to the test cell. Piping and electrical connections are made through the test cell wall.

**7—NERVA reactor is assembled** with a nozzle and pressure vessel on a test car, a railroad car modified to provide a shielded region for the control actuators and electrical equipment.

**8—Aerial view of the test cell** used for NRX testing. The cell has one 100,000-gallon and two 28,000-gallon liquid hydrogen dewars, and 700 instrument channels for data acquisition.

**9—Control room personnel** number about 20 operators. Other key operating personnel include a data acquisition team, television and photographic team, and other specialized groups.



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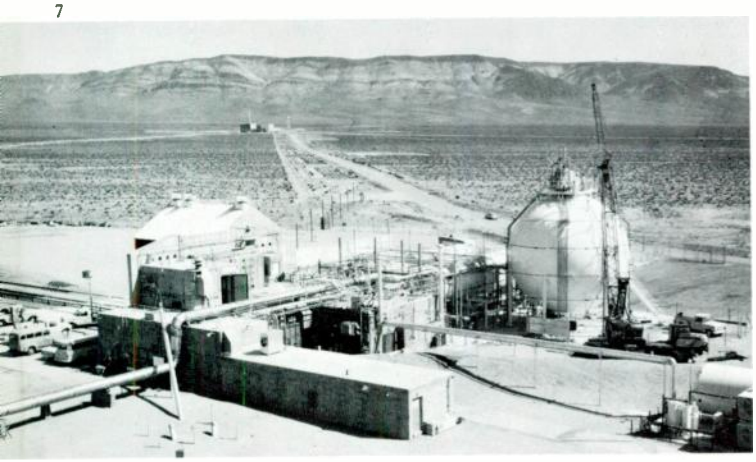

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run is obtained from SNPO-Nevada, who analyze weather conditions with relation to any possible malfunction.

When all the various checks are completed, the run phase of the test is started. The complete test profile, which includes power level, flow rate and temperature, is controlled by an automatic programmer. The Chief Test Operator has the ability to stop the test cycle and to override certain control parameters if unusual operating conditions exist. In practice, the operating sequences occur so rapidly that only a few trimming corrections on reactor power or temperature are possible during a run. No change in plan is possible at this time. The success achieved in the few minutes of testing is primarily the result of the months and years of planning that preceded the order to run.

The NRX-A1 test, run in the spring of 1964, was the first full-scale test conducted as a part of the NERVA Project. It was a nonnuclear test, used to prove out the structural and stability conditions within the reactor under the high-flow and vibratory conditions of engine operation.

A series of tests were performed to check the integrity of the system, starting with nitrogen flows and followed by gaseous and liquid hydrogen.

Flow rates representing a substantial fraction of full-flow conditions were passed through the reactor, and observations were made for any structural damage or any vibratory condition. Approximately 525 channels of instrumentation were used during the test. No major damage or unusual condition was observed, and the test was rated an unqualified success.

Following a test, the test car is returned to the R-MAD building. For NRX-A1, which was not a nuclear test, disassembly was not performed by remote operation, but for the "hot" NRX-A2 test, the reactor has been brought into a large disassembly bay, and operations performed remotely.

In July 1964, the second NRX reactor (NRX-A2) was delivered to Nevada and was installed on the test car. It was mated to the test cell, and on August 12 the first criticality was achieved on the reactor. Tests continued through the month of August and early September in preparation for achieving the first powered run in the NERVA program.

On September 24, the hot test of the NRX-A2 reactor was conducted. All of the test objectives were achieved, and the operating time and power level exceeded expectations. The reactor operated for slightly over six minutes at power levels above 50 percent of the full power rating. During the latter part of the run, full power conditions were attained. A photograph of the NRX-A2 test assembly during the firing is shown on p. 75. The proper functioning of the majority of the experimental instrumentation allowed significant amounts of data to be accumulated. A second test run was conducted on October 15 when the reactor was operated at low powers for a period of 20 minutes. Significant information was obtained on reactor stability with dense hydrogen and two-phase hydrogen entering the core. At present, extensive efforts are underway to analyze all this information; also pending are observations to be made during the remote disassembly of the reactor.

### *The Future*

The future course of the nuclear-rocket program involves testing more reactors, until the design is qualified for engine tests, and the simultaneous development of the other engine components such as the nozzle and turbopump. At that point, a complete engine will be mounted in an NRDS test stand, ETS-1. The stand includes a run tank containing 70,000 gallons of liquid hydrogen, installed in the superstructure above the engine firing positions. The engine will be tested with the jet firing downward into an altitude chamber approximating expected startup conditions of temperature and vacuum.

Following the series of NRX and engine system tests, the nuclear engine will be ready for flight operation. Its high specific impulse makes the nuclear rocket engine an attractive choice for deep solar system probes, for manned trips to nearby planets, or for ferrying substantial equipment to the moon and beyond.

For example, the substitution of a nuclear stage using the NERVA engine for the chemical third stage of the Saturn V configuration would result in 40 to 75 percent more payload landed on the moon than with the chemical Apollo mission.[2]

For planetary missions, the advantages of nuclear rocketry are even more impressive. For example, while the orbital relations for a Mars mission are favorable for a brief period every two years, the energy required varies greatly over a 17-year cycle. These energy requirements determine the total vehicle weight that must be launched into earth orbit. For these long-range manned Mars missions, Fig. 10 compares the launch weight of an all chemical vehicle to that for a nuclear-powered vehicle for beyond-orbital operation.[3] The comparison of the required launch weight is shown for each year up to 1987. The difference is noteworthy for the near optimum years, but is several factors for the nonoptimum ones.

With these performance capabilities, it is certain that the nuclear rocket engine will find a significant place in the spectrum of space propulsion power sources. For long-range space missions, there is no doubt that the nuclear rocket has an inherent superiority over any chemical rocket; in deep-space probes, nuclear-powered vehicles appear to be the only practical approach in the foreseeable future.

**Westinghouse ENGINEER**
**May 1965**

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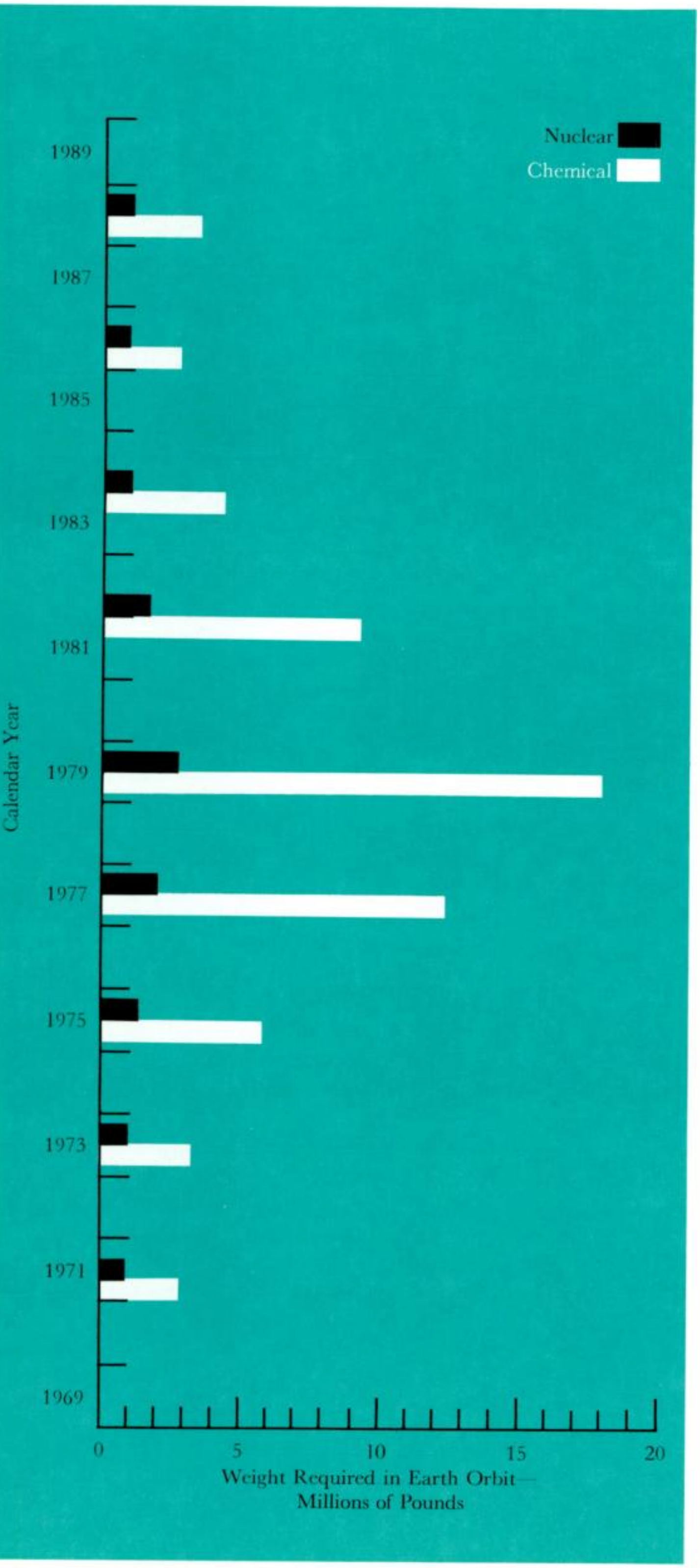
*References:*

[1] R. E. Schreiber, "Kiwi Tests Pave Way to Rover," *Nucleonics*, Vol. 19, No. 4, April 1961, 11.77-79.

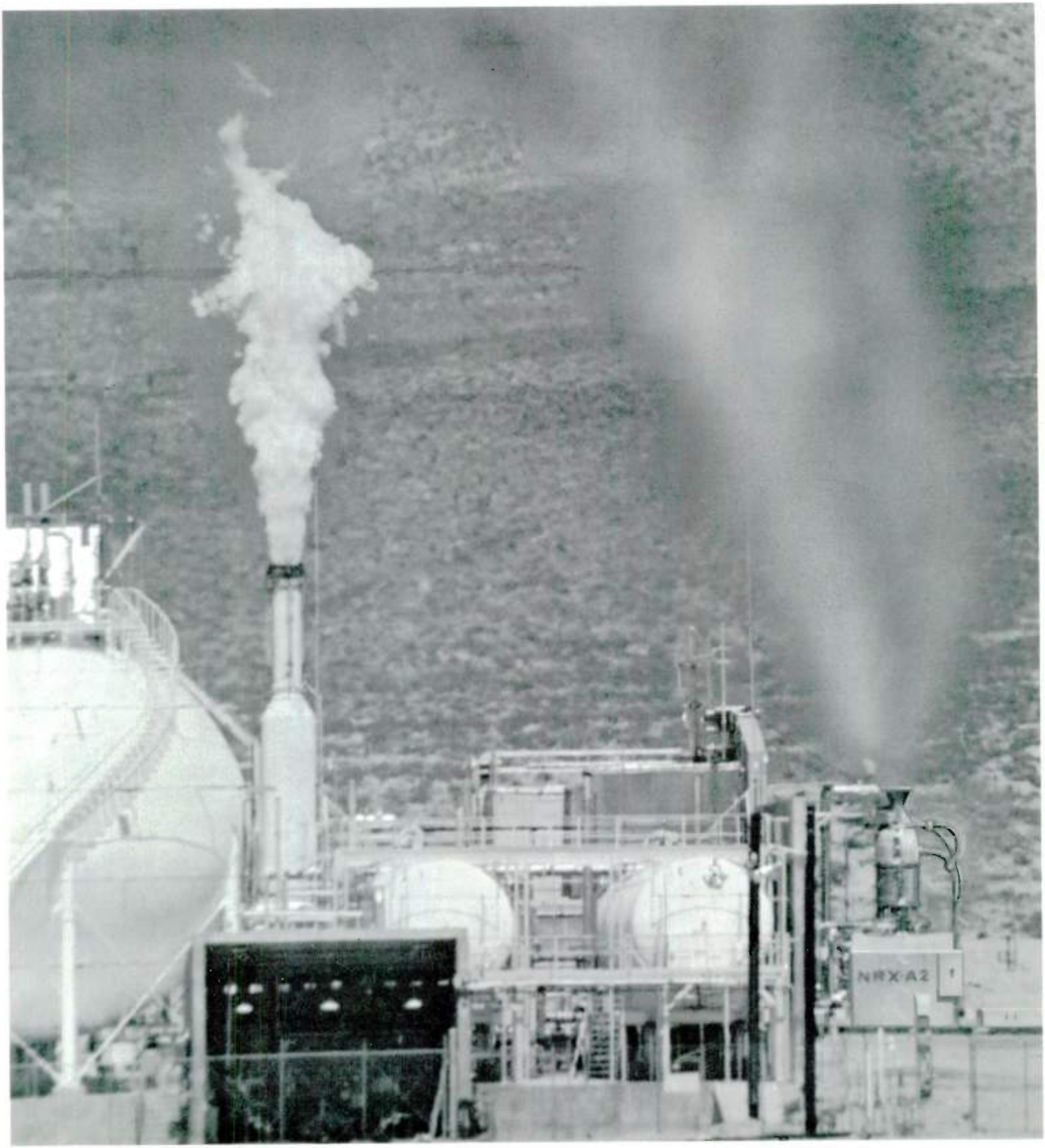
[2] Harold B. Finger, "Space Nuclear Propulsion Mid-Decade," *Astronautics & Aeronautics*, January 1965.

[3] LMSC-A66421 1—"Nuclear Rockets for Long-Range National Space Objectives," Lockheed Missiles and Space Company.



**10—A comparison of launch weights** of an all-chemical vehicle and a nuclear-powered vehicle for beyond-orbital operation, in this case for a Mars mission.

**11—Firing of the NRX-A2** is shown here. During these tests the reactor operated for slightly over six minutes at power levels above 50 percent of full-power ratings, and during the latter part of the run, full-power conditions were attained.


NRX-A2

# Station Efficiency Improvement With Gas Turbines

by V. P. Buscemi

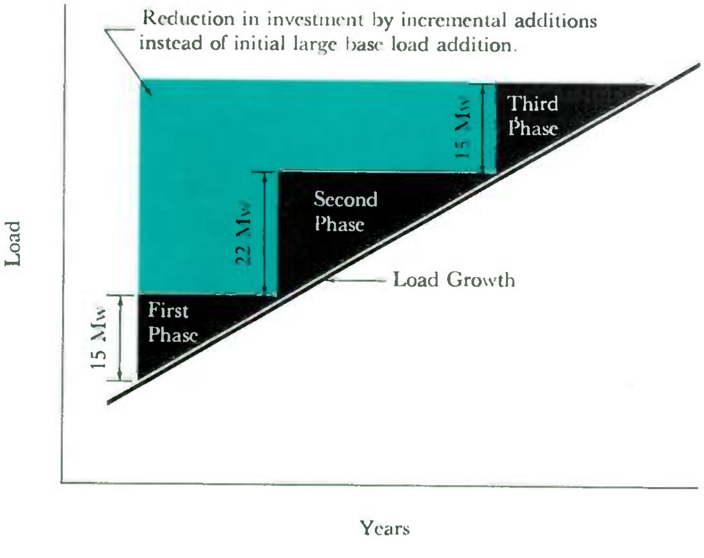
*The integration of the gas turbine into the steam power generation system can improve performance levels of electric utility generating stations.*

The process industries have realized two major benefits of the gas turbine: reliability, which has been verified by operating experience, and efficiency gains that have been demonstrated by integrating the turbine, with its enormous quantities of exhaust heat, into the overall system. The potential for similar advantages in electric utility generating station efficiency should be utilized. By exhausting gas turbines into waste heat recovery boilers, overall plant heat rates can be improved. Furthermore, gas turbines can provide these benefits over a wide range of plant sizes. For example, on moderate sized utility systems, the gas turbine can be used in efficient load growth plans, such as the Westinghouse PACE program; on medium sized utilities, the gas turbine can be used to modernize existing steam plants; and on large systems, gas turbines can be integrated into large combined plant cycles to surpass conventional plant efficiencies.

### *PACE Program*

For many moderate sized utility systems, the desirable system addition should approximately match the yearly incremental load growth. Incremental size additions require a relatively small amount of investment and thereby minimize fixed charges by deferring the total investment. If efficiency could be improved with each plant addition, the procedure would ideally fit the growth pattern of many typical utilities, as shown in Fig. 1.

The PACE program (*P*lant *A*dditions at *C*ombined *E*fficiencies) was specifically developed to meet these requirements.



Plant additions take place in three distinct phases. The program begins with a 15,000-kw gas turbine plant, as shown in Fig. 2a. Ideally, this phase should be installed ahead of need so that its high heat rate, about 15,000 Btu per kilowatt hour, can be justified on the basis of short-time peaking duty. In any case, the poor heat rate at this stage of the program will be more than offset economically by the excellent plant efficiency obtained at the completion of the program.

The second step, Fig. 2b, is the addition of a heat recovery boiler, steam turbine, and condenser. The gas turbine is provided with reheat burners so that a full 22,000 kilowatts, with steam conditions of 850 psig at 900 degrees F, can be developed by the steam turbine. The exhaust gases from the gas turbine provide preheated combustion air to the recovery boiler. This addition lowers the heat rate to 10,500 Btu per kwhr, so that the plant can be used economically for either base load or spinning reserve duty.

The third and final addition, shown in Fig. 2c, is a second 15,000-kw gas turbine. All of the steam is now generated from the exhaust heat of the two gas turbines, increasing nominal plant output to 45,000 kilowatts. The heat rate at this load point is 10,500 Btu per kwhr. The reheat burners can be ignited to extend the steam turbine to 22,000 kilowatts for a plant output of 52,000 kw. The composite plant heat rate is shown in Fig 3. The heat rate is better than that of a conventional steam plant over the whole operating range except at very light loads.

The PACE plant has been designed to minimize installed cost by use of a single grade for mounting all equipment. The steam turbine is provided with a top exhaust, which is connected to a condenser mounted alongside the steam turbine, thereby eliminating the need for a basement. Other plant arrangements may be dictated by the site location and utility requirements. Since all components are separate elements of standard design, no additional development is required to build the gas turbine or the steam turbine plant to meet the electric utility's needs.

### *Plant Modernization*

The practice of using old steam units for peaking is effective when plant efficiencies can be improved with improved steam conditions. However, in the future, the spectacular improvements of the past are not expected because new additions will

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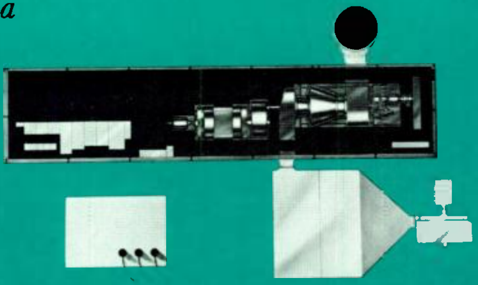
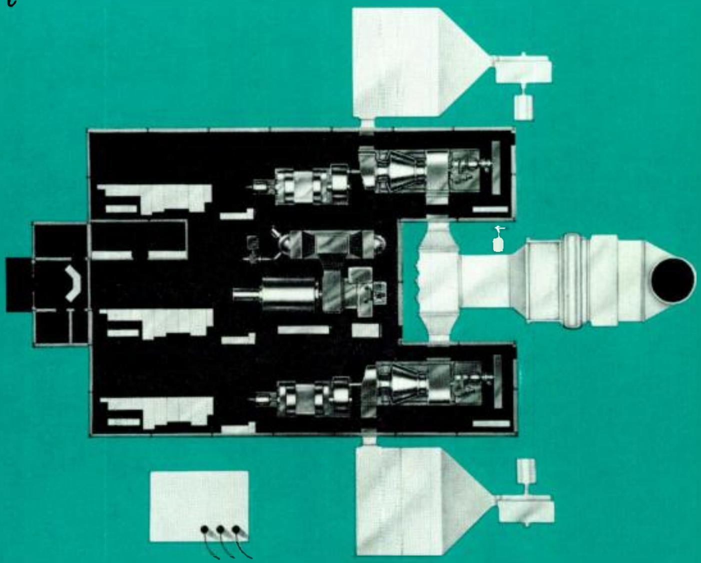
V. P. Buscemi was a Project Engineer at the Small Steam and Gas Turbine Division, Westinghouse Electric Corporation, Lester, Pennsylvania at the time of submission of this article. He is now a Fellow Engineer in the Steam Systems Department of the Atomic Power Division, Forest Hills, Pennsylvania.

**1—Load growth** *(left)* of moderate size utility systems can be matched by plant additions with the Westinghouse PACE program.
**2—PACE program** *(above right)* consists of three plant additions: *(a)* 15,000-kw gas turbine for peaking; *(b)* heat recovery boiler, 22,000-kw steam turbine, and condenser for base-load operation; and *(c)* second 15,000-kw gas turbine for central-station operation.
**3—Composite heat rate** *(lower right)* for 52-mw PACE plant, consisting of two 15,000-kw gas turbines and one 22,000-kw steam turbine.

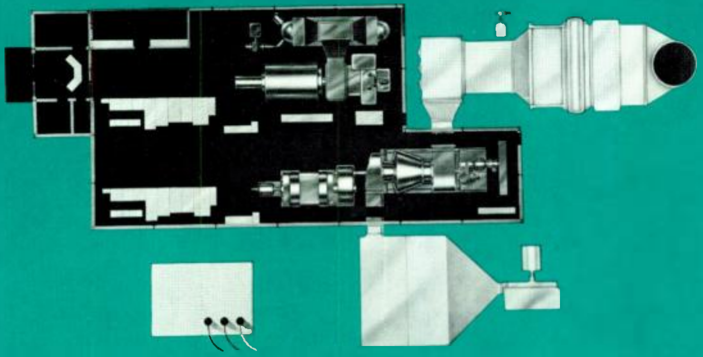
*a*

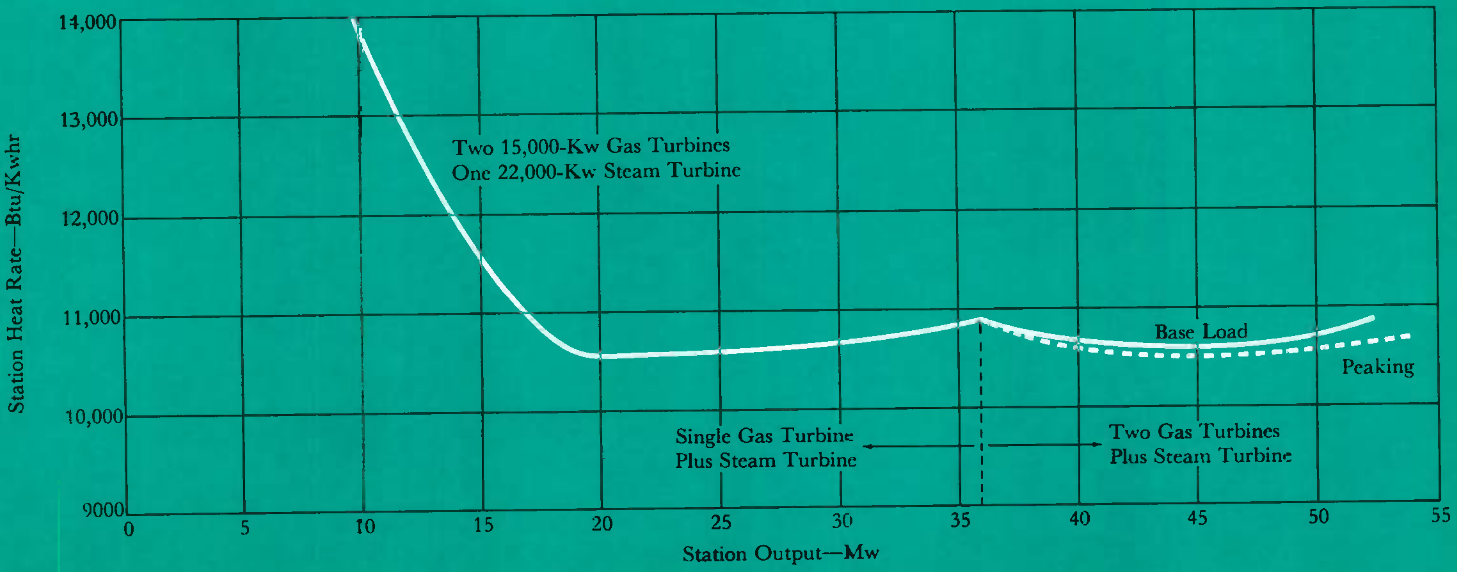


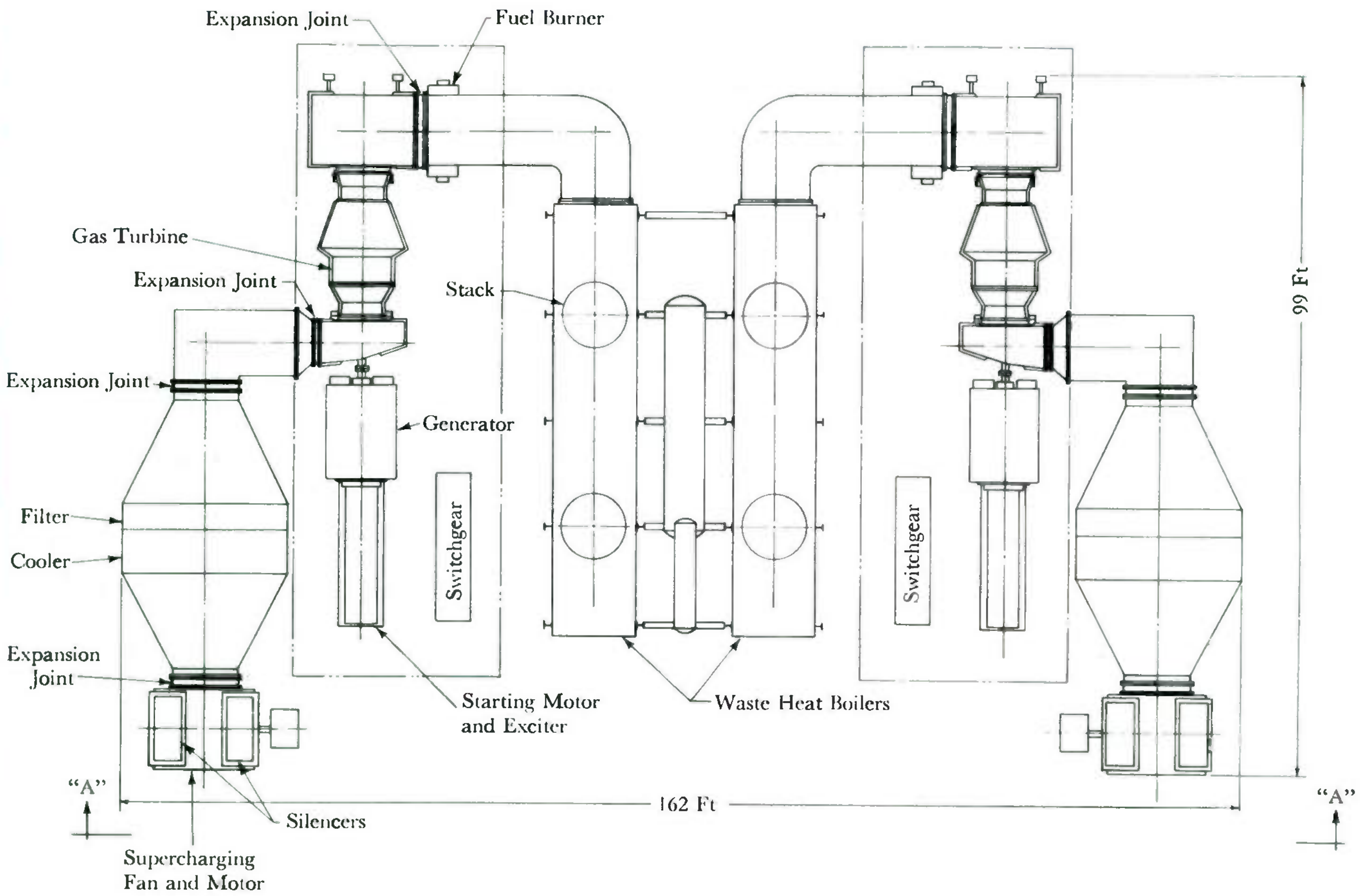
*c*

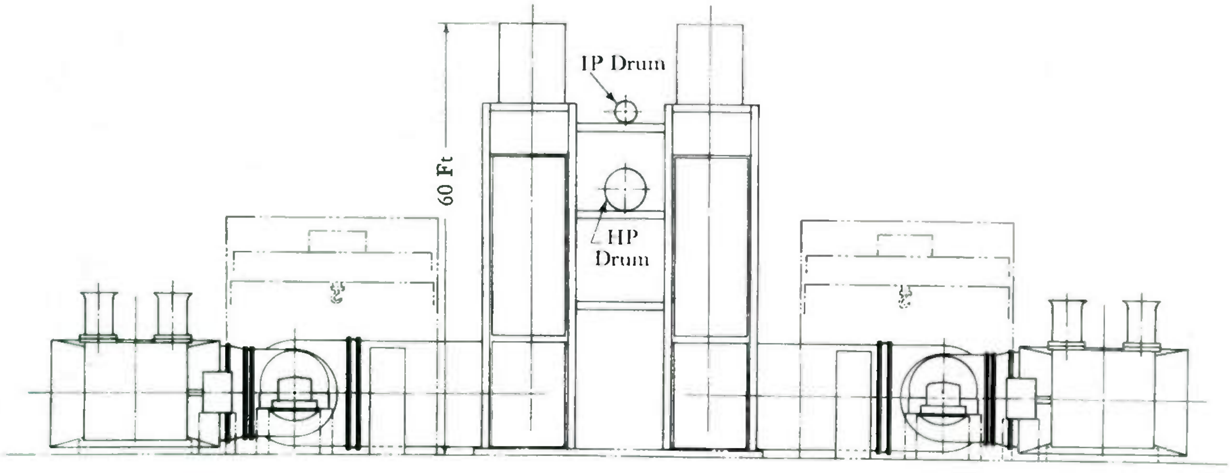


*b*




14,000
13,000
12,000
11,000
10,000
9000
0
5
10
15
20
25
30
35
40
45
50
55
Station Heat Rate—Btu/Kwhr
Station Output—Mw
Two 15,000-Kw Gas Turbines
One 22,000-Kw Steam Turbine
Base Load
Peaking
Single Gas Turbine
Plus Steam Turbine
Two Gas Turbines
Plus Steam Turbine


Expansion Joint
Fuel Burner
Gas Turbine
Expansion Joint
Stack
Expansion Joint
Generator
Filter
Cooler
Switchgear
Switchgear
Expansion Joint
Starting Motor and Exciter
Waste Heat Boilers
99 Ft
"A"
162 Ft
"A"
Silencers
Supercharging Fan and Motor


IP Drum
60 Ft
HP Drum

Section "A-A"

offer only slight improvement over present machines. Furthermore, improved efficiencies will be available to many utilities only by increasing the size of base-generation additions, and will require large outlays of capital. In these cases, plant modernization of older steam units may be a more attractive method of improving efficiency levels.

The typical medium size utility has one or more units relegated to cycling operation in the 33 or 44 mw range. These steam units are perhaps 10 to 20 years old and operate nonreheat with relatively low steam conditions. If the utility is considering an expansion program for 100 mw of base load, the addition would usually be a reheat unit with 1450 or 1800 psig inlet pressure, and 1000 degree F inlet and reheat temperatures. However, an alternative is the modernizing of the existing 40-mw generation system with gas turbines. With the latter approach, a 100-mw plant can be developed that offers the possibility of equal or even better heat rates than can be obtained with a conventional 100-mw reheat unit.

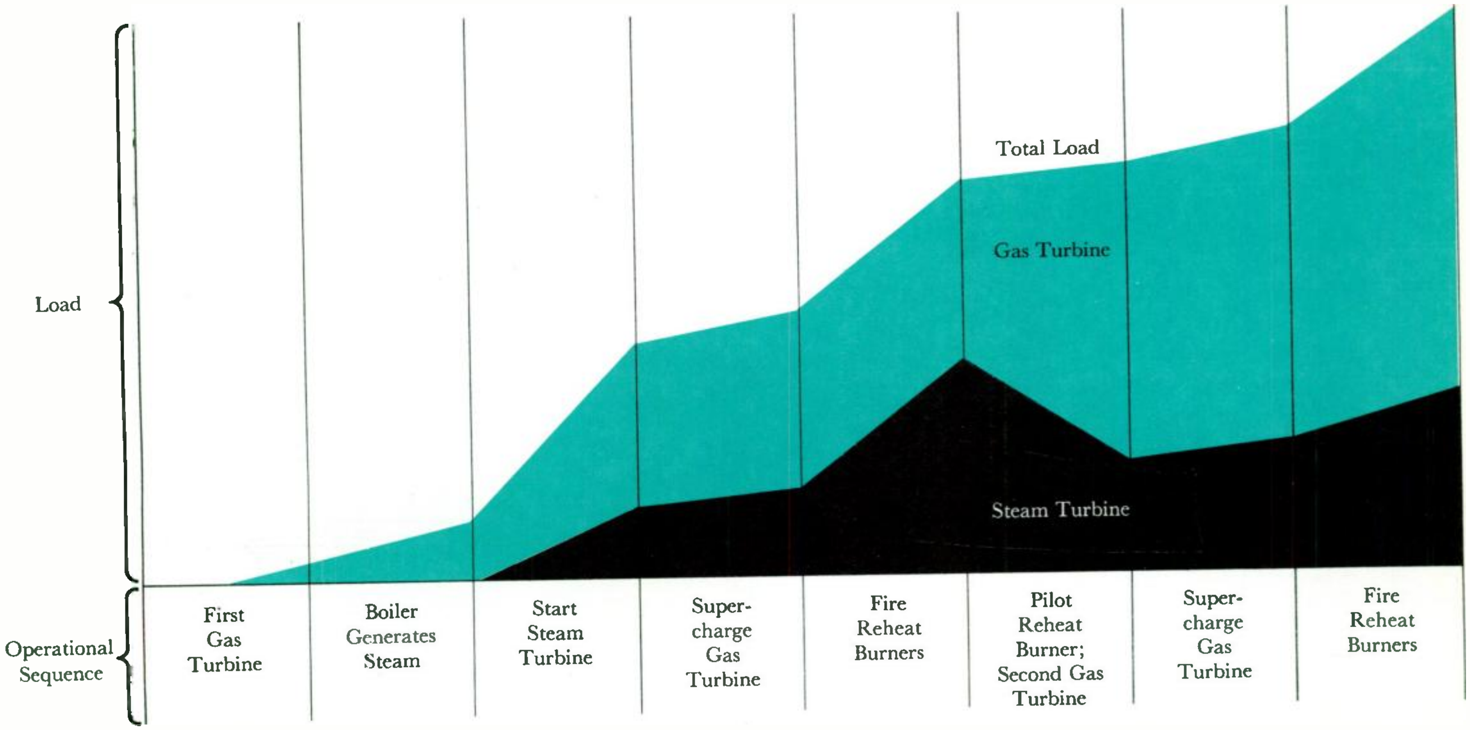
A suggested arrangement of the required additional equipment, two 30-mw gas turbines and one waste heat recovery boiler, is shown in Fig. 4. The gas turbines are located on each side of the waste heat boiler. The motors and generators are on one end of the gas turbine, and the fuel-firing and steam leads to the steam turbine are on the other end. The boiler is divided into two elements of heat transfer surface and connected to single high-pressure and low-pressure steam drums. With this arrangement, either one or both gas turbines can be used with no need for dampers in the large exhaust ducts. Each evaporator element has two exhaust stacks that are approximately 60 feet high. The boiler elements have forced circulation in both the high-pressure and low-pressure elements. This provides uniform heat transfer over all of the tube length, a desirable feature because of the relatively low-temperature exhaust from the gas turbine.

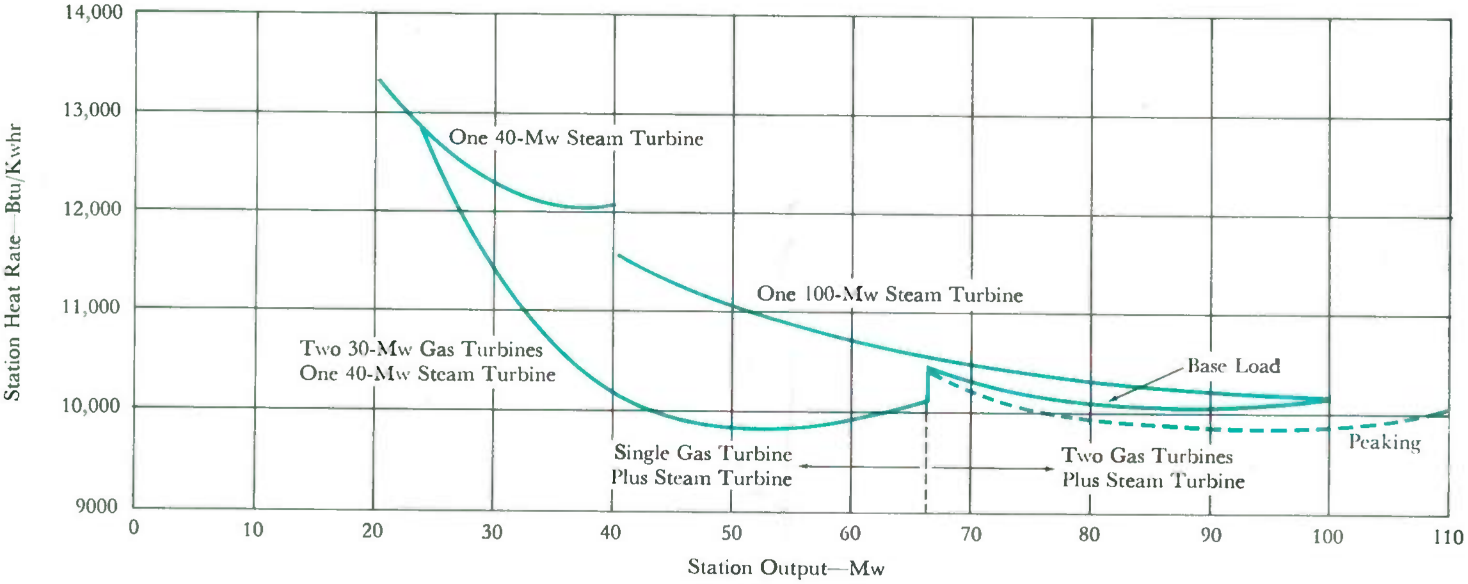
A suggested mode of operation is summarized in the unit loading curve, shown in Fig. 5. This typical curve illustrates the sequence, but not the time requirement, since any particular curve will depend on the parameters of the existing steam turbine, such as size, type, and steam conditions.

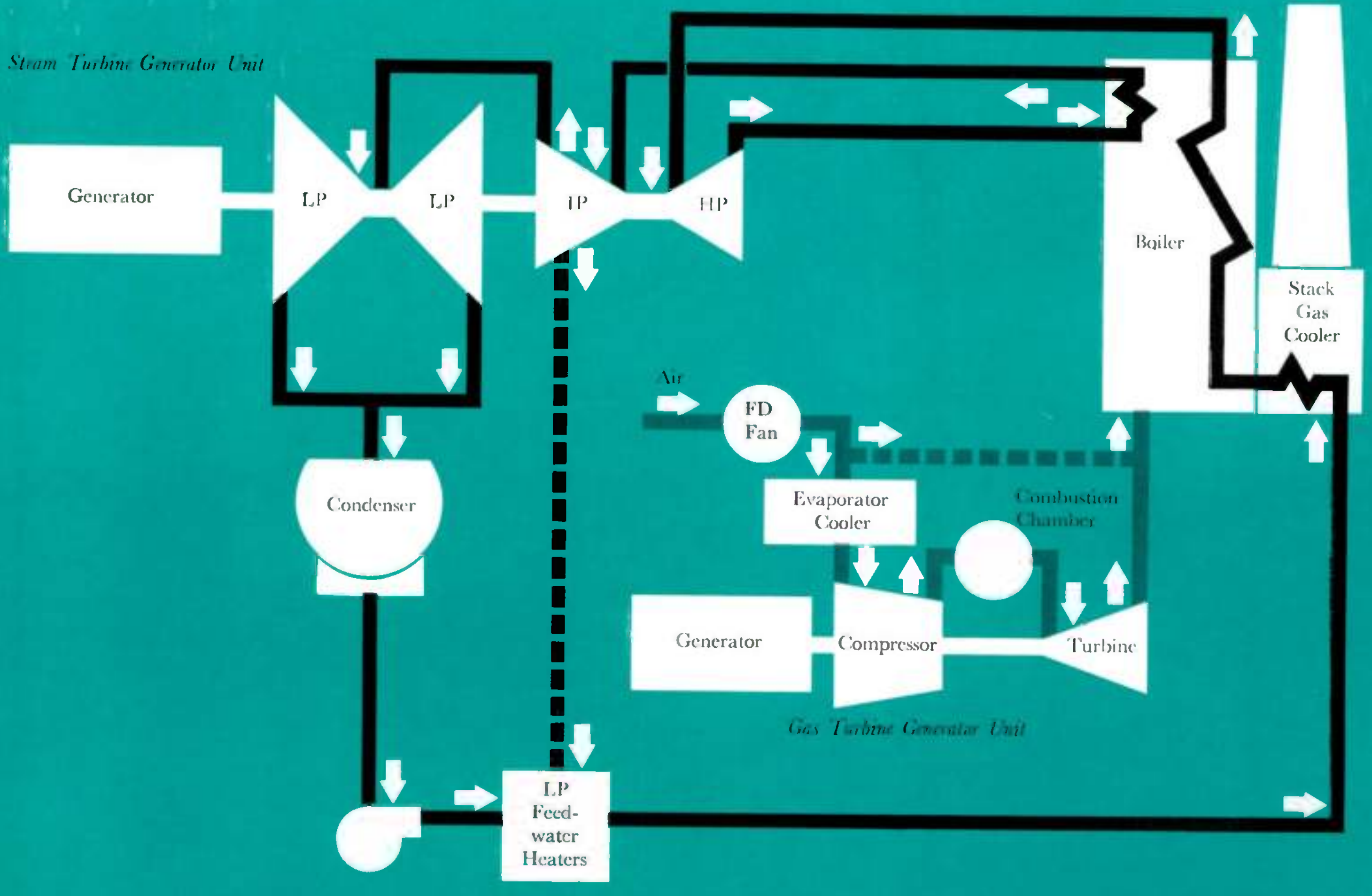
The heat rate curve for such a modernized plant is shown in Fig. 6. A break in the curve occurs when the second gas turbine is started and operates at part load. Just as in the single gas-turbine operating situation, efficiency improves as full load is attained and the reheat burners are put in operation. An attractive feature of the modernized plant is that the steam turbine and one gas turbine can be operated in the 40-mw range at a reasonably good heat rate. This combination could provide good spinning reserve because output could be increased to 60 or 70 mw just as fast as the steam turbine could

**4—Suggested arrangement of two 30-mw gas turbines** and one waste-heat recovery boiler. This equipment, added to an existing 40-mw steam turbine, could provide a 100-mw plant with excellent heat rates, both at part and full load.

**5—Typical unit loading curve** for modernized 100-mw plant consisting of two 30-mw gas turbines and a 40-mw steam turbine.




14,000
13,000
12,000
11,000
10,000
9000
Station Heat Rate—Btu/Kwhr
0
10
20
30
40
50
60
70
80
90
100
110
Station Output—Mw
One 40-Mw Steam Turbine
One 100-Mw Steam Turbine
Two 30-Mw Gas Turbines
One 40-Mw Steam Turbine
Base Load
Peaking
Single Gas Turbine
Plus Steam Turbine
Two Gas Turbines
Plus Steam Turbine


Steam Turbine Generator Unit
Generator
LP
LP
IP
HP
Boiler
Stack
Gas
Cooler
Condenser
Air
FD
Fan
Evaporator
Cooler
Combustion
Chamber
Generator
Compressor
Turbine
Gas Turbine Generator Unit
LP
Feed-
water
Heaters

accept the load. The proposed waste-heat boiler has a minimum of refractory and is capable of rapid increases in the output. The response time is fast because this boiler has approximately eight times the air flow of a normally fired boiler. In the typical case, the maximum firing temperature of the reheat burners will be approximately 1300 degrees F, which is a relatively small temperature rise in the boiler tubing, refractory, and structure.

The gas turbine could also be used to take the cycling duty and the peak power generation, while the steam turbine would be on continuous duty. Additional kilowatts with an improved heat rate can be obtained for emergencies and short durations by peak firing of the gas turbines (as shown by the dotted curve in Fig. 6).

The results of any particular plant modernization plan will depend on site restrictions at the existing station, ambient air conditions, and steam turbine parameters. For example, steam generation must match the inlet and extraction steam conditions of the existing steam turbine. The maximum power system limit will be dictated by either the inlet or exhaust flow limit on the steam turbine.

Plant modernization studies should be made on each particular application to properly evaluate this arrangement. In addition to minimum investment requirements and a maximum gain in heat rate, plant modernization with gas turbines offers such additional benefits as: elimination of steam turbine cycling; no increase in cooling water required; use of existing site and manpower; shorter delivery times and shorter start-up periods than would be required for a new conventional plant.

## Combined Cycles

Large electric utility systems have the opportunity to surpass conventional efficiency levels by as much as 9 percent through the use of large combined cycles.[1] All combustion air is supplied by the gas turbine exhaust at elevated temperatures, and ordinary boiler firing at about 3000 degrees F is employed.

A combined cycle can be evaluated only on the basis of a complete power plant. The changes entailed will affect almost all parts of the power generation system. The primary changes that must be evaluated when comparing a combined-cycle plant with a conventional plant are:

*Boiler design*—Throttle and reheater flows decrease; cold reheat and final feed temperatures change; fans and air preheaters disappear; stack-gas coolers and economizers are reoriented; air intakes are repositioned; because of the nature of these changes, complete boiler redesign is required.

*Steam-turbine design*—The steam turbine must be specifically designed for flow and temperature changes; unit size decreases for constant station capability; and economics may dictate small exhaust-end sizes in the comparison.

*Station design*—Fewer feedwater heaters; smaller condensers; small boiler-feed pump; altered crane designs; and the plant layout is dependent on the interrelation of the necessary equipment instead of mere alteration.

*Heat rate*—Influenced by many factors, such as operating steam conditions, plant size, proportion of gas turbine in the cycle individual equipment efficiencies, and the particular feedwater-heating-cycle arrangement.

Thus, the evaluation and economic justification of a combined cycle, can only be made from an overall power plant viewpoint. The outcome will depend on plant load factor, fuel costs, and percent capitalization figures. In some studies, approximately equal station costs on a dollar per kilowatt basis have been indicated; in these cases, the large heat-rate improvements and resulting fuel savings would provide a large bonus, which could run into considerable savings on a yearly basis.

A combined-cycle plant that has resulted from such an intensive evaluation is the Lake Nasworthy Power Station of the West Texas Utilities Company. The nominal rating of the combined unit is 110,000 kw—25,000 kw from the gas turbine and 85,000 kw from the steam turbine. A schematic diagram of the Lake Nasworthy plant cycle is shown in Fig. 7. The cycle is commonly called a full-stack gas cooler cycle because full condensate flow passes through the stack-gas cooler before entering the boiler. There are no high-pressure heaters following the low-pressure heaters. Steam generation takes place in the boiler with all combustion air supplied by the gas turbine exhaust at elevated temperature.

The Lake Nasworthy arrangement provides for mutually exclusive operation of the steam and gas turbines. This is accomplished with the bypass line between the forced-draft fan and boiler. The use of this fan to supercharge the gas turbine during normal combined-cycle operation is also a novel approach that will contribute to the expected efficiency gains. The steam turbine is of conventional design except that only low-pressure extraction points are provided for feedwater heating.

## Potential for Gas Turbines

Although the gas turbine has been relatively dormant in the electric utility industry, its potential is becoming evident. Plant modernization with gas turbines offers economic improvements to all sizes of utility systems. The actual economics of gas turbine applications will vary with each situation, but the potential improvement is worth the investigation. With independent gas turbine installation and operation, utilities are offered the benefits of large unit ratings with the flexibility of smaller ratings.

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6—**Composite plant heat rate curve** for modernized gas turbine-steam turbine plant can be better than that of a single 100-mw reheat steam turbine unit.

7—**Full stack-gas cooler cycle** combines a 25,000-kw gas turbine with an 85,000-kw steam turbine for a nominal plant rating of 110,000 mw. Either steam or gas turbine can be operated without the other.

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*Reference:*

[1] Stephens, J. O., and Buscemi, V. P., "100, 200, and 400-Mw Steam and Gas Turbine Power Plants," Paper No. 63-PWR-18 presented at ASME-IEEE National Power Conference, Sept. 1963.

# Resistance-Controlled DC Arc Welder

*Weak spots in a weld must be chipped out of high-quality work, an expensive procedure. Two causes of weak spots are metallic short circuits between the electrode and the workpiece and lost arcs. The possibility of these two eventualities are greatly reduced by this new welder.*

The stability of the arc and fast response of the power supply to prevent lost arcs are two important and necessary characteristics in high quality welding. A new welder, called the WSR, is designed to have an exceptionally stable arc, and instantaneous and linear response.

This dc rectifier welder uses resistance control, rather than the more conventional reactor control with its inherent time delay and nonlinear response. Moreover, the new welder allows precise selection of welding current, from 320 amperes down to one ampere, so that the operator can select the exact current best suited to his work conditions; because of the unusual stability of the arc, the welder can be run over the entire current range without losing the arc.

These characteristics make the new welder particularly suitable for critical welding operations, such as welding HY-80 steel and pipe welding, as well as for more general welding operations where reject rates are high.

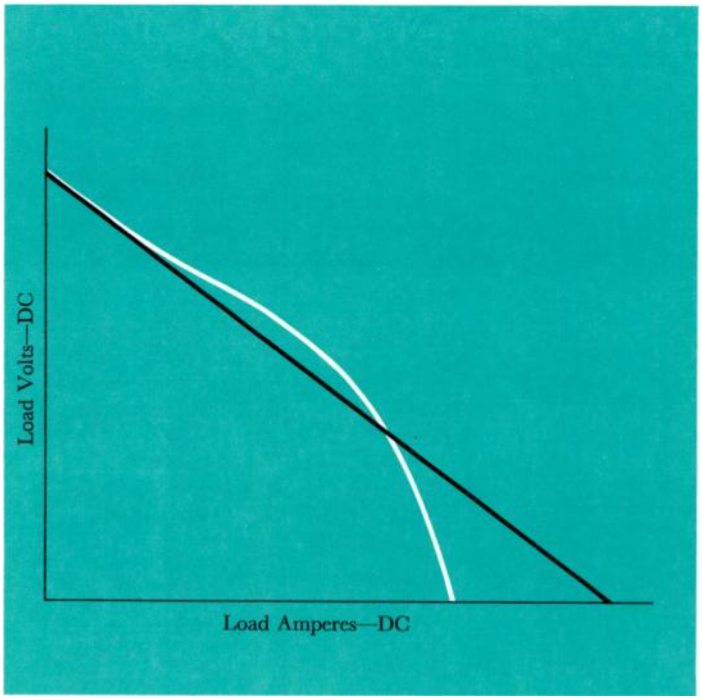
### *Design Considerations*

In arc welding, material transfers from the electrode to the workpiece in a noncontinuous manner. As arc current melts the tip of the electrode, a molten globule extends toward the work and shortens the arc gap. The exact moment when this molten globule leaves the electrode and is transported to the work depends on many factors, and most welding problems are related to these factors.

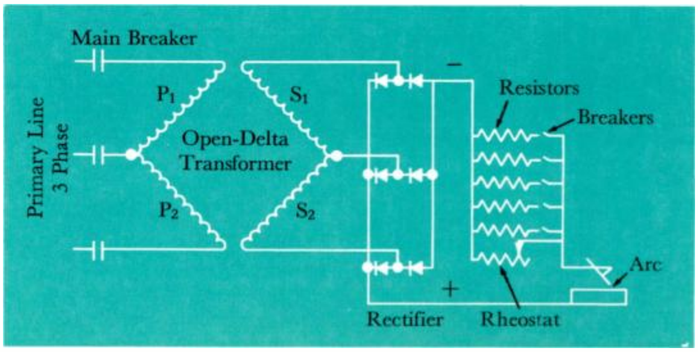
For example, arc voltage depends on the distance across the arc. The extension of the molten globule shortens the arc, reducing arc voltage. If the globule becomes too large, it can bridge the arc, resulting in a metallic short. This condition is commonly called "cold shorting" because the arc disappears, arc voltage drops to zero, and the globule solidifies and welds the electrode to the work. This is intolerable in high-quality work; the cold short is a weak spot that must be chipped out and rewelded.

Arc current helps remove the molten globule from the electrode tip by the "pinch effect": magnetic force squeezes the drop, causing necking down and finally separation of the globule from the electrode. It appears that if current can rise fast enough—respond quickly as the molten globule increases in size and as voltage drops—the rapidly increasing current increases the pinch-effect force fast enough to squeeze off the molten globule while it is still small. This makes for material transfer in smaller drops, reducing the probability of cold shorts.

The period between transfer of one drop and the next is in microseconds, presenting the welding supply with rapidly



**1—Volt-ampere characteristic** of the WSR welder (black line) compared with that of a conventional reactor-controlled constant-current welder (white line). As the arc voltage drops, the current increases linearly and also achieves a higher value at low voltages. The result is better fusion and transfer of the welding rod with consequent better arc stability.



**2—WSR rectifier welder** is designed for simplicity, light weight, and low cost, as well as for unusually stable arc operation and precise current control. Transformer is of open delta design. A rheostat and fixed resistors that can be switched in or out of the load circuit control the welder's arc current.

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Information in this article was supplied by the Welding Department, Westinghouse Electric Corporation, Buffalo, New York.

varying transient electrical parameters. Consequently, the dynamic response characteristics of the power supply are of major importance in the performance of the arc.

### *Design of the Welder*

The new WSR industrial dc welder is engineered especially for applications where fast response is critical because lost arcs cannot be tolerated. As mentioned, its arc current is controlled by resistance instead of by the traditional inductive reactance system (see Fig. 2). The higher arc current achieved as arc voltage drops aids fusion of the electrode tip and tends to prevent cold shorting. More important, the resistance-controlled welder has no time delay in response to arc voltage drop. In contrast, inductance in the conventional reactor-controlled welder causes a definite time delay in current response after a change in arc voltage. This time delay and the lower maximum current value achieved result in less pinch effect.

The arc of the WSR welder is so stable that the entire current range can be run (from 320 amperes down to one ampere) without losing the arc. The welding arc can be maintained at extra low currents for light work. Arc current is established precisely and consistently by switching load resistors in series with the arc.

### *Construction and Circuitry*

To minimize weight and volume, the welder's three-phase transformer has two coils instead of the conventional three (see Fig. 2). Electrical performance of this open-delta construction is equivalent to that of the more conventional three-coil design, since the transformer load is balanced on all three phases. The load is balanced because it is pure resistance, with unity power factor. The entire transformer is impregnated with insulating varnish, then baked, making it highly resistant to heat and moisture.

The primary breaker is a shunt-trip, three-pole, sealed De-Ion circuit breaker for manual on-off. Thermostats embedded in the transformer coils in series with the breaker protect against coil overheating, which may be caused by exceeding welder current or duty cycle rating, internal faults, single phasing, fan motor failure, or restricted ventilation.

The three-phase, full-wave rectifier uses silicon diodes that are guaranteed for the life of the welder.

The dc output of the rectifier is connected to a bank of fixed resistors, connected in parallel, that can be switched in or out of the load circuit. Each additional resistor connected into the circuit adds another current path and thus increases arc current. The resistors are sized so that current can be stepped from 10 up to 80 amperes. When all the breakers are closed, they combine to a value of 310 amperes. A dial rheostat provides vernier stepless current adjustment over a 10-ampere range.

The IR drop in the control resistors reduces the electrical efficiency of the WSR welder as compared with that of reactance-controlled welders. (Electrical efficiency is the ratio of arc voltage to open-circuit voltage.) However, the WSR welder has the advantage of greater arc stability. Also, primary current is the same as that drawn by conventional rectifier welders having the same open-circuit secondary voltage, and the power factor is 100 percent as compared with 65 to 70 percent for other rectifier welders. The higher power factor improves the stability of the supply lines.

The pronounced arc stability of the WSR welder and the ability to precisely select arc current facilitate welding of x-ray quality on difficult work with any of the popular welding techniques—TIG (tungsten inert gas), consumable-electrode, and MIG (metallic inert gas). Field tests have shown outstanding results.

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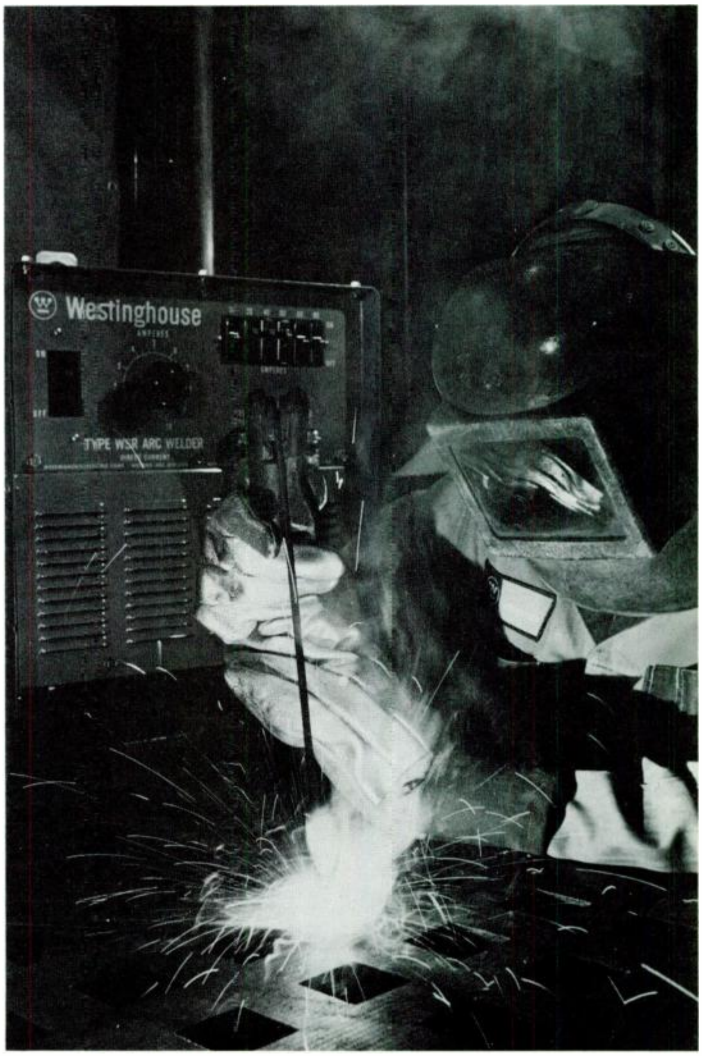
**May 1965**



3—**Welding unit** is shown at left in this photograph. The operator is using it for consumable electrode welding.

# T-100: A New Systems Drive Concept

by S. J. Campbell

*Component design, application engineering, and factory testing by computer process simulation combine to provide effective systems drives that require far less startup time.*

A totally new concept in systems drives has been developed and applied successfully in a number of industries. It consists partly of a basic reorientation of application engineering, design engineering, manufacturing, system testing, and system startup so that all of these activities are more fully geared to immediate and long-term customer needs. The other part of the T-100 concept is a standard set of modular power and control components, including a unique regulator, that can be combined as required to perform the varied drive and control functions demanded by modern process systems.

The T-100 concept benefits users directly through improved system accuracy and response, faster shipments, lower costs, versatility, rapid generation of drawings and engineering data, quick efficient startups, and easy maintenance. Several hundred T-100 drive systems have been applied in the paper industry, and increasing numbers are being applied as drive systems in the rubber, textile, and metals industries and for dynamometers.

### Systems Drives

A systems drive consists of five basic elements—prime mover, power source, power hardware, director devices, and a feedback regulator (Fig. 1). The prime mover is one or more dc motors with suitable gearing. The power source might be a dc generator or a static thyristor supply. The power hardware includes such devices as line contactors, overload relays, ammeter shunts, and knife switches. These devices are all large power-transmitting units, with ratings determined by the size of the drive motor.

The director devices include panel-mounted sequencing relays and also such external devices as pushbuttons, limit switches, selector switches, and speed or position sensors. The regulator is essentially a process-oriented function generator that provides control of speed, voltage, torque, tension, or position as required by the process.

### The T-100 Concept

The five basic elements were listed intentionally in the preceding paragraphs in order of increasing complexity and amount of special engineering required to tailor the element to the individual process requirements. The T-100 systems drive concept exploits this relative complexity of elements in the design and application of a system: the elements requiring the least special engineering are processed first. This approach benefits users directly because better control of shop loading, material inventories, and work scheduling all lead to lower costs and faster shipments.

The prime-mover and power-supply elements are usually selected in the early stages of a system application. Consequently, they can usually be processed immediately from order entry to detail design and manufacture.

The remaining three elements require more engineering, so the T-100 approach centers mainly on them. Except for those director devices that are externally located, these three

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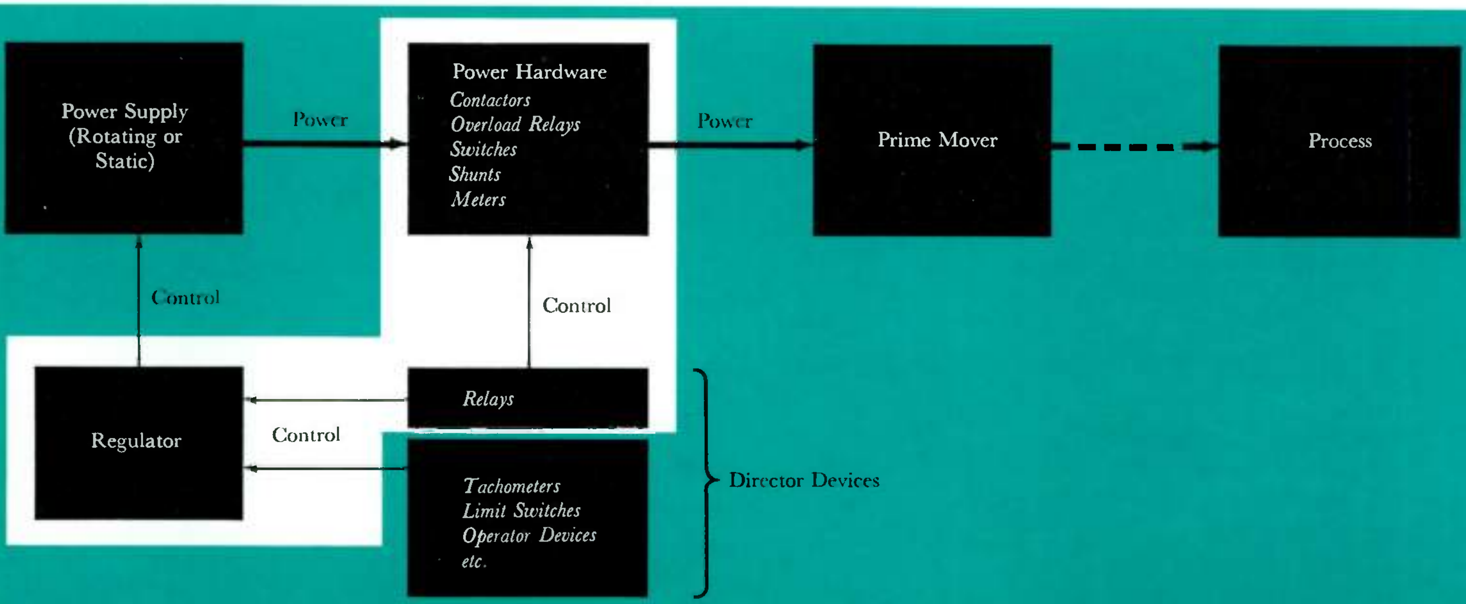
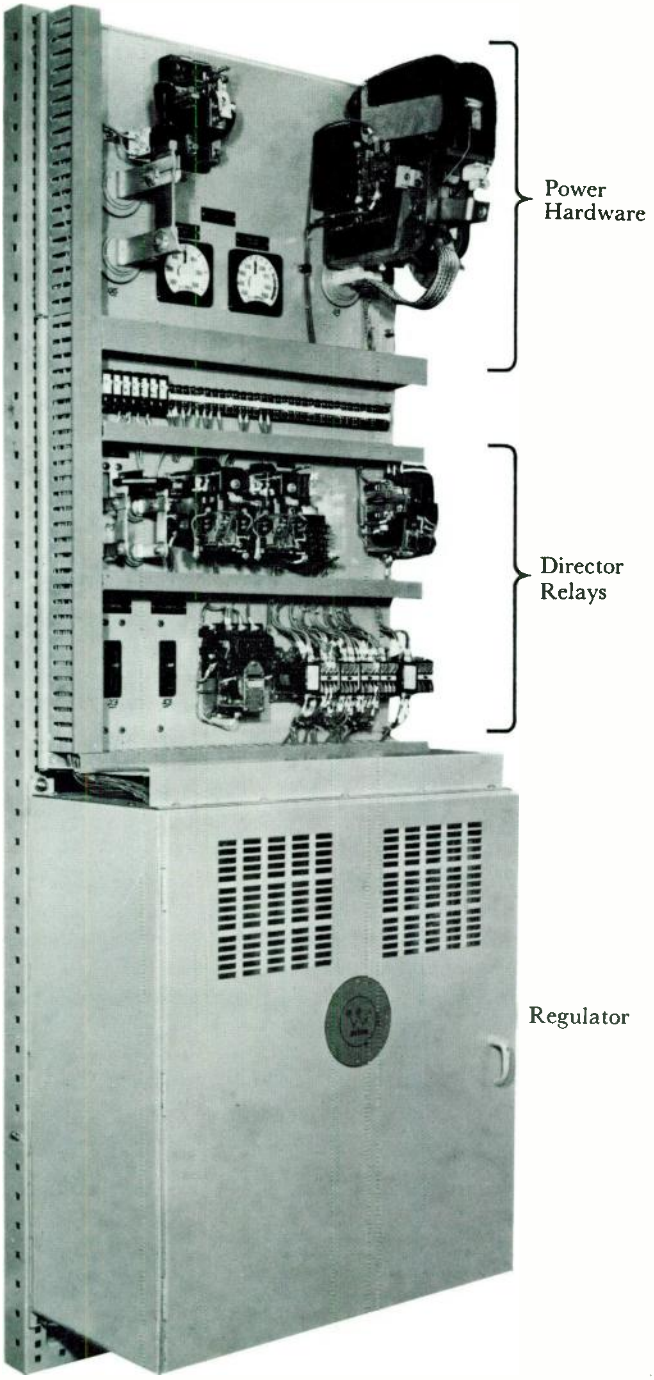
S. J. Campbell is Manager, General Industries Systems, Westinghouse Electric Corporation, Buffalo, New York.





1—**Generalized systems drive** *(left)* includes power supply, power-handling hardware, director devices, regulator, and prime mover. In the T-100 concept, the central elements are grouped in a controller *(above)*. Although they are thus grouped, the elements are kept separate so that they can be designed, manufactured, tested, and shipped separately for maximum production flexibility. All logic communication with the controller is through the director relays.

elements form parts of a single controller for a particular driven section of the process to be controlled. This basic controller is divided physically so that it, too, can be engineered and manufactured on an individual-element basis. For example, a typical controller includes a power panel, director panel, and regulator panel (Fig. 1). The power panel can be laid out and manufactured as soon as basic drive functions are settled. (These basic functions may include power metering, type of overload protection, disconnects, reversing, dynamic braking, and whether one or more motors are to be used.)

The prime purpose of the director panel is to control the logic sequencing between the power panel and the regulator and between the entire controller and the external operator-control and sensing devices. This panel is the smallest element, physically, but is extremely important to the total system because the functional requirements that are peculiar to the controlled process are all centered on inputs to and outputs from the director panel. The panel is made up of a row of relays. All external sequence control signals are wired to these relays, and the relays in turn provide logic for sequencing the regulator and power panel. The array of relays includes space for future additions so that the user is assured that last-minute decisions on sequencing, interlocking, and additional operating functions need not result in a major design change. For example, a decision to add a maintained "Slow-Run" function instead of momentary contact requires only the addition of another relay in space already available.

Although process-oriented engineering and manufacture of the logic and power panels is an important element in assuring a successful system, by far the most vital element in any systems drive is the regulator. It must reflect the best possible combination of total know-how in process requirements, engineering design, manufacture, quality control, test, startup, maintenance, and long-term process modernization. The present generation of T-100 regulators is a true optimization of these items. Each startup of systems with these regulators gives further evidence that new benchmarks of quality performance are being established. Process startup times are as low as two hours with the T-100 regulators, with no further adjustment required after the process is in full production. This is a reduction in startup time from that of previous systems of about 75 percent.

### *The T-100 Regulator*

The T-100 regulator is an adaptation of industrial modular solid-state devices in a circuitry that permits control parameters (such as response, stability, and gains) to be calculated, verified, and preadjusted before startup. Input-output impedance and voltage levels are such that each regulator can be directly and fully closed-loop tested with a computer process simulator before shipment. This testing is performed on every T-100 regulator.

The modular components, known as the Westinghouse M3 line, have important user advantages. No plug-in construction is used; instead, all modules are front connected with screw terminals to eliminate malfunctions due to poor or corroded connections. The rugged steel modules also are front mounted with captive screws, so there is no need to provide rear access to the assembled regulator. All adjustments for gains, damping, output ranges, and so on are made with front-mounted switches and with rheostats operated by a screwdriver. This arrangement speeds startups by eliminating the need for internal rewiring and internal component replacement for final adjustments.

The M3 modules are available in a complete line of functional designs to provide separate external control functions. They include power amplifiers, current/voltage transducers, operational amplifiers, tension transducers, gating amplifiers, saturation curve function generators, motor-operated memory rheostats, and ramp function generators (time-based speed/voltage change). Since each module is oriented to an external function, the historic interface between regulator application and design has been largely eliminated. The application engineer can easily select a complete set of function modules, once he has determined the total requirements of a regulated system. The result is a custom regulating system built up of standard modules (Fig. 2).

The circuitry, module selection, and physical configuration of the T-100 regulator also offer distinct advantages.

The circuitry is an adaptation of a type two servo system, with two forward integrating loops. The historic approach to feedback systems was to provide not more than one stage of integration, if any; all reference inputs, stability feedbacks, and controlled variable feedbacks were directed back to the regulator input amplifier (Fig. 3a). This arrangement, while successful in many instances, had several definite limitations. First, the calculations for stability, response, and output ranges required to select regulator component sizes and settings were time-consuming and often inaccurate. In many designs an educated guess was made, which resulted in effect in completing the design at startup. Another limitation was the difficulty in arriving at standard regulators to reduce manufacturing and engineering time and also to reduce the cost of maintaining spares. The new T-100 regulator abolishes these limitations.

The T-100 regulator has two or more forward integrating loops for regulating instead of the historic single loop (Fig. 3b). In the two-loop principle, the armature current (i.e., output torque) is regulated first. This inner current loop provides a mass stability in the forward direction. The outer loop then becomes the overall process controller for speed, tension, voltage, or position. The use of separate operational amplifiers within each loop provides sufficient predictability so that the outer loop is a continuous stabilized reference to the inner loop. With this circuitry, the number of interacting variables has been greatly reduced. Calculations for component settings are much simpler and can be made with assurance that the values are predicted with the desired accuracy. Moreover, final adjustments on startup are noninteracting. Consequently, "tuning a regulator" has become an art of the past. Each adjustment has to be made only once; there is no need to repeat it for optimization.

The T-100 regulator includes a complete complement of metering equipment. This metering, along with the terminal accessibility of all wiring, allows full trouble-shooting without shutting down the controlled process.

Each regulator is complete with its own power supplies and isolating modules. This feature provides full electrical separation between adjacent driven sections of the process and between, say, a high-voltage dc motor bus and the low-voltage control circuits. It also completely eliminates the "common ground" source of sneak circuits and the generation of intermittent noise signals. All wiring to the rows of modules is made in a radial fashion to eliminate any possibility of noise generating loops. Similarly, all wiring external to the regulator is made in accordance with prescribed "quiet wiring" techniques, with combinations of twisted pairs, single or double wire shielding, and proper spacing between adjacent signal carriers.

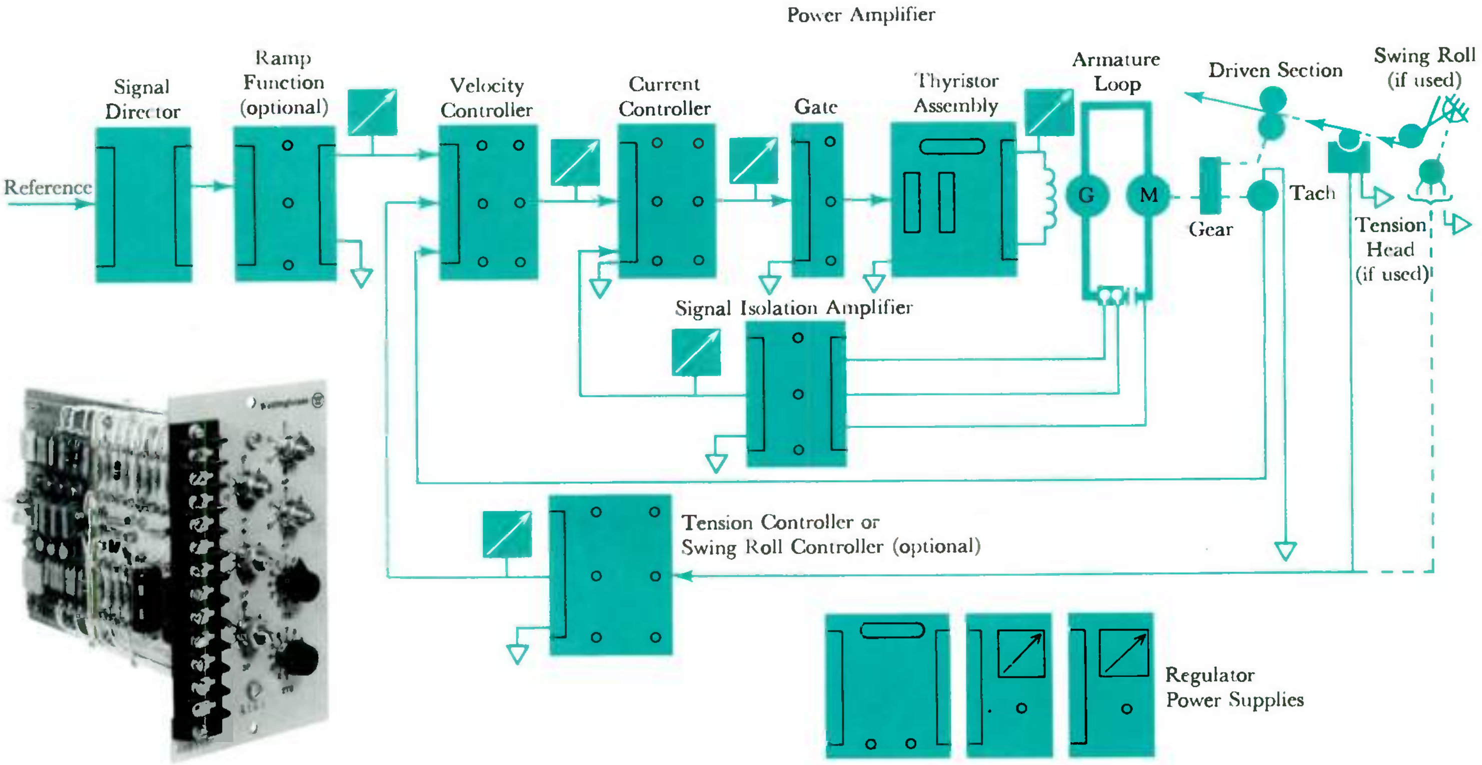
The use of sealed mercury-wetted relays within the regulator itself further reduces noise or loss of system signals through high-impedance coupling. Most regulator systems require a number of make or break circuits to calibrate for separate functions such as jog, slow, tension on-off, and torque limit on-off. Ordinary relays, including those with noble-metal contacts, eventually become sources of noise or gain changes because of changes in contact resistance. The sealed mercury-wetted relays completely eliminate these causes of process downtime.

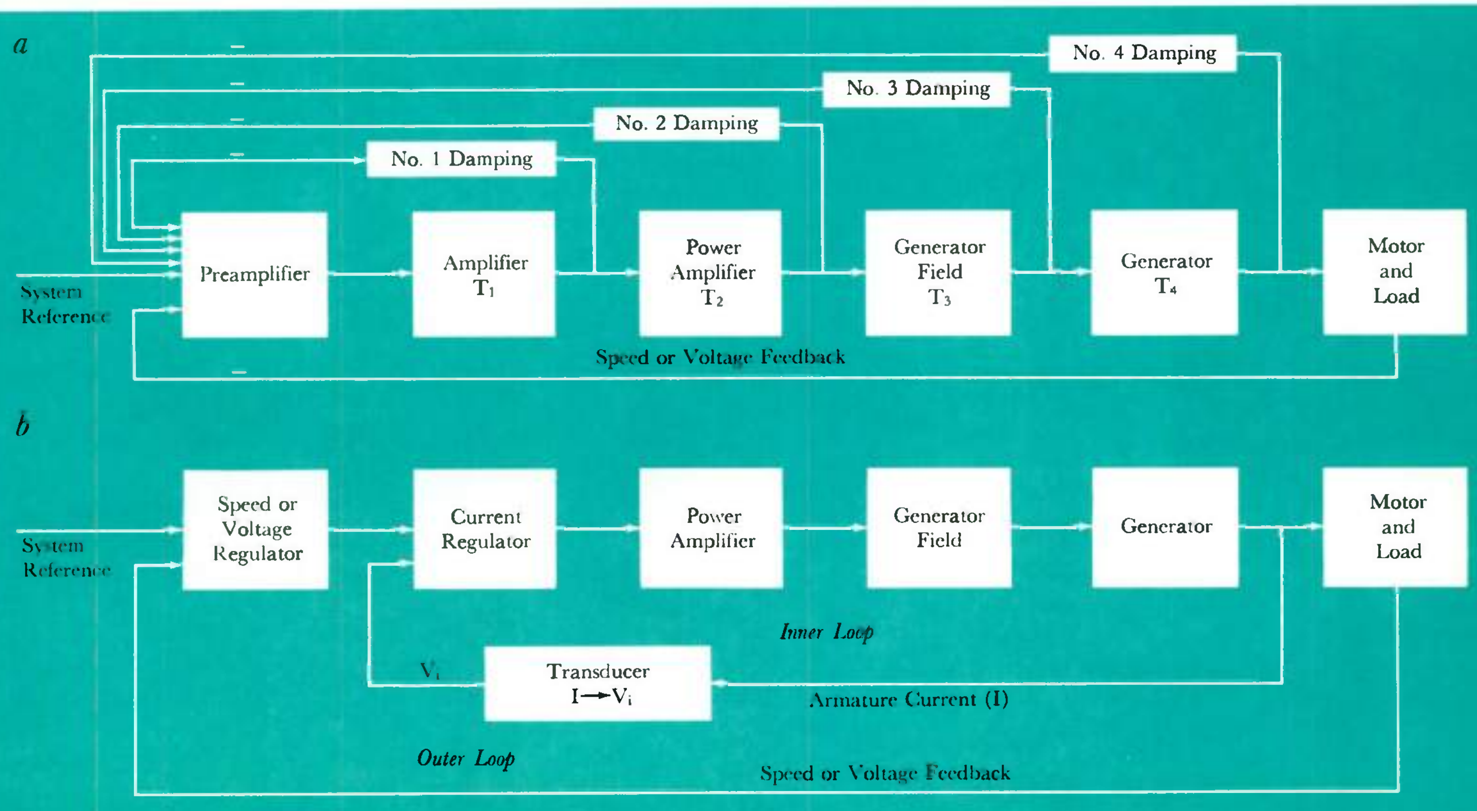
Space is usually provided within the regulator enclosure for later addition of such process control functions as tension control, time limit, torque limit, and position setting. This gives the T-100 regulator long-term versatility to meet changing process needs.

A most important advantage of the T-100 regulator is its application flexibility, which enables it to fit into existing driven processes as a modernization replacement to meet process needs not available with existing regulators or to provide additional regulated drives to new sections of a process. The standard T-100 regulator has its own power supply and

**2—Typical T-100 regulator** consists of a number of M3 function modules arranged to provide the required control of the user's process. Each regulator has its own power supply for electrical isolation, and each has provision for addition of control functions for flexibility. The photo inset shows an M3 module (a velocity controller) with its sheet-steel enclosure removed.

**3—Regulator design** consisted traditionally *(a)* of feeding back each time constant ($T_1 \ldots T_n$) through transformers, resistor-reactor networks, or resistor-capacitor networks to achieve closed-loop stability. The resulting interactions, and the complex system equations needed to provide system stability at the required responses and gains, often made it necessary to complete the system design by time-consuming adjustments at startup. The T-100 regulator *(b)* takes a totally different approach. It has multiple forward regulating loops so that it can be adjusted for optimum performance by the use of simple step-by-step calculations.


Power Amplifier
Reference
Signal Director
Ramp Function (optional)
Velocity Controller
Current Controller
Gate
Thyristor Assembly
Armature Loop
G
M
Driven Section
Swing Roll (if used)
Gear
Tach
Tension Head (if used)
Signal Isolation Amplifier
Tension Controller or Swing Roll Controller (optional)
Regulator Power Supplies


a
No. 4 Damping
No. 3 Damping
No. 2 Damping
No. 1 Damping
System Reference
Preamplifier
Amplifier T₁
Power Amplifier T₂
Generator Field T₃
Generator T₄
Motor and Load
Speed or Voltage Feedback
b
System Reference
Speed or Voltage Regulator
Current Regulator
Power Amplifier
Generator Field
Generator
Motor and Load
Inner Loop
Vᵢ
Transducer I→Vᵢ
Armature Current (I)
Outer Loop
Speed or Voltage Feedback

is completely self-contained. It can be incorporated singly or in any desired number without requiring major changes to existing power panels and director devices. For these reasons, more than half of the present T-100 regulator installations have been in existing processes.

Performance quality is illustrated by the following typical performance figures for the T-100 regulator used as a high-accuracy speed controller: Steady-state regulation of plus or minus 0.1 percent with 50-percent load change; system drift during any eight-hour period of plus or minus 0.1 percent with ambient temperature change of 68 degrees F to 104 degrees F, ac supply voltage change of plus or minus 10 percent, and frequency change of plus or minus one-half cycle; regulator response time of 0.16 to 0.2 seconds; and ability to follow a ramp input with essentially zero error.

### *Regulator Testing*

Factory testing of the T-100 regulator by closed-loop process simulation has two major benefits to users. First, it gives the systems engineer an immediate factory check of the performance parameters and of the stability of the circuits he has selected for the controlled process. In the past, this checking was often done during startup and led to costly delays before the process could be turned over to production. Second, the closed-loop simulation provides a total quality test of the regulator system, which assures that all wiring, sequencing, and module-to-module components are in full working condition. Again, in the past many of these potential troubles could not be detected and corrected until the control loops were closed in the field, with the user's process directly involved. Simulation of the user's process as an integral part of the factory test substantially reduces the length of time that the process must stand idle before going into profitable production. Testing by simulation also eliminates the need for costly downtime after startups to make final system adjustments. A high-speed paper machine equipped with T-100 systems drives recently went into production within 20 minutes after startup. No drive adjustments were required during or after this period. In the past, it has been necessary to schedule several hours of process production time after startup for these adjustments.

To test a T-100 regulator, an analog of the process is first drawn up from such information as gear ratios and inertias, supplied by the user, and process dynamics calculated by the system designer. This analog is then transferred to the process simulator (an analog computer with strip-chart recorder) by adjusting rheostats and capacitors in the simulator. The assembled regulator is then wired to the simulator (Fig. 4). When the control, feedforward, and feedback loops are closed, the regulator in effect "sees" the entire process it is to control. The chart recorder and the meters on the regulator reveal the control performance, which must agree with the calculated parameters before the regulator is assembled into a controller.

In addition to the simulator shown in Fig. 4, a similar but more complex simulator is available in the factory. It is used when such quantities as sheet tension, swing roll position, and flux memory are included in a regulator. Small portable simulators are used in the field for final checking before startup and also for trouble-shooting; though small, these units have ample capability for complete testing.

These testing and setting techniques, the unique T-100 regulator, and the T-100 systems drive concept as a whole are providing users with a highly profitable answer to today's process control needs.

**Westinghouse ENGINEER**
**May 1965**

**4—T-100 regulators are tested** at the factory by connecting them to a process simulator, which is an analog computer set up to simulate the process to be controlled. Its inputs and outputs are electrical equivalents of the process motors and generators and such quantities as tachometer voltages, load inertias, and friction. Chart recorder and meters tell whether the regulator is performing properly.

# Direct Tension Regulation for Large Winders and Rewinders

by C. L. Ivey
W. C. Carter

*A new drive system for high-speed winders produces rolls of superior quality. It is built largely from the standard proved T-100 modules.*

In the paper industry, as in many continuous-strip process industries, the product is produced in an endless strip as rapidly as possible. As a result, the strip (or "sheet") is delivered from the processing machine (say a papermaking machine) in a roll that not only contains salable product but may also contain product that is off specifications and has one or more breaks. Also, the core on which the roll is wound is a nonexpendable part of the machine, and the sheet may be too wide for commercial use. The function of the winder or rewinder is to remove these deficiencies and provide a product neatly wound on expendable cores in the widths and diameters demanded by the customer. (Some production operations require more than one winding operation as the sheet undergoes various processes; the second and all subsequent winding operations are often called *rewinding.*)

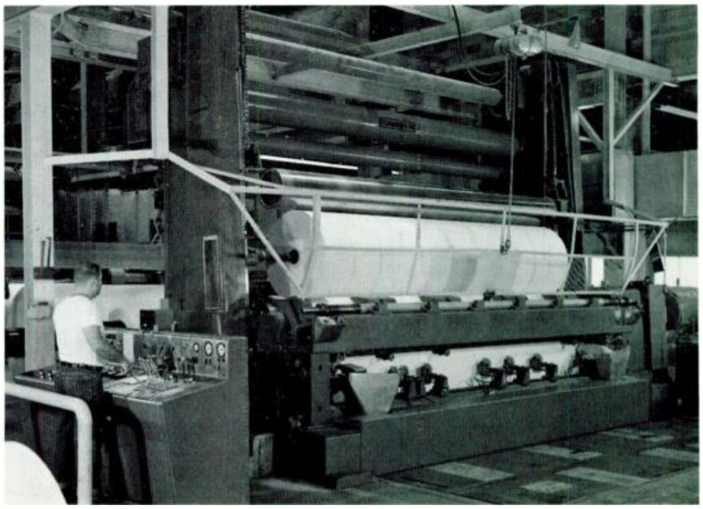
A winder is basically a very simple machine (Fig. 1). The original roll of paper ("parent roll") is unwound from one stand over one or more idler or guide rolls and rewound on a second stand. The edges are usually trimmed to give the sheet a uniform width, bad portions are removed and the sheet neatly spliced together again, and the sheet may be slit into various widths as required by the customer. The unwind stand is normally core driven (i.e., its drive or brake is coupled directly to the core on which the paper is wound) to accommodate the large-diameter (perhaps 84-inch) rolls it must unwind. The windup stand consists of one or two drums that drive the windup roll by frictional contact. Small (about three-inch) expendable cardboard windup cores are used because they are easily cut to the length dictated by the slitting being done.

Perhaps the most important variable in the winding operation is tension in the sheet. If tension varies, the sheet will tend to decrease slightly in width as tension increases and increase slightly in width as tension decreases. This condition is intolerable if the wide parent roll is being slit into many narrow windup ("shipping") rolls, as the edges of adjacent shipping rolls interleave and do not separate cleanly. Variations in tension also cause variations in the "hardness" of the wound roll. This affects its storage properties (such as moisture absorption) and its suitability for use in high-speed high-quality printing operations. A roll wound with variable tension will unwind with variable tension, and the resultant variable extension of the sheet as it unwinds plays havoc with sensitive register controls for color printing, with precision length-cutting operations, and the like. Control of sheet tension is thus a most critical function of a winder drive.

Modern winder drives are of several hundred horsepower and produce sheet speeds of 6000 feet per minute (fpm) or more. They are required to accelerate and decelerate between standstill and top speed as often as once every two or three minutes, all the time precisely controlling sheet tension. The tension may be adjusted by the operator over perhaps a 10-to-1 range. Acceleration and deceleration rates must be quite high —in the range of 100 fpm per second—to maximize top-speed running time and thus production throughput. These stringent drive requirements have led to the virtually exclusive use of adjustable-voltage dc drives, since those drives lend themselves best to sophisticated control schemes. Because the windup drive turns fixed-diameter drums, its rpm/fpm and torque/sheet-tension ratios remain constant; consequently, a normal Ward-Leonard drive arrangement is used. The unwind drive, however, is subjected to varying rpm/fpm and torque/tension ratios, so it requires a more complex drive than is required on the windup.

Since the sheet will not support compression, the windup drive is given the task of setting the speed of the sheet—more or less pulling the unwind along. The unwind is assigned the task of maintaining the correct tension in the sheet by applying the correct amount of braking (or motoring) torque. Since the required unwind effort is usually in the braking direction, pneumatically or hydraulically controlled shoe brakes are extensively used for this purpose. However, brakes cannot supply motoring torque, so the sheet tension must supply all the torque required to accelerate the massive parent roll. This tends to make the acceleration time of the winder unaccept-

C. L. Ivey and W. C. Carter are in General Industries Systems, Westinghouse Electric Corporation, Buffalo, New York.



**1—Paper winder** built by Cameron Machine Company is driven and controlled by the system described in this article. The winder unwinds the large hastily wound roll delivered by the paper machine or other production machine and rewinds the material with precisely controlled sheet tension to produce high-quality shipping rolls. Simultaneously, it trims the edges of the sheet and may slit the sheet into several shorter rolls.

ably long when winding thin paper (which requires light tension) at high speed from large parent rolls; consequently, the trend is to the use of electric machines on the unwinds of the newer winders.

In the past, the biggest failing of electric unwind drives was that they used electrical quantities roughly indicative of sheet tension as the regulated variable. The most common method was to arrange the unwind motor (often called a braking generator) in such a way that its cemf was proportional to sheet fpm during normal running. This arrangement forces the machine armature current to be proportional to the pull exerted at the surface of the roll. The pull, it was correctly reasoned, is primarily sheet tension, so the regulation of sheet tension is reduced to regulating the armature current. Minor factors such as friction and windage losses were ignored, and the effect of parent-roll inertia (which tends to increase tension during acceleration and decrease it during deceleration) was accounted for by various methods of changing the value of armature current being regulated during periods when the speed was changing. These measures were fine in their day, but the magnitude of the varying friction and windage losses and the difficulty of accurately accounting for the effect of parent-roll inertia (as the parent roll varies over a diameter range of six to one or more) limit their usefulness to operating tensions of about one pound per inch width or more. At lighter tensions, variations in losses and errors in any practical inertia-compensation system are too large a percentage of the desired tension, and the system is unsatisfactory.

In the past few years, increasing postal rates, transportation costs, and material costs have given rise to a trend to lighter papers. Such papers have to be wound at lighter sheet tensions, often about half a pound per inch width. To meet this requirement, an all new drive system has been developed, the keystone of which is sensing and regulation of sheet tension *directly* rather than through electrical quantities.

### *System Design*

The selection of a tension-sensing transducer was the most obvious decision to be made in the design of the system. Two general types are available. One uses sheet tension forces to work against a spring, with the slight spring motion (about 0.030 inch) detected by a linear differential transformer to provide an electrical signal. The other uses the sheet force to develop a hydraulic pressure that is converted to an electrical signal in a pressure-to-current transducer. With the second system, sheet deflection is very small (about 0.001 inch). Both systems have a full-width guide roll mounted on the tension-sensing devices at each end.

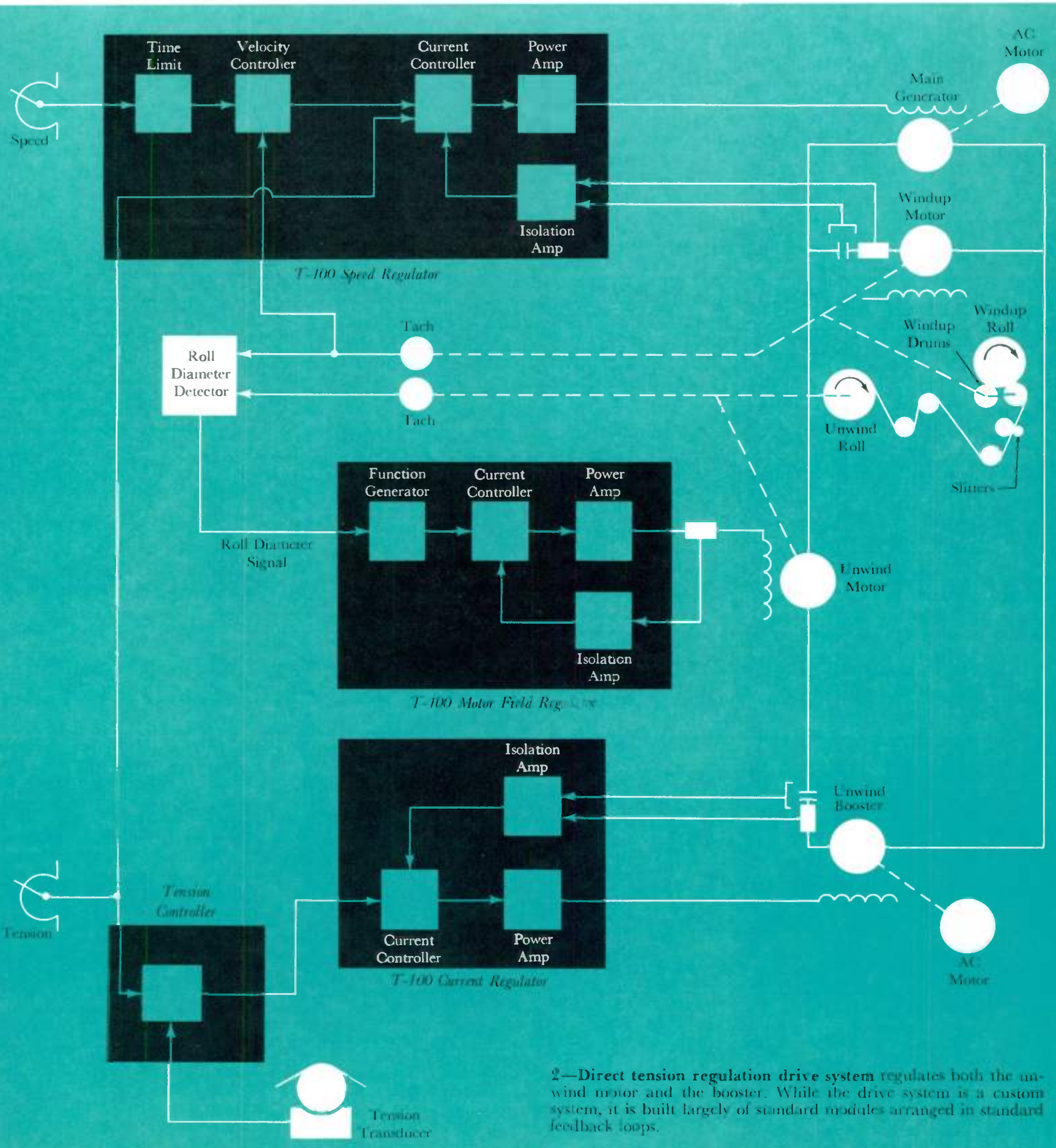
The hydraulic type of tension transducer was chosen to gain the advantages of hydraulic damping and to avoid the resonant frequency problems that analysis indicated could be presented by the guide-roll mass mounted on a spring.

The second decision involved the manner in which the braking generator field was controlled. The use of a direct tension regulator instead of an armature current regulator with inertia compensation promised, and has delivered, exceptional performance. However, the old system of controlling the braking generator field to keep the braking generator cemf proportional to sheet fpm had a serious defect—at standstill, there was neither any cemf nor any sheet fpm, and the braking generator field strength was undetermined. This would result in a transient when the winder was first started, while the field got to the proper value. Since the first few wraps on the windup are very important, being in a sense the foundation of the roll, it was decided to eliminate this transient (even though the direct tension loop would have minimized its effect on sheet tension).

In any core drive, it is usually desired to maintain drive-motor flux proportional to roll diameter; this causes the cemf to be proportional to roll surface speed and the armature current to be roughly proportional to sheet tension. This characteristic was still desired in the new system so that the windup and the unwind could, if desired, share a common armature voltage source. To achieve it, a servo divider called a roll diameter detector was developed. This unit determines the ratio of sheet fpm to parent roll rpm. Since this ratio is proportional to roll diameter, the output of the unit can be used wherever diameter information is useful, the most obvious use being as a reference for the braking generator field regulator. Coupled with a function generator representing the relationship between braking generator flux and field current, the roll diameter detector maintains the braking generator flux proportional to roll diameter and thus keeps the tension regulator within its operating range. When a new parent roll is placed in the winder, the operator presets the new diameter into the system with a calibrated meter; the system is then fully automatic, with no starting transients caused by the braking generator field hunting for its proper value.

The overall drive system is illustrated in Fig. 2. Its windup is driven by a standard T-100 two-loop speed regulator. This regulator is probably the most flexible dc drive regulator available, short of a general-purpose analog computer. It is characterized by an inner current loop that inherently provides overriding current-limit protection and, in the winder, a place to insert a windup current proportional to the unwind current being called for to produce tension. This feature prevents the winder from creeping forward or backward (at a speed so low the speed feedback tachometer cannot recognize it) when the winder is nominally at a standstill with the unwind drive putting stall tension into the sheet.

The operator's speed cue gets to the speed regulator through a timed acceleration-deceleration circuit to minimize operator-initiated transient disturbances. The windup speed regulator includes adjustable speed droop with load, a characteristic necessary to avoid interaction between the windup and unwind regulators. The roll diameter detector and its signal connection to the braking-generator (unwind-motor) flux regulator are shown in the figure, as is the unwind direct tension loop that operates on the unwind booster. Note that the tension loop feeds an unwind current loop; this arrange-



**2—Direct tension regulation drive system** regulates both the unwind motor and the booster. While the drive system is a custom system, it is built largely of standard modules arranged in standard feedback loops.

ment provides current limit protection for the unwind drive and also enables the new direct tension regulation system to oversee the older current regulation system, making correcting adjustments only when a tension error so dictates. The overall system is composed of several simpler regulating loops, each of which is in turn composed of several standard M3 modules, the heart of which is the operational amplifier. Isolation amplifiers between the high-energy armature bus and the low-energy regulator circuits eliminate sneak-circuit maintenance problems.

### *Component Development and System Test*

The first problem in the drive design was to develop the servo divider for calculating roll diameter. It was decided to use a motor-operated rheostat with its armature supplied by a constant voltage, rather than using the variable output voltage of a power type amplifier as has been done with rheostats in the past. The signal for the rheostat to run is provided by relay contact closures initiated by the output of a unidirectional operational amplifier. The inputs to the amplifier are sheet speed and unwind core speed, modified by the shaft position of the motor-operated rheostat. As the parent roll unwinds with constant sheet speed, the core speed increases; this causes the relays to be energized, driving the motor-operated rheostat. This in turn reduces the core speed signal and cuts off the amplifier, stopping the rheostat. Thus, the angular shaft position of the rheostat is proportional to roll diameter regardless of sheet speed. A preliminary study determined that the roll diameter detector must have a deadband and a rather large time lag in the amplifier to prevent high-frequency operation of the control relays, which have a definite maximum frequency. Analysis on an analog computer quickly determined the optimum parameters.

The entire drive was then simulated on the analog computer. This complete simulation required more than 60 amplifiers, 4 multipliers, 2 function generators, and a 6-channel recorder. Comparisons were made between tension regulation

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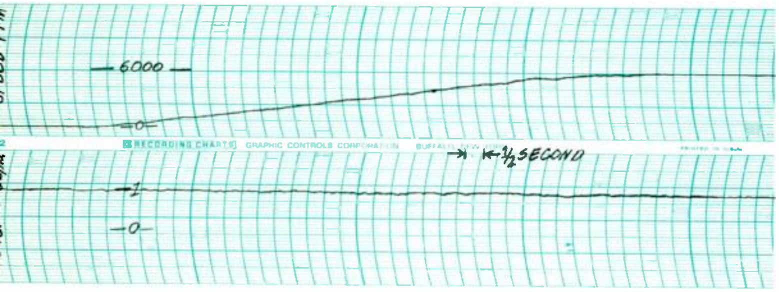

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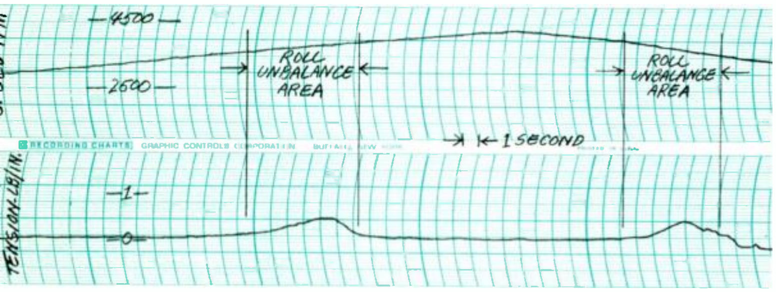

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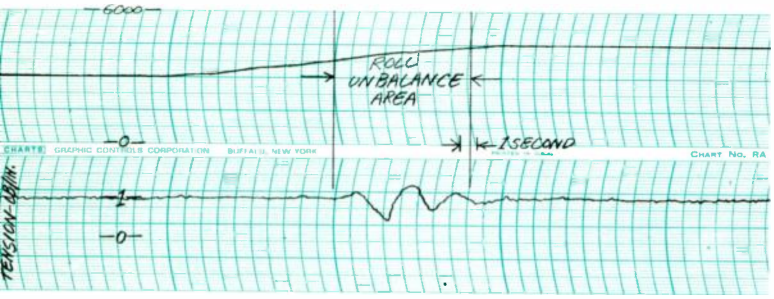

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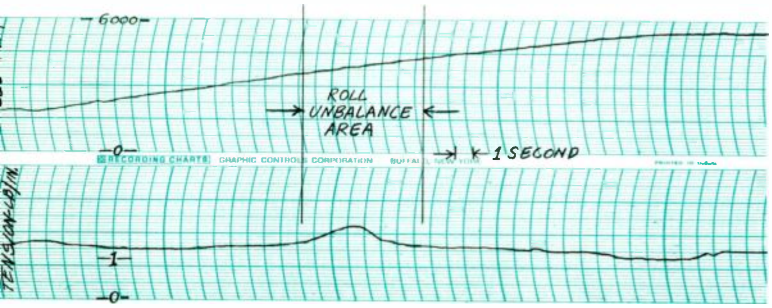

**3a—Normal operation of a winder** under direct tension control (with a balanced tension roll) is illustrated by these strip-chart recordings from an actual installation. Tension is maintained accurately during acceleration from standstill to top speed.

**3b—Erroneous apparent tension indication,** recorded during winder operation with no paper web, was caused by vibration of the tension-sensing roll due to unbalance. The "roll unbalance area" is the speed range in which roll unbalance excites vibrations in the roll.

**3c—Acceleration through roll-unbalance area** under direct tension control. The tension control system reacts to the erroneous tension signal caused by tension-roll vibration, correcting for a tension change that does not exist. The result is tension variation continuing until the roll unbalance area is passed.

**3d—Acceleration under current control.** The apparent tension increase at about 3700 fpm is again due to tension-roll unbalance, but the current-control system does not react to it. Direct tension control (Fig. 3a) holds tension more accurately than does current control with inertia compensation, provided the tension roll is properly balanced or the unbalance does not excite roll vibration.

and armature current regulation; as expected, tension regulation proved far superior.

With the theoretical design verified, the next concern was the mechanics of building the control. The actual physical component values were determined from the scaled computer solution. The modular concept of component packaging was used throughout, even to the power and sequencing relays. As many standard modules were used as possible, but several had to be developed. The sequencing panels have machine-tool relays. Individual standard armature panels rated on a horsepower basis fill the top portion of the cabinets. A number of meters are permanently connected to monitor all outputs and most input signals. Switches are provided on the faces of several of the modules in place of high-resistance potentiometers to permit easy calibration of the drive for a wide range of parameters.

While the computer is an invaluable tool in the design of such a system, testing is just as (or more) important. Each regulator was tested with the analog computer to find and eliminate any possible errors in transposition of computer parameters into physical components or in drawing and wiring. Also, this testing again verified the system as a whole. The computer simulates the rotating equipment and sheet dynamics, receiving inputs from the regulator and making outputs to the regulator. A computer test of this nature enables the designer to verify his design for specific data received from the machinery manufacturer and process operator, and also to vary such parameters as inertia and friction.

This type of regulator easily lends itself to computer testing because predictable operation occurs repetitively, which was not always true of the previous regulating systems. In practice, the designer calculates all potentiometer and switch settings before test. The time required for this task is greatly reduced from that required with other systems by the multiple loop design of the regulator. In the past few years, since systems using operational amplifiers as control components have been used, the calculated values have rarely had to be changed more than a few percent. This leads to the almost unheard of type of startup in which one pushes the button and goes into production.

### *System Startup*

The most difficult regulator to set up in the paper industry has been a winder with regenerative braking. The previous type current regulator was hard to keep in range, inertia compensation was difficult to adjust over the range of roll diameters and acceleration rates, and no measure of actual tension was available. Such a drive would require over a week to set up.

Use of the direct tension control has reduced startup time considerably. The first drive was put into service as a current-regulated type in less than 10 hours. Addition of direct tension control took about 8 hours longer, for a total time of setting up all regulators of about two 8-hour days. Calibrating the tension-sensing system is a simple matter, since downward force on the roll can be converted to pounds tension; placing known weights on the sensing roll enables one to make the tare and calibration settings directly without the sheet.

Several possible problems were foreseen during the drive development that could not be verified in the design stage. The main concern was for the aerodynamics of the guide rolls at high and low speeds. It was thought (and verified at startup) that, as sheet speed increased, air films would be built up between the first guide roll and the sheet; if the roll were driven only by sheet contact, the air film would cause slippage at high speeds resulting in uneven tensions on each side of the tension-sensing guide roll. It was decided to drive the roll with a dc motor to make its speed approximately the same as that of the sheet (with a booster to provide IR compensation) and thereby to remove the problem of sheet slippage changing with speed and causing apparent tension changes. The actual accuracy of the speed match was not determined, but the startup seemed to justify driving the first guide roll. Tension changes over the speed range without the guide roll driven were significant.

Another nonelectrical problem occurs when the sensing roll is not accurately balanced. A roll unbalance, caused by roll or bearing eccentricity or by a critical (resonant) frequency of the roll, produces vertical oscillations of the roll at certain speeds. This causes a displacement of the sensing device not proportional to actual force or tension. The basic advantage of the hydraulic transducer over the system of mechanical spring and differential transformer is the higher resonant frequency of the former, due to its smaller displacement, and its inherent hydraulic damping. Tension roll balance is still critical, however, and on one installation the sensing roll had to be rebalanced and additional hydraulic damping added to the system by the use of needle valves.

Tension regulating performance of the system under direct-tension and current modes of control are shown in Fig. 3. These curves vividly illustrate the effect of tension roll unbalance and the reaction thereto of the system.

Yet another problem is vibration of the entire winder frame. As a winder is composed essentially of rolls running at high speeds, critical frequencies are always present. Different finishes on the paper as it comes from the paper machine cause vibrations at certain speeds that resonate with the critical frequencies, causing the entire winder to vibrate. Since the pressure-to-current transducer consists of mechanical linkages, the vibrations also cause the transducer to produce an output not indicative of actual tension. It is therefore necessary to mount the transducer on the most rigid part of the frame.

### *Summary*

The present need to wind paper at light tensions with large parent rolls and high speeds has tended to force the use of electric unwind drives instead of hydraulically or pneumatically controlled friction brakes. A practical and economical all-electric winder drive of high performance, incorporating direct sensing of sheet tension, has been developed and is producing rolls of superior quality.

**Westinghouse ENGINEER**
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## Power-Water Plant Makes Guantanamo Self-Sufficient

A combined seawater conversion plant and electric power plant has made the U.S. Navy base at Guantanamo Bay, Cuba, self-sufficient in its fresh-water and electric-power supplies. The seawater conversion plant consists of three multi-stage flash evaporator units, each capable of producing 750,000 gallons of fresh water a day for a total output of 2,250,000 gallons a day. The power plant consists of two turbine-generator units, each rated 7500 kilowatts.

Of the 15,000 kilowatts of electricity produced by the generators, 3500 kilowatts are used in the seawater conversion plant. The remaining 11,500 kilowatts are available for the base supply.

Westinghouse Electric International Company was prime contractor to the U.S. Navy Bureau of Yards and Docks for the project. In the first phase of the operation, Westinghouse dismantled, transported, and reassembled the seawater conversion plant previously built by the company at Point Loma, California. The next steps were design and construction of the two additional conversion units and the turbine-generator units.

The automatic extraction turbines are powered by steam furnished by three boilers. This steam is then used at low pressure in the flash evaporators of the water conversion plant before being fed back to the boilers.

Research on salt-water processing methods led Westinghouse to develop the flash evaporation technique. In it, raw seawater is heated to approximately 190 degrees and passed through a series of flash chambers that are maintained at less than atmospheric pressure. Part of the water flashes into steam, leaving behind salt and other impurities, and the steam is condensed into fresh water.

The Guantanamo installation is the thirtieth Westinghouse water conversion plant in operation or on order. These installations produce a total of nearly 14 million gallons of fresh water a day for public water supplies, for industrial plants, and for electric power plants scattered throughout the world.

## Radio Telescopes Will Have 130-Foot Movable Antennas

Design work is under way for the first of several 130-foot dish antenna systems to be used as radio telescopes at the Owens Valley Radio Observatory of the California Institute of Technology. The units will be the world's largest antennas that not only can be pointed to any spot in the sky but also can be moved on wheels along rails. The initial 130-foot antenna is made possible by a grant from the National Science Foundation. (The observatory itself was built by the Office of Naval Research, which also sponsors its operation.)

The Owens Valley observatory has already shed much light on the nature of radio sources, including the most distant known objects in the universe. The new antennas will augment twin 90-foot dishes, increasing the observatory's power manyfold and enabling it to "see" farther and more accurately than any other radio observatory. Addition of the new antenna system is expected to make the observatory the world's most powerful and flexible for the study of objects in and beyond our galaxy that radiate energy in the radio frequencies. It will be capable of attacking a wide variety of problems, ranging from investigations of the surfaces, atmospheres, and temperatures of the planets to the size and shape of the universe. The observatory is located in the Owens Valley 250 miles north of Pasadena, a good location for radio astromy because it is shielded from man-made radio signals by the Sierra Nevada and White Mountains.

The dish antenna, the gears and drives for turning the dish, and the trucks and motors to move it along rails will be built at the Westinghouse plant at Sunnyvale, California, where the system design is also being developed. Completion is scheduled for mid-1966.

The new radio telescopes will be mounted on heavy wheeled pedestals. They will move on rail lines in the form of a "T", whose stem will ultimately extend for three miles north-south and whose east-west crosspiece will be 7500 feet long.

**Fresh water and power** for the U.S. Navy base at Guantanamo Bay, Cuba, are produced by this integrated plant. The plant makes the base self-sufficient in water production and in power generation.

The rails will permit the dishes to be moved into a variety of patterns. They can be used singly or linked together as a single observing unit, the equivalent of a much larger dish than could be built.

As an optical telescope's mirror reflects light waves into an eyepiece, so the parabolic surface of the dish will catch and reflect radio waves to a receiver mounted in front of the dish. Each dish antenna and its pedestal will weigh 406 tons. The accuracy of the 14,000 square feet of aluminum parabolic reflecting surface on each dish will have to be maintained to within one-sixteenth to one-eighth of an inch under all conditions of gravity, motion, wind, and temperature. A steel rib complex provides stiff support for the parabolic aluminum surface, which is in the form of panels that have 936 adjustments.

## Supermagnet Maintained Four Days With Refrigeration System

As superconducting magnets continue to increase in field strength, in size, and in variety of applications, the ability to maintain the cryogenic environment economically, reliably, and continuously becomes a primary concern. To demonstrate that such magnets can be operated unattended and maintained indefinitely in the superconducting state, a magnet has been maintained in the superconducting state for four days with a closed-loop helium refrigerator.

Up to now, most superconducting magnets have been maintained in the superconducting state by immersing them in a container filled with supercold liquid. Their operation has been limited to the time required for the refrigerant to evaporate or by the need for periodic replacement of the refrigerant. The combination of an unattended refrigerator and a superconducting magnet demonstrates the feasibility of applying superconducting techniques to a wide range of problems outside the laboratory.

The standard Westinghouse superconducting magnet system employed during the four-day demonstration produced 50,000 gauss in an eight-cubic-inch working volume with a 15-pound magnet. The helium refrigerator system was designed by A. D. Little especially for unattended liquefying service. Helium gas at 250 psig is precooled by liquid nitrogen and then by a helium refrigerator. At 15 degrees K the gas enters a Joule-Thomson expansion circuit, and a portion is liquefied directly into the magnet operating dewar. The remaining cold gas returns through the system to the compressor. The compact refrigerator can liquefy up to 100 liters of helium a week in continuous operation with small utility requirements.

## Magnetic Vehicle Suspension Foreseen

New technologies, such as automatic control by electronic computer, are increasingly being incorporated into modern rapid-transit systems with the aim of making them faster, safer, more comfortable, and more convenient. Broad growth in science and technology, along with bold new ideas for improved mass movement of people, can be expected to produce entirely new concepts of mass transportation. One such concept is a magnetic highway that appears to have promise for high-speed land transportation systems.

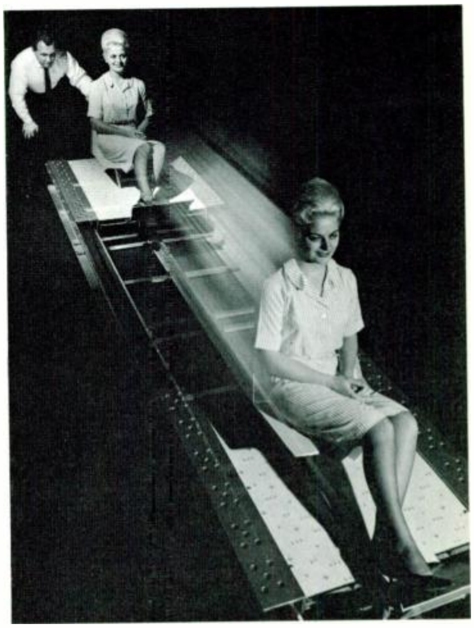
To demonstrate the principle of the magnetic suspension system, a small one-passenger vehicle has been constructed by the Westinghouse Transportation Systems Department. The test vehicle is supported by strong ceramic permanent magnets fastened lengthwise along its underside. Similar magnets of the same polarity form a double track beneath it. Since magnets of like polarity repel each other, the experimental car floats about one-fourth of an inch above its magnetic track. There is no physical contact and, therefore, no friction between the vehicle and its magnetic rails.

While not yet a proven system of vehicle suspension, the use of permanent magnets is being considered for future systems because of several potential advantages. Magnetic suspension would give vehicles excellent riding qualities, it would reduce propulsion power requirements, it would eliminate noise, and it would permit land travel above 150 miles per hour. Data from the laboratory model show that freight and passenger loads comparable to those transported by present methods of transit can be supported by such a magnetic suspension.

A magnetic suspension system requires that the magnets be strong and extremely resistant to loss in strength over extended periods. New ceramic materials commonly known as ferrite permanent magnets have the strength to supply the necessary repulsion force, and they resist demagnetization three to five times better than materials available only a few years ago.

The transportation specialists say that, in a full-scale system, the vehicle probably would be suspended from overhead instead of being supported from below as in the laboratory test model. The magnetic suspension and an electric drive could then be more easily shielded from the weather.

The drive system might be a linear nonrotating electric drive, essentially a



**Magnetically "floated" transit cars** of the future are demonstrated in principle by the small test vehicle photographed here in a double exposure. Magnets on the underside of the vehicle and in the double rails suspend the car slightly above the track. A light push sends the car on its almost frictionless trip.

motor stretched out. The stator would be mounted on the overhead roadway structure; the "rotor" would be mounted atop the vehicle, directly beneath the stator.

## Fuel-Cell Battery Produces Power Directly From Coal

A new experimental 100-watt fuel-cell system operates on coal, converting gases from the coal directly into electricity. The system was developed at the Westinghouse Research Laboratories under a contract with the Office of Coal Research, U.S. Department of the Interior. The program is aimed at the eventual development of a practical coal-burning fuel-cell system for large-scale electric power generation. However, the fuel cells are expected to be used for generation of dc power in industrial plants before they are applied in central-station power plants; electrolytic industries probably would be the first commercial users.

The experimental system consists of a fuel-cell battery and a chemical reactor for producing gases from the coal fed into it. Both the reactor and the battery operate at 1800 degrees F. High-temperature operation is considered the most promising approach for a fuel-cell system capable of burning natural carbonaceous fuels (such as coal, oil, wood, and natural gas) with air.

The 400 fuel cells in the battery are of a solid-electrolyte type pioneered by Westinghouse. Use of the ceramic electrolyte permits all-solid construction of the cells, doing away with the liquid or paste-type electrolytes employed in most fuel cells. It also permits compact designs, with high power output for a given cell volume and weight.

The cells are small ceramic cylinders, which are connected electrically and mechanically by assembling them end to end. Electrical contact is made through metal electrodes plated on the inside and outside of each cylinder. The cells are physically arranged in 20 stacks of 20 cells each and electrically connected to form two parallel strings of 200 cells in series. In laboratory tests, this battery of cells has achieved a power output 15 percent greater than the design value of 100 watts (100 volts at one ampere).

The gases extracted from the coal by the reactor are mainly hydrogen and carbon monoxide. This gas mixture is led into the battery and flows upward through the pipe-like stacks of fuel cells. Here it contacts the inner terminal (cathode) of the cell stacks. At the same time, heated air passes upward around the outside surface of the stacks, in contact with the outer terminal (anode). Oxygen in the air removes electrons from the anode surface, forming negatively charged oxygen ions. The ions move through the solid electrolyte and collect at the cathode. There they combine with atoms of the fuel gases, freeing the electrons that were picked up at the anode. This movement of electrons constitutes an electric current.

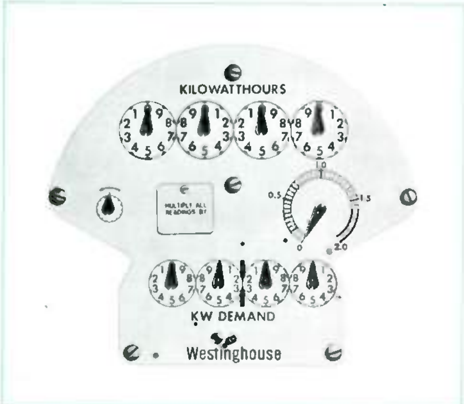
The experimental fuel-cell battery is housed in a heated oven to maintain its 1800-degree temperature. Cell systems of several kilowatts would generate enough heat to maintain this operating temperature without an external heat supply.

## Products for Industry

Mark II demand register features low friction load on the meter, excellent repeatability of readings, short open time, large kilowatt-hour and kilowatt demand dials, and visible test dial. It can be mounted directly on any Westinghouse D-Line single-phase or polyphase watthour meter in place of standard kilowatthour register. A motor resets the pusher to a positive stop at the end of each interval, eliminating the burden of springs or weights on the moving element. At the end of each reading period, demand reading is transferred from test dial indicator to demand dials and added to existing reading. Last reading is thus retained for check purposes until next periodic reading. *Westinghouse Meter Division, P.O. Box 9533, Raleigh, N.C. 27603.*

A 175-ampere silicon controlled rectifier (Type 220) has forward blocking voltage and peak reverse voltage to 1000 volts. It has 17 percent greater half-wave and rms current capability and 33 percent greater surge current capability (4000 amperes) than the 150-ampere thyristor currently used in many designs. These higher ratings permit greater design flexibility and safety margins. Compression-bonded construction eliminates thermal fatigue by eliminating solder joints. *Westinghouse Semiconductor Division, Youngwood, Pa. 15697.*

Zero-speed pulse tachometer provides accurate speed measurement down to zero for digital instrumentation systems. Photoelectric principle provides square-wave pulse output of 10 volts per pulse into 10,000 ohms regardless of rotational speed. Both unidirectional type (output of 250 pulses per revolution) and bidirectional type (output of up to 1000 pulses per revolution) are available. Maximum speed is 10,000 rpm. The units operate on 120 volts 50/60 cycles at minus 20 to plus 60 degrees C, consuming 10 watts of power. *Westinghouse Relay-Instrument Division, Plane and Orange Streets, Newark, N.J. 07101.*



# About the Authors

**Vincent P. Buscemi,** author of this month's article on gas turbines, has been involved in almost all phases of steam and gas turbine application.

Upon graduation from Pratt Institute with a BSME in 1951, Buscemi joined Westinghouse on the graduate student course, and from here went to the thermodynamic section of the Steam Division at Lester, Pennsylvania. At this location, he has had assignments in central station engineering, development engineering, large turbine application, steam systems engineering, and gas turbine application engineering.

Late in 1964, Buscemi transferred to the Atomic Power Division in Pittsburgh to become a Fellow Engineer in the steam systems department. Here, he is responsible for evaluating the total nuclear power plant with the objective of integrating the primary and secondary systems into an optimum total system.

Buscemi obtained his MS degree from Drexel Institute in 1964.

**S. J. Campbell** is in his element as manager of the newly formed General Industries Systems group of the Industrial Systems Division. His major interest has always been in regulated systems drives, and he has worked in that area throughout his career with Westinghouse. His present responsibilities include application, marketing, design, and startup of systems drives for the pulp-and-paper, textile, rubber, lumber, mining, and allied industries.

Campbell joined Westinghouse on the graduate student course in 1950 after earning his BSEE at the University of Wisconsin. He was assigned to the general mill section of the former Industry Engineering group to work on systems drives, and while doing so he earned his MSEE at the University of Pittsburgh. In 1961 he was made manager of project engineering in the metal industry section (later Metals Province, Industrial Systems Divisions). He became manager of Pulp and Paper Systems in 1963 and assumed his present post in March this year.

Campbell has five patents to his credit, has had about 15 technical articles published, and has contributed substantially to the development of drive systems based on magnetic amplifiers and on thyristors.

**Walter H. Esselman** has had essentially three different careers in Westinghouse, although from an engineering standpoint, the experience from each consecutive phase has carried over strongly into the next phase.

Esselman received his BS degree in EE from Newark College of Engineering in 1938, and a short time later joined the Westinghouse Elevator Division. Later he earned his MS degree from Stevens Institute of Technology, and his PhD from Brooklyn Polytechnic Institute. At the Elevator Division, he contributed heavily to the early development of the control concepts that are the foundation of modern automatic elevator design. He holds nine basic patents in this area. Later, during World War II, he carried this control experience into the design of servo and computer systems for antiaircraft director systems.

In 1950, Esselman joined the Bettis Atomic Power Laboratory, where he soon became manager of the design of reactor plant instrumentation and control systems for the submarine *Nautilus*. Here, his previous control experience was put to good use.

Subsequently, he became manager of power plant systems, then technical assistant to the manager of the Naval Reactor Facility in Idaho, where he supervised the test program for the *Nautilus* prototype. In 1955, he returned to the Bettis Laboratory as manager of the advanced development department, a position he held until 1959.

In 1959 he moved to the Westinghouse Astronuclear Laboratory, and since that time has been associated completely with nuclear-powered rocket engine design. With the award of the NERVA contract in 1961, Esselman became manager of engineering and development for the nuclear reactor, and since early 1964 has been the Deputy Manager of the project for Westinghouse.

Both **C. L. Ivey** and **W. C. Carter** are senior engineers in General Industries Systems, and both contributed to the standardization of the winder control system described in this issue.

Ivey graduated from the University of Akron with a BEE degree in 1953 and joined Westinghouse in general mill control engineering at Buffalo. He has worked primarily on paper-mill systems and has contributed to the development of modern closed-loop regulating systems for the pulp and paper industry. Along the way, he earned his MSEE from the University of Buffalo and has submitted 14 patent disclosures.

Carter attended Carnegie Institute of Technology on a Westinghouse scholarship, graduating in 1956 with a BSEE; since then he has completed his course work for an MSEE at the University of Pittsburgh.

Carter worked as an engineer with the Bell Telephone Company of Pennsylvania before joining Westinghouse on the graduate student course in 1957. He was assigned to Industry Engineering, one of the predecessors of his present organization, to work on control-system application, design, and startup. Carter's present work is mainly in drive and instrumentation systems for the pulp and paper industry. He has submitted 13 patent disclosures and has filed two applications.

The Verrazano-Narrows Bridge, linking Staten Island and Brooklyn, presents a striking appearance at night—mercury, fluorescent, and incandescent lighting illuminates the structure with some 350,000 watts of light. Westinghouse OV-25 fixtures, with 400-watt Hi-Output white mercury vapor lamps, are spaced every 100 feet along the roadway to provide two maintained footcandles of light on the roadway. These luminaires contain a special refractor lens that directs light downward and eliminates glare.