Westinghouse ENGINEER

May 1967

Markette to Market

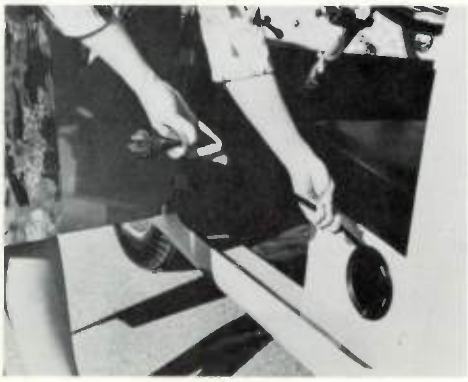
The Markette is a new concept in transportation—a small two-passenger electric vehicle especially designed to provide convenient short-range transportation for urban dwellers. The need for such a vehicle has been demonstrated by recent surveys which show that the majority of automobile trips are less than 10 miles. Under average in-town driving conditions, the Markette has a range of 50 miles between battery chargings and a top speed of 25 miles per hour. Thus, the vehicle is suited to those short trips to the store, school, or rapid-transit stop where most of the travel is on streets with speed limits of 25 mph and under.

The Markette weighs 1730 pounds, including 12 six-volt lead acid batteries that account for about 800 pounds. The vehicle is driven by two 4½ horsepower dc motors that accelerate it to top speed in about 12 seconds. The batteries are located under the storage area behind the seat; they are recharged by unwinding a retractable power cord from beneath the seat and plugging it into any 110-volt receptacle. If the batteries are completely depleted, a full charge takes about eight hours. The electric control system is under the front hood.

The vehicle runs a mile on about a penny's worth of electricity. The 12 batteries, with adequate care, should last for two or more years of normal in-town driving, before they need to be replaced at a cost of about $300.

The vehicle shown is the first commercial model manufactured at the Westinghouse Marketeer plant in Redlands, California. Most of the initial production of a few hundred vehicles will be limited to community developers, electric utilities, and government agencies that want to explore the possibilities of electric in-town vehicles under their own controlled conditions.

Specific applications have not been fully explored, but inquiries have indicated several potential uses for the Markette. For example, developers foresee the possibility of providing tenants with electric-vehicle transportation that is included in the cost of the home or apartment. Some developers are thinking of providing whole fleets of vehicles for the exclusive use of the residents in their planned communities.



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Cover Design: Some day man will leave instruments on the moon to view the earth. One of these instruments may be a small telescope, depicted on this month's cover by artist Tom Ruddy and described in the article that follows.

Scientific Studies on the Moon

V. B. Morris
E. J. Sternglass
R. D. Shelton

The moon should be an excellent site for mounting sensitive instruments to study the earth and the universe. A preliminary design for a lunar-based scientific station was the subject of a recent study conducted for NASA.

Once the Apollo program develops the capability to transport men and equipment to the moon, what will the next step be? This question has not been answered, but, provided that measurements pertaining to astronaut safety prove satisfactory on the first Apollo missions, relative priorities can be assigned to subsequent investigations. The following suggested priorities are based on the recommendations made by NASA and by university and industrial consultants.[1, 2]

Of highest priority will be investigations of the lunar structure and the lunar atmosphere. This may provide information on the origin of the moon, the origin of the planetary system, and possibly information about some form of primitive life on the moon at some time in its history.

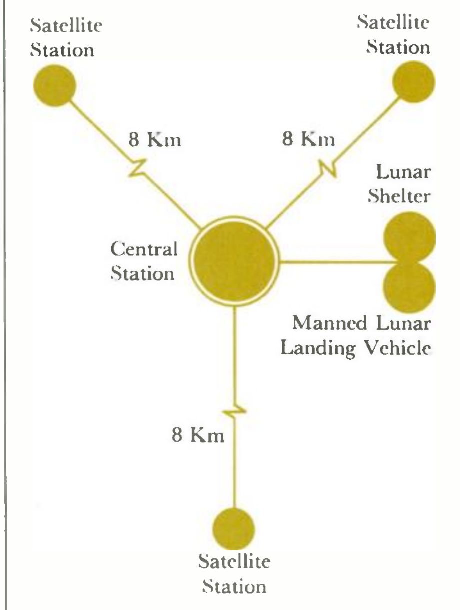
Following in interest and importance are those investigations directed towards a better understanding of the physical processes on earth. A lunar station would be particularly useful for observing large-scale phenomena on the earth and in the space immediately surrounding earth. For example, such an observation station could be used for studying auroral displays and ionospheric variations. Cloud cover dynamics could be measured, and oceanographic studies could be made on a global scale.

Next in priority are observations relating to the interplanetary medium and the study of nearby planets.

And finally, although generally regarded as coming last in order of importance for the first few lunar scientific missions, there seems to be universal agreement that, ultimately, exploration of the universe beyond the solar system will be of greatest fundamental interest.

The first Apollo astronauts to reach the moon will deploy a group of scientific instruments* on the lunar surface during their brief landing. These instruments will continue to transmit scientific data back to earth after the astronauts have departed. However, because of the payload restrictions of the early Apollo lunar missions, the resulting data will be of a somewhat limited nature.

Post-Apollo missions, it is hoped, will permit the establishment of a larger and heavier long-term monitoring station. Therefore, the purpose of a design study recently carried out for NASA by Westinghouse was to develop a preliminary design and a full-scale nonfunctional mockup of a possible lunar surface scientific station.[3] The *E*mplaced *S*cientific *S*tation (ESS) study was done to help manned space flight people design a future lunar landing spacecraft, and was not an Office of Space Sciences and Applications study to design a satellite. The proposed ESS installation would constitute an extension of the data-collection capabilities planned for the initial ALSEP package.



1—Arrangement of Emplaced Scientific Station (ESS) components.

The original objective set for the ESS project was to monitor lunar phenomena that would permit further determination of the lunar environmental parameters. During the course of the study, however, the objective was broadened to include the initial steps in a program to determine the suitability of the lunar surface as a stable platform from which to study the earth, sun, planets, and stars.

Emplaced Scientific Station

The proposed emplaced scientific station would be transported to the moon on an unmanned Apollo landing vehicle. The largest unit in the payload of this landing vehicle would be a shelter capable of supporting two astronauts for a period up to 14 days. A small surface vehicle should also be included to permit the astronauts to explore the lunar surface and for use in placing station components.

After landing, all equipment would "stand by" for as long as several months, awaiting arrival of a second Apollo vehicle, which would bring astronauts to put the station into operation. Once activated, the station could be operated unattended for up to two years.

When installed, the scientific station would consist of a broadly capable central station, supported by three smaller satellite stations. The central station, located near the lunar shelter, contains a telecommunications package and an electric power source, which provide the supporting subsystems for a group of 17 fixed and oriented experiments.

The central station communications package includes a VHF transmitter and receiver, with a 100-foot antenna mast, for transmitting control commands to and receiving experimental data from the

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*Apollo Lunar Surface Experiment Package (ALSEP).

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satellite stations. An S-band transmitter and receiver, with a two-foot-diameter parabolic antenna, will receive control signals from earth and transmit all experimental data to earth.

The proposed central-station power source is a thermoelectric generator, capable of generating 100 watts. It will be isolated from the station to reduce thermal radiation to other equipment.

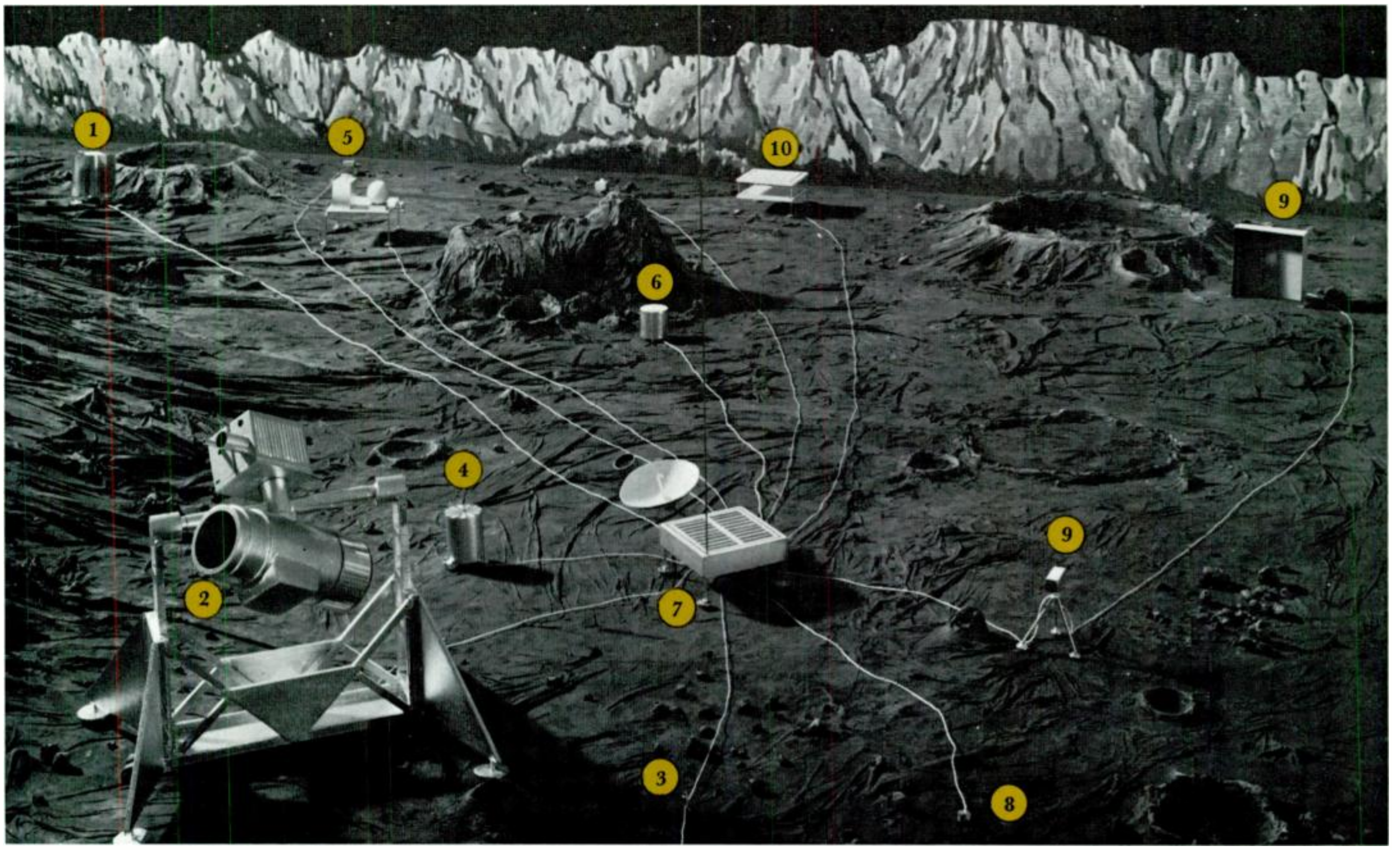
Each satellite station, situated on the periphery of a circle surrounding the central station, contains a telecommunication subsystem and a 10-watt thermoelectric generator capable of supporting five fixed instruments. The satellite VHF communications equipment, with a 100-foot antenna mast, provides communication between the satellite station and the central station but will not transmit data directly to earth.

Two classes of scientific studies—seismic and astronomical observations—provided the major considerations that shaped the overall station design.

For example, the choice of a master-and-satellite station arrangement was dictated by the need for an array of seismic instruments with the largest possible baseline. Even a small array would permit determination of direction and distance of a seismic event far better than the most elaborate multiaxis instrument at a single location.

The second group of studies having a major influence on the overall station concept are the geodetic and astronomical measurements. These require instruments that can be remotely oriented with high precision to any part of the lunar surface or the sky. Since some experiments require simultaneous pointing of more than one instrument, it follows that beyond

2—Scale model of ESS central station depicts instrument deployment about the central telecommunications package. Instruments are identified in the accompanying legend.



● Radioisotope Thermoelectric Generator

● Telescope and Pointed Instruments

● Geophones

● Three-Axis Seismometer

● Total Radiation Dosimeter (Spherical Unit) and Mass Spectrometer

● Tidal Gravimeter

● Communications Package

● Bore-Hole Temperature Sensor

● Electric Field Meter

● Meteorite Detector

arranging for the remote pointing of a single optical telescope, the ESS concept should provide for a frame on which a number of diverse instruments can be mounted and simultaneously oriented to a desired position. Therefore, in developing the central station package, the instruments were divided into two groups: fixed instruments and oriented instruments.

Ideally, each of the fixed instruments should be isolated from every other instrument, but such factors as difficulty of placement, cable weight, and power line losses tend to prohibit this. However, in some cases, instruments such as magnetometers and electric field meters must be isolated from neighboring instruments as much as possible to reduce the effects of stray electromagnetic fields.

All oriented instruments are mounted on a two-axis (x-y) gimbal platform, which is equivalent to an equatorial mounting when located near the lunar equator. The base of the structure serves as a container for the entire assembly while it is being stored or transported to its permanent site.

Table I—ESS Instrumentation

Geophysical and Geodetic Studies
Three-Axis Seismometer
Single-Axis Seismometer (4)*
Geophone Arrays (4)
Tidal Gravimeter
Bore-Hole Thermal Flux Probes (4)
Surface Temperature Radiometer
Corner Reflector
Laser Ranging Apparatus**
Atmospheric Composition, Particle, and Field Measurements
Redhead Magnetron Total Pressure Gauge
Mass Spectrometer
Resonance Spectrophotometer**
Electric Field Meters (4)
Magnetometers (4)
Solar Wind Analyzer**
Total Radiation Dosimeter
Cosmic Ray Telescope**
Meteoroid Ejecta Spectrometer
Earth, Planetary, and Stellar Studies
Telescope with the following sensors:
TV Camera for Planetary and Stellar Photography
Ultraviolet Spectrometer
Wide-Band Photometer
Photographic Film Camera

*Where four (4) installations are indicated, instruments will be located at both master and satellite stations.

**Requires pointing; mounted on telescope platform.

The three satellite stations contain only fixed instruments, and each of these stations may have somewhat different instrument complements. All satellite stations would include seismic equipment; other experiment instrumentation would be limited by weight, volume, and power requirements.

The instruments for the lunar scientific station were selected on the basis of ability to return the most meaningful information for as many different experiments as possible. For example, an optical telescope can be used for lunar surface photography and mapping, as well as for studies of the earth, planets, and stars. Other selection criteria included maximum use of equipment already proven on NASA developmental programs, equipment reliability, adaptability to remote control, and minimum weight and volume.

The specific ESS instruments listed hereafter are not necessarily final selections; rather, they are a representative group of typical instruments based on existing capability and developments in the foreseeable future. The instrumentation suggested can generally be classified in three categories: (1) Geophysical and geodetic experiments,† (2) measurements of atmospheric composition, particles, and fields, and (3) studies of the earth, planetary system, and stars. The suggested instruments for making these measurements are listed in Table I. Only a brief description of the instrumentation will be attempted here.

Geophysical and Geodetic Experiments

Measurements relating to the deep interior structure would be most significant in determining the origin of the moon. This information will come from passive seismic studies (natural disturbances such as moonquakes, volcanic eruptions, or impacts of large meteoroids), measurements of the thermal gradient in the moon's crust, geodetic measurements of the shape of the moon, measurements of tidal distortions of the lunar surface, and gaseous atmosphere measurements that might reveal deep outgassing or volcanic activity.

Measurements of the lunar surface geology and its origin would include active seismic studies to probe the first few kilometers of the lunar crust by creating artificial seismic disturbances, accurate mapping of lunar surface features, optical and thermal measurements of surface material, surface electric and magnetic fields, electrical properties of the surface and subsurface material, radiation damage effects due to incident solar and cosmic radiation, lunar surface erosion, dust formation and dust-transport mechanisms, meteoroid impact damage studies, and surface radioactivity, both long-term and short-lived.

The passive seismic instrumentation consists of a three-axis *seismometer* for the central station and a vertical-component seismometer for each of the satellite stations. For example, the three-axis seismometer developed by the Lamont Geological Observatory could be used at the central station, and the seismometer developed for the Ranger program could be used at each of the satellite stations.

For an active seismic experiment, four geophones are strung out from each station along the line connecting the satellite stations with the central station. Explosive charges buried at intervals from the end of each geophone array would be detonated by remote control some time after the astronauts depart to provide data on the subsurface structure of the moon.

Lunar surface temperatures and thermal energy flow from the moon's interior could be determined with a *surface temperature radiometer* and *subsurface thermal flux probe.* The information resulting from these measurements would help establish the moon's past thermal history and the character of internal energy sources.

The surface temperature radiometer uses a bolometer and a Michelson interferometer to measure the temperature of the lunar surface. Light emitted by the surface is first filtered to admit only infrared frequencies. The interferometer

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† To be semantically correct, these experiments would be more accurately labeled "selenophysical" and "selenodetic" since the measurements are of the moon rather than earth. However, because of their similarity to corresponding measurements on earth and the familiarity of these terms, the "geo" prefix will be used.

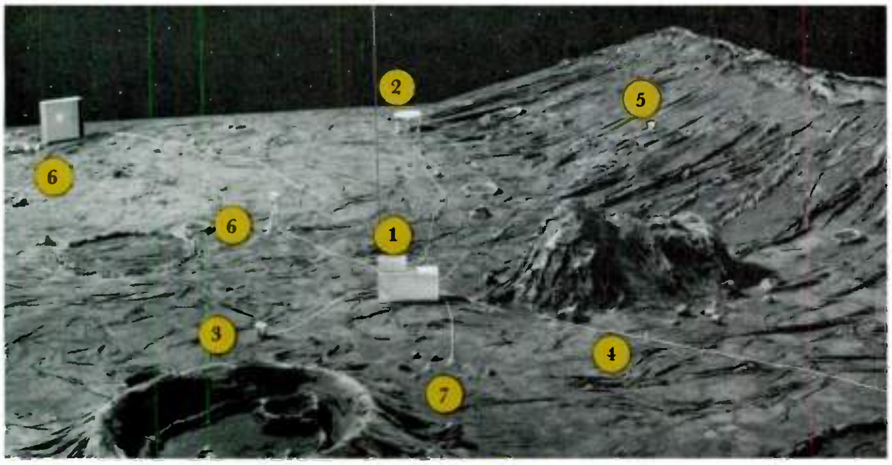
then transmits one of these frequencies to the bolometer which produces an output voltage whose amplitude and frequency are proportional to the energy (amplitude) and frequency of the incident light. All the other infrared frequencies are passed in turn to the bolometer by moving the interferometer mirror.

Each subsurface thermal flux probe, consisting of an array of ten temperature sensors, will be placed in a bored hole. Each sensor is a bell-shaped assembly of spring fingers, which are restrained during emplacement and then released to press against the sides of the hole. A platinum resistance thermometer, located at the junction of the spring fingers, will reach an equilibrium temperature equal to the average temperature of the contact points of the spring fingers.

Just as the moon causes tidal changes in the earth's oceans, the earth causes tidal fluctuations in the lunar surface. A *tidal gravimeter*, which is in essence a very sensitive accelerometer, will measure these lunar surface fluctuations, and give an indication of the overall rigidity of the moon.

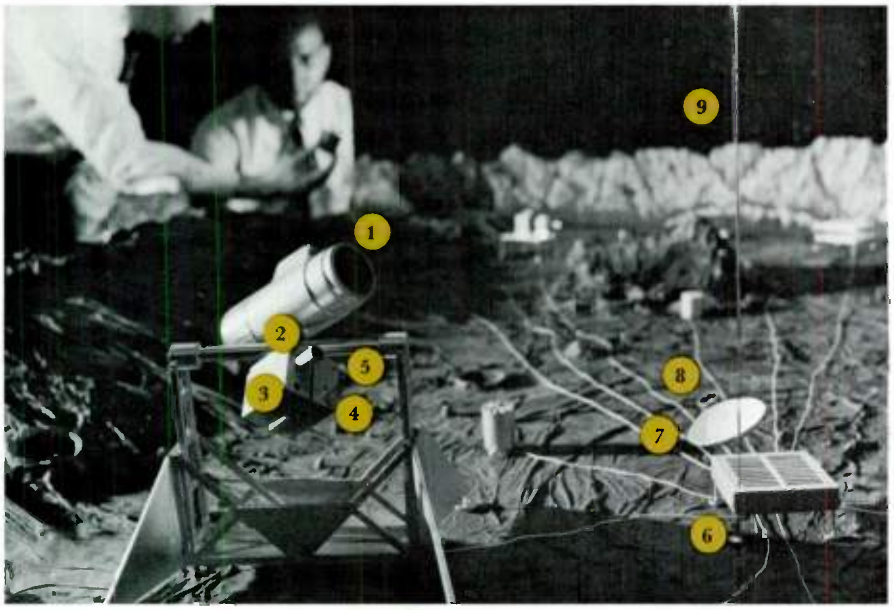
Size and orbit parameters of the moon, and the location of the lunar landing site, could be determined very accurately with a *corner cube reflector* located at the ESS site. The reflector would reflect a highly collimated pulse laser beam from earth. In addition, the reflector could be used to measure deterioration of optical surfaces placed on the moon over long periods of time. The reflector would be mounted on a common bracket with the S-band parabolic antenna, since both must be pointed toward earth.

A laser *mapping and ranging instrument*



① Telecommunications Package
② Radioisotope Thermoelectric Generator
③ Single-Axis Seismometer
④ Geophones
⑤ Magnetometer
⑥ Electric Field Meter
⑦ Subsurface Thermal Flux Probe

3—*(Above)* Scale model of ESS satellite station. Instruments are identified in accompanying legend.



① Telescope With Sensors:
  Electronic TV Camera
  Ultraviolet Spectrometer
  Wide Band Photometer
  Photographic Film Camera
② Ultraviolet Spectrophotometer
③ Cosmic Ray Spectrometer
④ Laser Mapping and Ranging Instrument
⑤ Solar Wind Detector
⑥ Telecommunications Package
⑦ Parabolic S-Band Antenna
⑧ Corner Reflector
⑨ 100-Foot Antenna

4—*(Below)* The platform for the telescope and pointed instruments is shown in this 1/10th scale model. The two-axis gimbal system is equivalent to an equatorial mounting when located near the moon's equator. On the nearby telecommunications package, the corner reflector and parabolic antenna are mounted on a common bracket since both must be pointed towards earth (see accompanying legend).

is an optical radar that uses a short pulse of highly collimated light to measure the distance to a reflecting surface. Mounted on the gimbal platform at the central station, the instrument can be used to accurately locate the astronauts during their lunar surface explorations and as a tool to map the terrain surrounding the central station.

Atmospheric Composition, Particles, and Fields

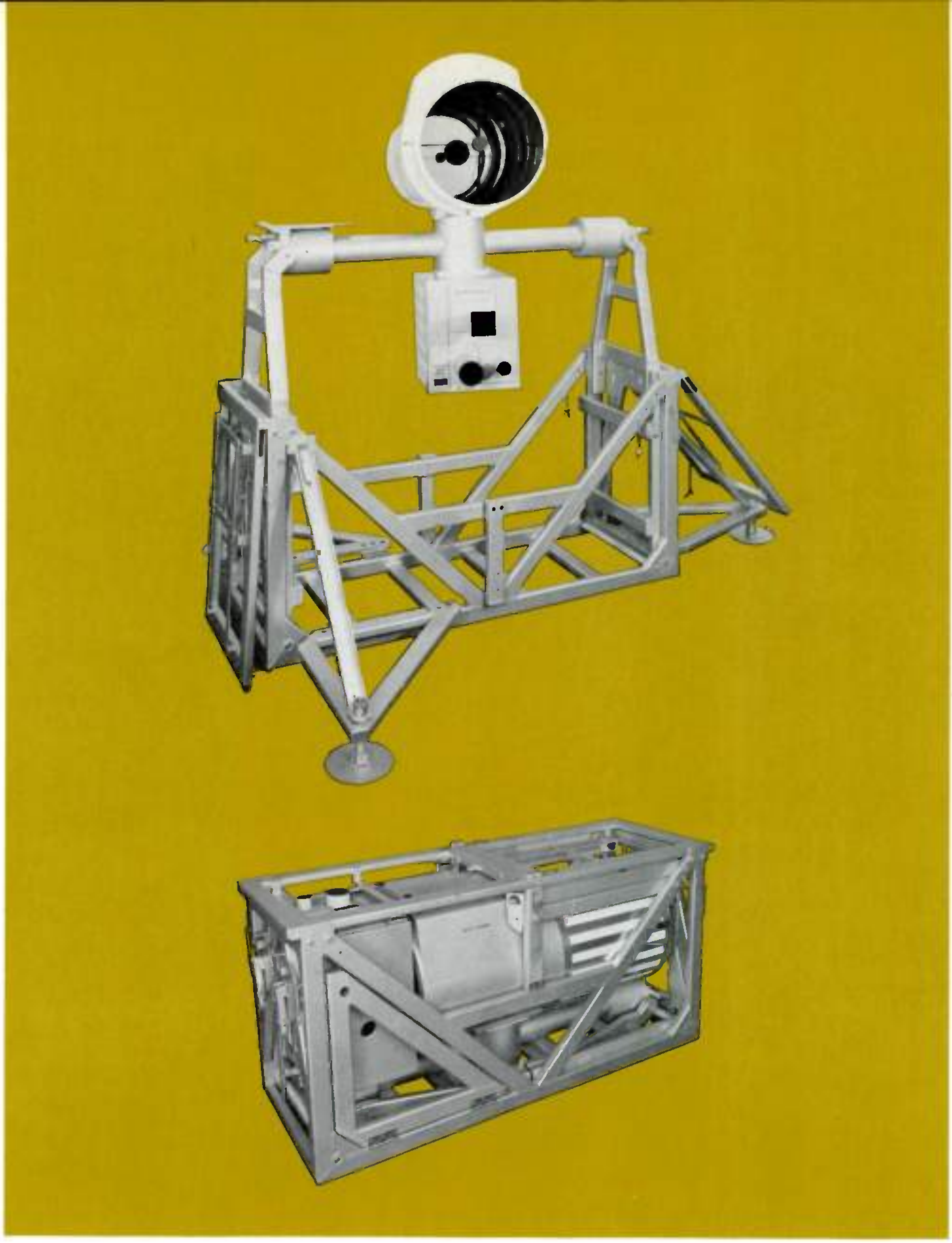
Measurements of the lunar atmosphere are of interest both from an atmospheric physics viewpoint and from the fact that knowledge of the moon's atmospheric constituents is important in other scientific disciplines.

Estimates of the lunar atmospheric pressure indicate expected pressure ranges from 10^{-10} to 10^{-14} torr (mm Hg), with momentary local pressures possibly as high as 10^{-5} torr. This wide variation in theoretical predictions arises mainly from differing concepts of the steady-state atmosphere, or the sum of contributions arising from various source mechanisms minus losses arising from various escape mechanisms.

The lunar atmosphere will be measured and analyzed with a Redhead magnetron *total pressure gauge* and a *mass spectrometer*. The total-pressure gauge, by providing information of total pressure as a function of time, will permit discrimination between periodic meteoric volitilization and steady volcanic outgassing from the interior of the moon; individual meteoric inputs could be distinguished by the rapid rise and subsequent decay of fluctuations in the atmosphere due to the sudden release of gas in contrast to the relatively steady outgassing process.

The Redhead magnetron gauge was selected because of its rapid response and ability to measure pressures in the 10^{-5} to 10^{-14} torr range.

In addition to total pressure, partial pressure measurements are needed for analyzing the constituents of the lunar atmosphere. For this measurement, a mass spectrometer is required. The magnetic-deflection, double-focusing mass spectrometer selected will be capable of analyzing neutral and ionized particles in



5—The complete ESS, with the exception of power supplies, will be transported in three packages (Table II). Central station package No. 1 contains the orientable platform, telescope, and pointable instruments *(below)*.

Fully deployed platform *(above)* will be about six feet high. Since lunar gravity is only about 1/6 that on earth, ESS equipment can be readily handled and assembled by two men on the moon.

Table II–ESS Launch-Package Weight and Size Estimates

Instruments		
Central-Station Package No. 1 Orientable Platform, Telescope, and Pointable Instruments	160 lbs	12 ft^3
Central-Station Package No. 2 Fixed Instruments and Telecommunications Subsystem	250	8
Satellite-Station Package (three stations) Instruments and Telecommunications	210	3
	620 lbs	23 ft^3
Radioisotope Thermoelectric Generators		
Central Station—100 watts	70	*
Satellite Stations (three)—10 watts each	50	*
Total	740 lbs	23 ft^3

*Special packaging is required by generators for heat dissipation. Central station generator occupies less than three cubic feet, the satellite generators less than one-half cubic feet.

the 10^{-10} to 10^{-15} torr range. To analyze neutral particles an electrostatic screen will be used to deflect charged particles. The neutral particles will then be collected and ionized to be analyzed in a magnetic field. Charged particles in the atmosphere will be analyzed by simply de-energizing the electrostatic screen and the ion source.

An ultraviolet *resonance spectrophotometer* will measure the abundance of various gases in the lunar atmosphere by optically observing the resonance lines of the gases that are produced by the scattering of solar photons. The spectrophotometer is mounted on the oriented platform.

The solar wind is a stream of charged particles, primarily protons and electrons and nuclei of lighter elements, which flow outward from the sun. The number and energy of the particles reaching the moon can be measured by a *solar wind detector*. This device is in essence an electrostatic analyzer capable of measuring particles in the 10 ev to 100 kev range. The solar wind detector would also be mounted on the telescope platform.

The electric field near the lunar surface is derived from the interaction of solar plasma, fluxes of charged particles, and photoelectric emissions at the surface. Measurement of this field together with particle and magnetic field measurements is essential to an understanding of these and other related phenomena. A major problem to be overcome in measuring the moon's weak electric field will be the disturbance of the field caused by the measuring instrument itself. Therefore, an electron beam *electric field meter* has been suggested to minimize this interaction. By observing the motion of the point where an electron beam hits a fluorescent target screen, it would be possible to accurately measure the electric field deflecting the beam.

A three-axis fluxgate *magnetometer*, such as that used on unmanned satellites, will be used to measure the moon's magnetic field, which is expected to be only 10^{-4} or less as intense as the earth's field.

Ionizing radiation on the moon's surface will be measured with the *total radiation dosimeter*. This device consists of an electrically conducting quartz fiber enclosed in a thin metal sphere. The quartz fiber is charged to a few hundred volts with respect to the sphere and the resulting electrostatic forces deflect it from a fixed charging contact. Any ionizing radiation gradually discharges the fiber until it comes to rest against the contact and is recharged. These current pulses are relayed by external circuitry, and they provide a measurement of total radiation dose and dose rate.

The interpretation of cosmic ray measurements at the earth's surface or aboard earth-orbiting satellites is complicated by the effects of the earth's atmosphere and magnetic field. The moon's tenuous atmosphere and very small magnetic field should make it an especially favorable platform from which to study cosmic rays. A *cosmic ray telescope*, mounted on the movable platform, will measure the density and direction of energetic electrons, protons and alpha particles in the energy ranges above those of the solar wind.

Since meteoroid impacts are considered a major factor in shaping the lunar surface, studies related to meteoroid flux are of fundamental importance. The proposed *meteoroid ejecta spectrometer* will record incident angle, time of passage between two horizontal planes, and momentum of each striking particle. Primary meteoroid flux should cause a much larger flux of secondary particles of lower energy. With the ejecta spectrometer, it should be possible to measure this secondary/primary ratio. These measurements should provide a better picture of the predominant lunar surface erosion processes.

Earth, Planetary, and Stellar Studies

One of the recommended tasks for the lunar station is to explore the suitability of the lunar surface as a base for future astronomical observations. A moon-based observation platform should have many theoretical advantages, but preliminary measurements will be needed before it can be certain that these advantages can actually be realized. For example, sky brightness in the ultraviolet spectral region should be measured to verify the potential advantage of a low sky background on the moon. Thus, just as on earth, a site survey is essential before constructing large telescopes for emplacement on the moon. Therefore, a small stellar telescope, combined with a group of optical instruments for making spectral and photometric measurements, could provide much useful data.

The telescope could utilize storage-type camera tubes[4] developed at the Westinghouse Research Laboratories under NASA sponsorship for the Orbiting Astronomical Observatory and the Apollo lunar television camera programs. This would make remotely controlled long exposures possible so that faint objects could be recorded, even with a telescope of relatively small aperture.

The theoretical limiting resolution in the proposed ultraviolet region near 1200 Å for a 12-inch aperture is 0.1 second of arc, which would be ten times better than that regularly attainable with the largest of earth-based telescopes. This is because large earth-based telescopes are limited in resolution by the motion of the earth's atmosphere and the absorption of ultraviolet light on its way to the surface.

Thus, if a small, high-resolution electronic telescope should prove to be capable of operating in the lunar surface environment for long periods of time, the instrument would have many potential uses.

These considerations led to the following tentative design objectives for a small exploratory UV telescope:

1) Operation in the UV range down to 1050 Å, which would require purely reflecting optics;

2) A field of view of 2° 10′, which would permit observation of the earth's entire hemisphere;

3) A second longer focal length arrangement with two possible fields of 1.5′ and 3′ of arc to permit high-resolution planetary and stellar photography;

4) A number of different optical instruments able to receive the image;

5) The whole optical system physically as short as possible to maximize rigidity of the structure and minimize total volume.

These requirements have led to the suggested design shown. The telescope is of the folded optics (Cassegrain) type with a 12-inch primary mirror and two secondary mirrors to provide effective focal lengths of 27 and 1200 inches. The larger secondary mirror would move out of the way when long-focal-length operation is desired.

The requirement for high-precision guiding dictates the use of the main optics for deriving the guiding signal. This can be accomplished with a half-silvered ultra-violet transmitting mirror, which allows part of the light to reach the main camera tube cathode at all times. This mirror can be rotated to transfer an image to any one of four other instruments located around the main camera. The other suggested instruments are:

A *UV spectrograph* utilizing an SEC camera tube as a receiver. The advantage of this device over a conventional scanning photomultiplier arises from the fact that integration can take place simultaneously over many spectral lines, thus giving a significant increase in speed over other scanning techniques. The spectrograph will be used mainly to perform ultraviolet spectrographic studies of planetary atmospheres and stellar absorption spectra.

A *wide-band photometer* with a single photomultiplier and a series of interchangeable color filters for precision photometry by photon-counting techniques. The photometer will give precise information on stellar sources from the ultraviolet into the near infrared region of the spectrum.

A *photographic film camera* for use during the 14 days that the astronauts will be on the lunar surface. The camera can be remotely actuated either from the ground or from the shelter. The photographic film holder can be used to take high-resolution photographs simultaneously with televised images. These would serve as valuable calibration checks for the entire optical telescope system.

And finally, a *second TV camera* is recommended as a backup to the main TV camera, to insure reliability of the telescope over its two-year operating period.

Recent Developments

The basic feasibility of an emplaced lunar scientific station has been proven by the successes of Luna 9 and Surveyor 1. They demonstrated that the lunar surface can support station components with little or no settling, and that delicate optical and mechanical equipment can operate successfully for extended periods in the lunar environment.

Photographs of the lunar surface obtained from the lunar orbiters have shown areas where Apollo landings are possible. Any area that meets the Apollo landing requirements would be suitable for a lunar scientific station.

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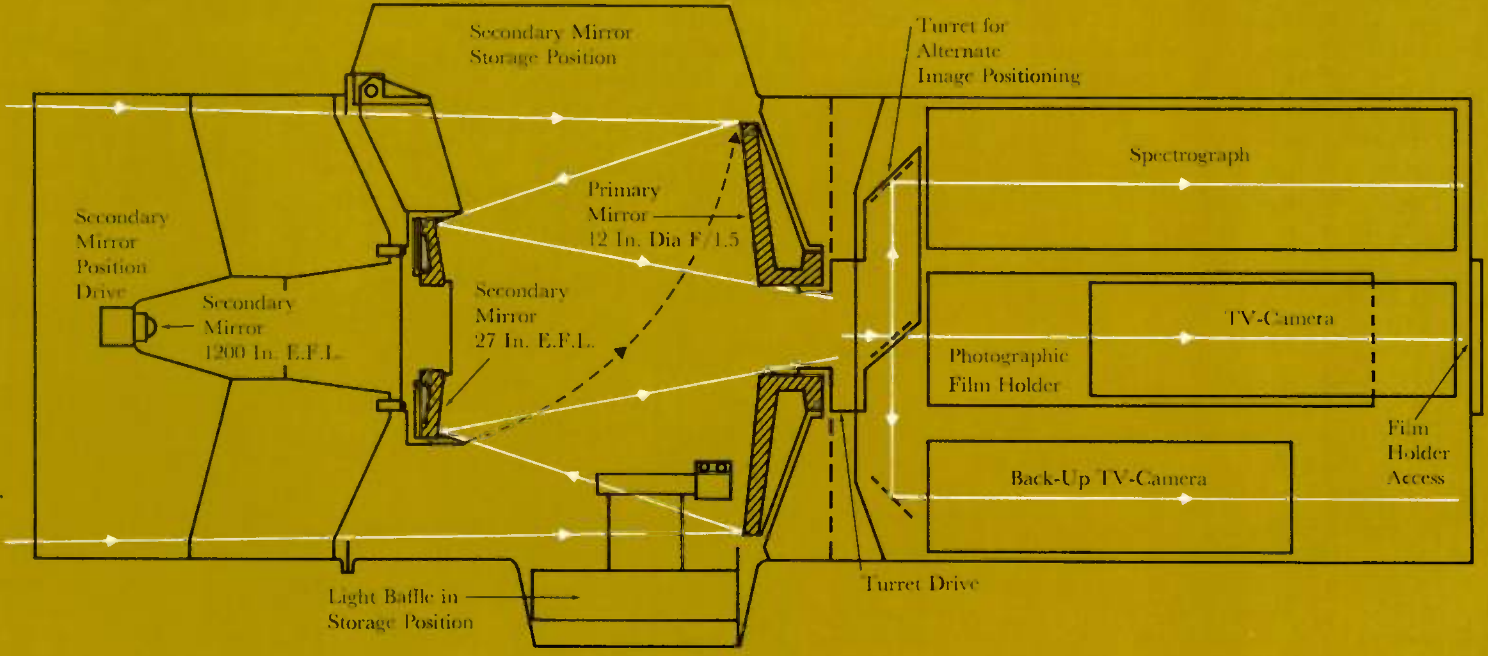

6—Sketch of ESS telescope configuration illustrates mirror and instrument arrangement.

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Underfrequency Operation of Large Steam Turbine Generator Units

E. G. Noyes
J. W. Skooglund

Turbine-blade vibration, generator cooling, and exciter operating point are the principal factors in evaluating the effect of underfrequency operation on large turbine generator units.

Power system emergencies may require periods of steam turbine generator operation at less than rated frequency. However, extended frequency excursions below a nominal limit under some operating conditions introduce some risk to both the turbine and generator. The operating utility must compare and evaluate these risks with the possible alternative of a cascading system disturbance. The fundamental turbine and generator problems associated with underfrequency operation must be considered when making this evaluation.

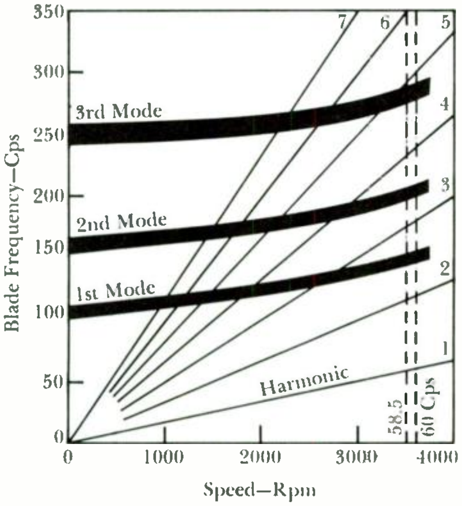
Turbine Blade Vibration

The principal risk in underfrequency operation of a steam turbine is the vibration and probable resonance of long low-pressure blades.[1] Blade vibration stresses are dependent on the excitation forces and on the vibratory response of the blade structural system. The predominate sources of excitation are the structural features in the steam-flow path, which cause steam-flow variations with a fundamental frequency equal to the turbine operating speed and to harmonics of this speed. The magnitude of the excitation force increases with the increased steam flow.

The vibratory response of a blade varies with the nearness of the excitation frequency to the blade natural frequency (nearness to resonance) and with blade damping. A resonant peak amplitude occurs when a frequency of the exciting force or some multiple of it is equal to the natural frequency of the blade.

Most turbine blades are designed to operate regardless of resonance. The exceptions are the last three rows in the low-pressure turbine and, in some cases, the last row in the intermediate-pressure turbine. These blades have their natural frequency controlled (or tuned) so that their vibration modes will not be in resonance at normal-frequency operation.

1—The first three natural vibration modes are usually considered in evaluating underfrequency performance of turbine blades.



2—Exhaust-end blading is designed so that there will be no resonant conditions in the operating range of 58½ to 60 cycles.

The natural vibration modes of grouped blades are shown in Fig. 1. The first or tangential mode is an in-phase vibration in the plane of maximum blade flexibility, perpendicular to the axis of the unit. The higher-frequency second mode is also an in-phase vibration, but with deflection essentially in an axial direction. The third or torsional mode is the vibration of the blade group in approximately an axial direction, but with one end of the group out of phase with the other. Even higher frequency modes may be considered in individual cases but these modes are not usually critical for underfrequency operation.

Typical first, second, and third mode frequency characteristics for long low-pressure blades are shown in Fig. 2. The width of these near horizontal lines indicates the scatter band and variation in natural frequency due to practical manufacturing tolerances. The radial harmonic lines are even multiples of turbine operating speed and represent the frequency of the steam exciting forces. An intersection of a natural frequency line with a radial harmonic line represents a condition of resonance. By tuning the natural frequency of the blades, intersections between the radial harmonic lines and the natural frequency lines can be avoided at normal operating frequency.

When the first three modes of vibration are tuned out of resonance, the vibratory stresses on last-row blades are reduced by factors of 10 to 30. But conversely, if a tuned-blade system is operated at reduced speeds that produce a resonant condition, the vibratory stresses can increase by these same factors. Thus, the probability of turbine-blade resonance coincident with maximum steam excitation is the primary problem of low-frequency operation.

Underfrequency Limits

As shown in Fig. 2, the frequency range of 58½ to 60 cycles is free from resonance in the important vibratory modes. Blade natural frequencies are controlled and the design margins are such that there is little likelihood of developing excessive vibra-

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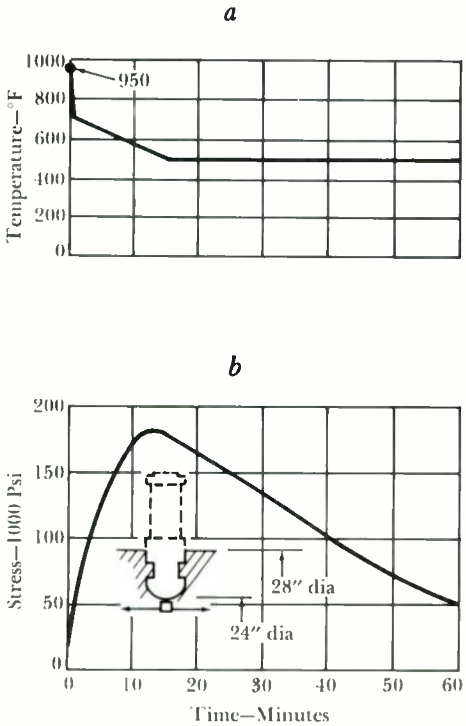
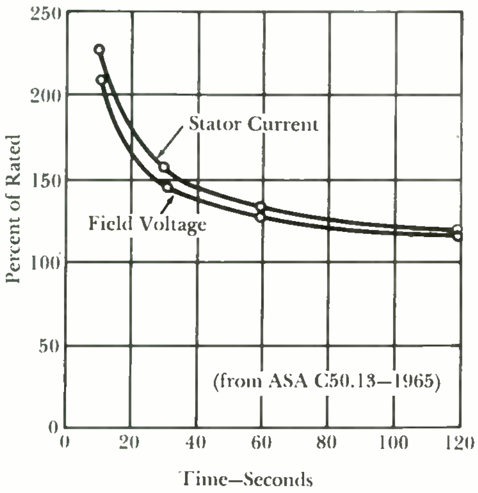
tory stress down to 58½ cycles. Below this level, however, resonance is probable and the vibratory stresses are more likely to increase to a point where blading fatigue cracks can be generated.

Both the generation of cracks and crack propagation to failure require time. The amount of time is dependent on the nearness to resonance, magnitude and nature of the steam exciting forces, system damping, and material fatigue properties. From a practical standpoint, the physical nature of the system defies unqualified predictions. Steam excitation forces are not sharply defined as normally assumed in classical vibration analysis. When plastic strain is a factor in resonant conditions, damping and system response probably do not follow simple elastic laws. These factors, together with the low order of reliability for predictions involving fatigue capacity of blade materials at stresses above the endurance limit, suggest that definitive recommendations for low-frequency operating periods would not be realistic.

Because of these uncertainties, it would be prudent to avoid low-frequency operation altogether. However, it is recognized that in some cases, power system integrity must be the predominant consideration and an operating period at less than 58½ cycles will be required. Thus, some reasonable period of underfrequency operation is necessary to permit continuity of the system until other emergency plans, such as load shedding, can be placed into effect. For example, a period of ten minutes would provide a reasonable time for initiating other corrective action. In the frequency range of 52 to 58 cycles, it is probable that the third (and in some cases the second) vibration mode of the last two rows in the low-pressure turbine will be in resonance (Fig. 2). For a ten-minute operating period, approximately 250,000 high-vibratory stress cycles will be accumulated. Depending on the other factors involved, this stress alone, even at full-power output, should not initiate fatigue cracks. However, the fatigue phenomenon is the result of the decreased resistance of material to repeated stress reversals, and such periods are accumulative and will reduce blade life. Thus, periods of low-frequency operation should be reserved for the few cases where such operation will contribute materially to the improvement of the electric power system operation.



3—The drop in first stage temperature (*a*) due to a step change from full load to auxiliary load causes axial thermal stress (*b*) at the first reaction blade groove.



(from ASA C50.13—1965)

4—The generator short-time thermal capability is associated with the material mass that limits temperature to safe values.

Auxiliary Load Operation

Under certain conditions, when a limited plant tie has been maintained or reestablished with the system, it may be desirable to hold a low auxiliary load of approximately five percent with the system frequency less than 58½ cycles. Under this condition, steam flow is not significantly greater than that normally existing when starting the unit and synchronizing to the line. Experience indicates that blade resonance is not a limiting factor when starting because the magnitudes of the steam exciting forces are low. The increase in blade excitation from no load to the five percent auxiliary load level is considered insignificant and extended operation under this condition should not affect blade fatigue life.

However, auxiliary load operation following a period of full-power output introduces another consideration not associated with underfrequency. The reduction in first-stage temperature that results from the drop in load causes a transient thermal stress in the turbine rotor.[2] The immediate effect is an instantaneous drop in first-stage temperature of about 250 degrees F, followed by a further decrease of 200 degrees F in about 15 minutes as the superheater outlet temperature adjusts to the newly established firing rate (Fig. 3a). This drop in stage temperature produces a peak blade groove stress in 10 to 15 minutes; this stress decays slowly to zero in about one hour as the rotor is forced-cooled to a new equilibrium state (Fig. 3b). Subsequent reloading following an extended period at low loads should be at a moderate rate to avoid a large thermal stress in the opposite direction.

For a typical 3600-rpm rotor, the peak thermal stress can be expected to initiate cracking in the rotor after 100 to 400 cycles. Thus, a single full cycle of this magnitude would account for approximately ¼ to 1 percent of the total fatigue capacity of the rotor.

Generator Cooling

A system disturbance with underfrequency is also likely to be accompanied by high load demands on the generators. Since generator ventilation is accomplished with a shaft-driven blower, high load demands at lower than rated speed will be accompanied by a simultaneous reduction in the effectiveness of the generator cooling system.

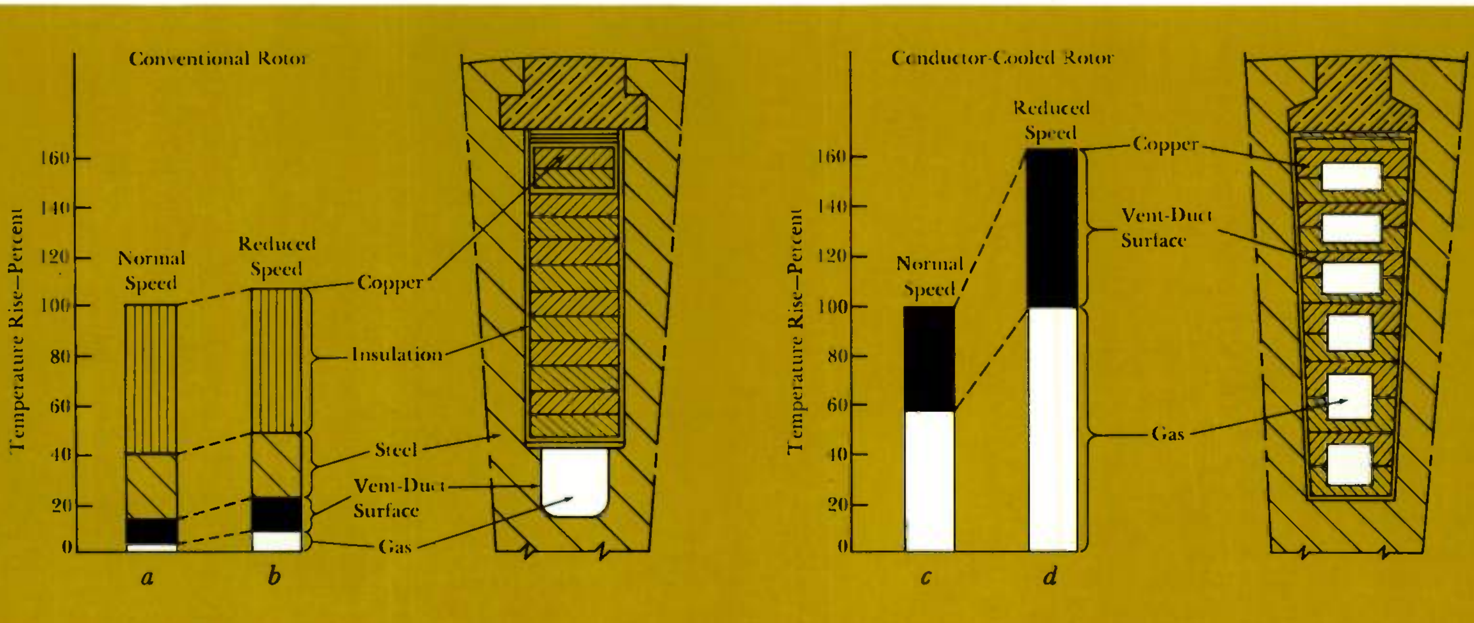
Short Time Operation—Industry practice recognizes the ability of a generator to carry higher than rated current for short periods because the thermal time constant associated with the material mass will limit temperatures to safe values. The short-time thermal capability of cylindrical-rotor synchronous generators (based on values given in ASA C50.13-1965) is shown in Fig. 4. For example, stator current may be 130 percent of rated for one minute, or 116 percent for two minutes. A similar limitation for rotor field windings is 125 percent of rated full-load excitation voltage for one minute and 112 percent for two minutes. These overload values produce higher than normal heat generation, which causes a rise in stator and field winding temperatures. By restricting the time period at the overload condition, the material thermal capacity will maintain the temperature within safe limits.

Long-Time Operation—For long-time operation at reduced frequency, thermal equilibrium must be considered and generator loading should be reduced to compensate for lower cooling capability. Generator kva capability is proportional to the product of stator voltage and current capability. Stator voltage is reduced in direct proportion to speed, assuming constant field current (constant flux density). Stator current capability is limited by the reduction in stator-coil current-carrying capacity.

Ventilation of a hydrogen-cooled generator is accomplished with the shaft-driven, axial-flow blower and the centrifugal pumping action of the rotor rotation. Thus, ventilating gas flow is reduced in direct proportion to speed reduction. In a *conventionally cooled* machine, gas is passed through the stator and rotor iron to remove the heat of losses. For larger units, conductor cooling is required and gas is passed through both the stator and rotor conductors. The temperature rise from the gas to the rotor conductor for both constructions at normal and reduced speed is shown in Fig. 5. A similar relationship exists for stator windings. A large speed reduction has been assumed to illustrate the phenomenon.

For a conventionally cooled generator (Fig. 5a and b), a significant temperature drop is developed across the insulation between the conductor and hot gas. At reduced speed, the hot gas temperature increases because of the lower mass flow, but conductor temperature is only slightly increased because of the large constant insulation temperature drop. Thus, the cooling capability of this construction is lowered slightly by a speed reduction to 95 percent of rated, but this has little effect on conductor temperature. The kva capability of the conventionally cooled machine at reduced speed is lower only by the reduced stator voltage. Thus, a conventional hydrogen-cooled generator can be operated down to 95 percent of normal frequency provided that output kva is reduced in proportion to frequency.

The conductor-cooled generator (Fig. 5c and d) has no insulation drops because cooling gas is in direct contact with the heat-generating conductor. Thus, a reduction in gas flow produces a greater increase in conductor temperature. Since conductor losses are primarily proportional to the square of current, conductor current must be reduced in proportion to



5—The difference in cooling capability between a conventional-cooled rotor (*a,b*) and a conductor-cooled rotor (*c,d*) is due to the fact that cooling gas is in intimate contact with the conductor in a conductor-cooled machine. (A large speed reduction has been assumed.)

the square root of speed to maintain safe conductor temperatures. Thus, at reduced speed, the kva capability of a conductor-cooled generator is limited by lower stator voltage and by reduced current capability of both the rotor and stator conductors. To summarize, conductor-cooled generators may be operated down to 95 percent of normal frequency provided that output kva is reduced in proportion to 1.5 × reduction in frequency, i.e., 92.5 percent kva for 95 percent frequency.

The above discussion has assumed underfrequency operation at rated power factor. If the operating power factor is above rated, the reduced ventilation directly affects and lowers coil current capacity. Operation at lower than rated power factor is limited by rotor current capability, which is also dependent upon ventilation. This is reflected to the stator by establishing the stator coil current that can be supported by the rotor current.

Excitation System

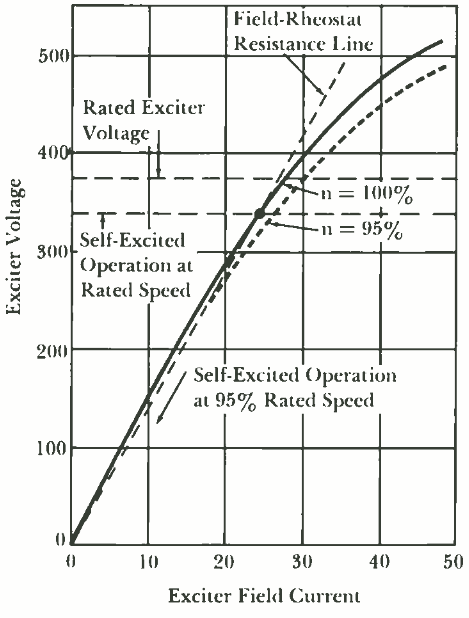
At frequencies down to 95 percent of rated, the generator excitation system can provide sufficient field current to maintain the required generator output. However, the exciter ceiling voltage is reduced to a level approximately proportional to the square of frequency.

Voltage regulator performance is essentially unaffected by variations in frequency, but exciter performance may be unsatisfactory if the regulator is not in service. The steady-state operation of a self-excited exciter with no regulator action is shown in Fig. 6. At normal speed (n = 100 percent), the intersection of the field-rheostat resistance line and the load saturation curve is shown to be 340 volts. It is assumed that the main generator is operating at approximately full load.

If speed is reduced, the saturation curve is reduced proportionally (n = 95 percent) and the self-excited operating point falls to a lower voltage. The amount of drop is dependent upon the exciter saturation characteristic, the setting of the field rheostat, the stabilizing field strength, and the amount of frequency change. The example in Fig. 6 has been so chosen that the slope of the field-rheostat resistance line is essentially parallel to the load saturation curve at 95 percent speed. For such conditions the exciter voltage will collapse. The exciter stabilizing field provides a small amount of excitation (approximately one percent of full load) to assure a stable intersection with the saturation curve at rated speed, when under manual control. However, this stabilizing field is largely ineffective in assuring a stable intersection at 95 percent speed.

Excitation systems that are not self excited, such as the Westinghouse Brushless System,[3] are not subject to this frequency dependence.

Since a period of system underfrequency is also likely to be accompanied by low system voltage, with the generator attempting to maintain voltage, the probability of excessive generator reactive output is high. Overexcitation protection should be provided to alarm or prevent extended operation of the generator at or near exciter ceiling voltage. The generator field short-time thermal capability is given in Fig. 4. Since most excitation systems provide a ceiling voltage of at least 125 percent of full load, a maximum forcing time of one minute is established. The specific value for each generator is determined on the basis of ceiling voltage and the curve of Fig. 4. Since systems with higher than normal speed of response generally have a higher ceiling voltage, the allowable time at ceiling for these systems will be reduced.



6—Exciter load-saturation curves for normal and reduced frequency operation illustrate the change in self-excited operating point.

Once the overexcitation time limit is reached, the base excitation adjuster should be set at full-load excitation before tripping the regulator to minimize the excitation change.

The allowable time at ceiling excitation is not long (usually one minute or less) and serious consideration should be given to automatically sensing over-excitation, tripping the regulator and reducing to a safe excitation level.

Summary

The turbine generator unit can be operated for extended periods at frequencies down to 58½ cycles (97.5 percent of normal) with a low probability of developing excessive vibratory stress. Although the generator can carry higher than rated load for a short time, it must be derated for long-time underfrequency operation.

As a general guide, turbine generator operation below 58½ cycles should be limited to periods of ten minutes or less. The efforts of such underfrequency operation periods are cumulative and will reduce blade life.

The generator excitation system, if self excited, will suffer a severe voltage collapse at a frequency lower than normal if the regulator is not in service. A number of factors affect the exact point of instability, but as a general rule, 95 percent of normal speed can be used. Excitation systems that are not self-excited, such as the Westinghouse Burshless System are stable during underfrequency operation, and need not be considered in an underfrequency evaluation.

Westinghouse ENGINEER **May 1967**

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[2] Ivar Johnson, "Steam Turbine Starting—Experimental and Analytical Studies," 1966 American Power Conference.

[3] D. B. Hoover, "Brushless Excitation System for Large AC Generators," *Westinghouse ENGINEER*, September 1964, pp. 141-5.

Continuous Casting and Rolling Process Makes Superior Copper Rod for Wire Drawing

R. E. Fromson
D. R. James

A new process vastly increases the continuous rod lengths that can be made and also improves metallurgical characteristics. Both advantages facilitate the subsequent wire-drawing operation and improve the wire.

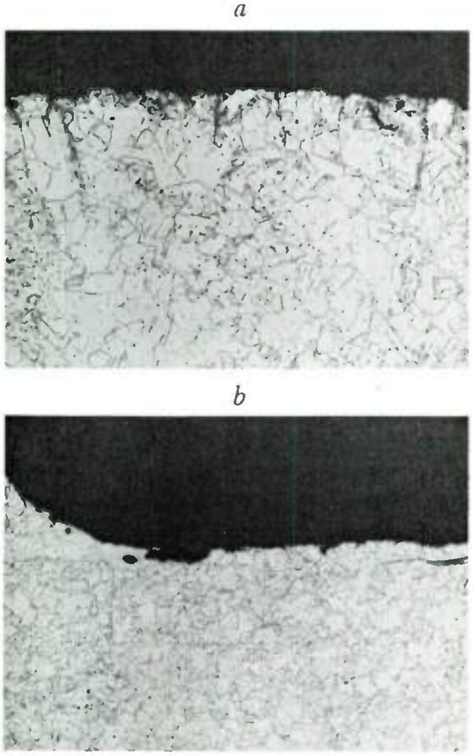
A dream of manufacturing engineers is to improve a production process and at the same time improve the product. This dream has been realized in a new continuous process for producing copper rod, the basic material in manufacturing magnet wire for electrical apparatus. Raw material is literally dumped in at one end of the process line, while at the other end a coiling machine stacks up continuous rod of higher quality than that produced by the conventional process.

Because the CMCR process (continuous melting, casting, rolling) is continuous and well controlled, the resulting rod is far more homogeneous and of higher quality than rod made by the conventional method. These characteristics greatly reduce wire breaking in the subsequent drawing and coating processes, thereby facilitating economical production of high-quality wire. Moreover, continuous production removes the need for welding shorter lengths of rod together and, in eliminating these welds, eliminates another common source of breaking in the drawing process and in coating.

Why CMCR?

Until the CMCR facility was started up last year, production of copper rod for wire drawing had not changed basically for about 100 years. In the conventional process, molten copper is poured into a long open-topped mold to make a "wire bar" that usually weighs 250 pounds. The bar is boat-shaped at its ends to facilitate entry into a rolling mill, but its cross-section shape is not the best for rolling; the flat top creates corners that can result in rolled-in defects. Also, oxides in the metal tend to float to the top and thus concentrate at the upper surface during solidification. For high-quality rod, the bar has to be "scalped" to remove the top surface. Besides being an additional processing step, scalping converts part of the bar into scrap at the very outset.

Continuous casting produces copper bar of virtually unlimited length. The molten metal pours into a cavity formed by a steel belt and a groove in the rotating casting wheel seen behind the operator.



1—Copper rod made by conventional process (*a*) has surface defects caused by oxide segregation there. (Magnification about 90×.) These defects often cause breaks when wire is being drawn from the rod. Moreover, rod made by conventional process comes in relatively short lengths, so a number of lengths are welded together for efficient wire drawing. The welds (*b*) are another cause of breaking in the drawing process (30×).

The scalped bar, in the conventional process, is then reheated and rolled into the desired rod diameter. For a given rod diameter, the 250-pound weight of the original wire bar governs the length of rod that can be produced. (For example, about 330 feet of half-inch rod.) These coils of rod are flash-welded together for processing efficiency. The flash is trimmed, and continuous drawing into wire then is possible.

Since the weakest points of the conventional welded rod and of the resulting wire are usually at the welds, the Westinghouse process-improvement program started with the assumption that longer continuous lengths should be produced. With rod length so important, why not search for a process *100 times* better?

The first step was to identify the necessary components for a continuous process—those that could be integrated into a melting, casting, and rolling line. The key components for such a system were seen to be a furnace with excellent metallurgical control and continuous (instead of batch) operation, a casting machine that would produce a continuous wire bar, a rolling mill to reduce the bar to the desired rod diameters, and a continuous rod coiler.

To make a system out of these components, it was necessary to add material-handling facilities and such auxiliary equipment as a molten-metal buffer, crop shear, bar-conditioning machine, and the necessary coolant and lubricating systems. To tie all this together, instrumentation and control were provided for flow, temperature, speed, and position. The resulting process system is described in more detail in a later section. Much of the equipment for it, and the basic process design, were supplied by Southwire Company, Carrollton, Georgia.

CMCR Advantages

The 100-fold increase in rod length has been achieved, with coils weighing 25,000 pounds being produced routinely. (Such

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a coil of half-inch rod is about 33,000 feet long.) Coils are usually kept within this weight to facilitate handling, although some weighing more than 30,000 pounds have been produced.

The rod is coiled on a steel pallet with a basket superstructure. A full basket is indexed out of the coiling position and an empty one simultaneously placed in the coiling position without interrupting the process, so the length of continuous rod that can be made at any one time is really a function only of process time. (However, the loop between baskets is severed to facilitate handling.) In the subsequent wire-drawing operation, the rod is payed out of the same basket for trouble-free feeding.

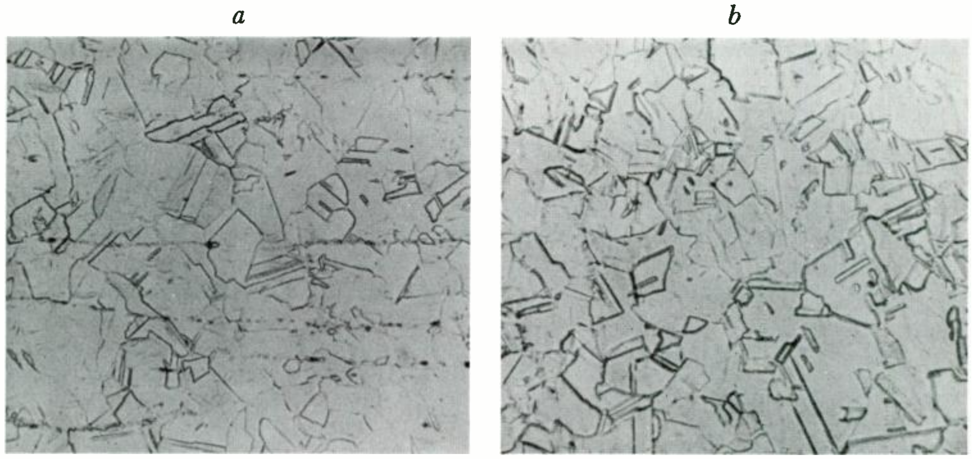
The other main advantages of CMCR rod are superior *metallurgical* properties that help make the subsequent processing much more trouble-free and, moreover, improve the quality of the wire. Copper rod made by the conventional method has three serious metallurgical disadvantages:

1) It has defects due to the original surface of the wire bar. As the bar solidifies from the side walls in the base of the mold, gases evolve and the metal has a progressively higher oxygen content. The oxygen separates out as a eutectic mixture of cuprous oxide and copper near the end of the solidification process. This eutectic has a marked segregation effect at the surface of the bar (unless it is removed by scalping). During the subsequent reheating, it forms particles of cuprous oxide. On rolling the bar, an area with a defective surface is formed in the rod (Fig. 1a). These cracks and particles in the rod surface are one of the two major sources of breakage in wire drawing.

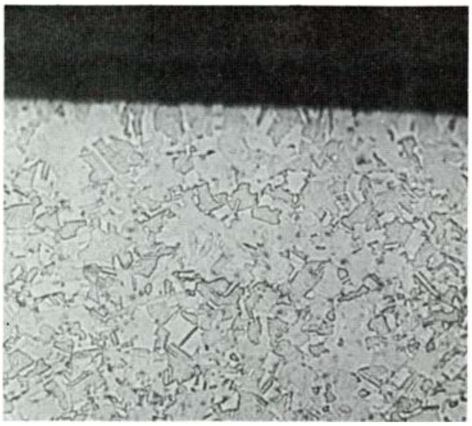
2) The welds that join the small lots into a continuous length for efficient wire drawing are often defective and therefore are the second major source of breakage (Fig. 1b).

3) Manufacturing is not easily controlled in the small batch process. So many variables enter into the various operations that consistently high-quality rod is difficult to produce.

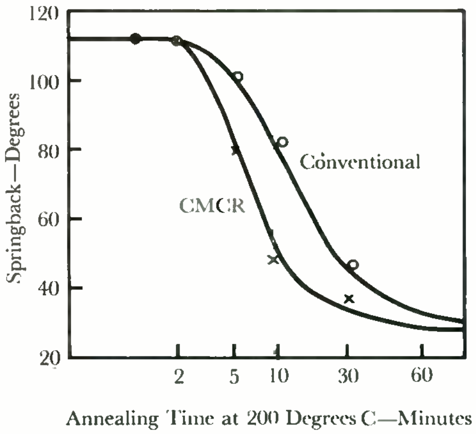
The CMCR process eliminates these defects. First, it eliminates welds or at least greatly reduces their number.



2—Rod made by the new CMCR process (*a*) has much finer oxide particles, much more even distribution of the particles, and smaller grain size than does conventional rod (*b*). These characteristics improve physical properties of the copper rod. (Both views, 380×.)



3—CMCR rod has better and more uniform surface than conventional rod because of the finer oxide particles, better distribution of the particles, and absence of surface oxide segregation (95×). Better surface and lack of welds result in far fewer breaks in wire drawing.



4—Annealabilities of CMCR and conventional wire were compared by measuring springback against annealing time. The wires used in the test were samples drawn down to 0.057-inch diameter and annealed in an oven at 200 degrees C for various times. CMCR wire annealed significantly faster, an advantage in subsequent processing of magnet wire.

Properties of CMCR and Conventional Rod and Bar

Property	*CMCR*	*Conventional*
Bar density (gm/cc)	8.84	8.62
Rod density (gm/cc)	8.94	8.94
Rod grain size (average diameter, mm)	0.027	0.035
Rod oxide particle size (average diameter, mm)	0.0010	0.0051
Rod conductivity, average (% IACS units)	101.4	101.4
Rod tensile strength (lb/sq in.)	33,960	32,440
Rod elongation (% of 10-in. gauge length)	44.4	42.5

Second, continuous casting produces a metal of more homogeneous structure than the wire-bar process because the solidification rate of the molten metal is higher. Higher solidification rate imparts desirable properties in four ways:

1) There is less segregation because oxide is distributed more evenly in CMCR bar, resulting in a more uniform distribution and also finer particles in the rod (Fig. 2).

2) The grain structure of the CMCR bar is very fine. This fine structure stems both from the high solidification rate and from the refining effect of the moving stream of metal entering the mold.

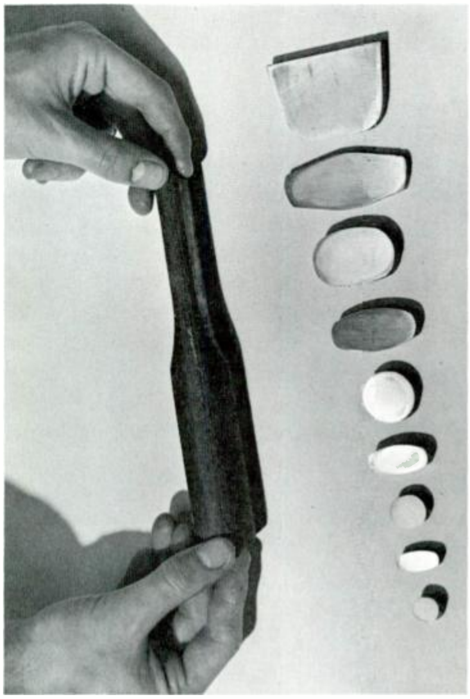
3) Porosity is much less, so less rolling is required to make a dense rod (see accompanying table).

4) Since solidification proceeds from the four sides of the casting, no oxide segregation takes place at any of the four surfaces. Rod with uniform surface characteristics is produced (Fig. 3). As this photomicrograph shows, the surface microstructure of CMCR rod is much better than that of the wire-bar rod shown in Fig. 1a.

Several other process advantages, in addition to the higher-quality casting, help account for the higher quality of CMCR rod. In the conventional wire-bar process, the bar is allowed to cool after casting, and before rolling it must be reheated to rolling temperature. The surface becomes oxidized while the bar is at high temperature, and the cuprous oxide eutectic breaks down and agglomerates into coarse oxide particles. Also, the rod is cooled after rolling and then pickled, but during cooling the rod is still above the recrystallization temperature and grain growth can occur.

CMCR bar, on the other hand, is passed continuously from the casting wheel to the rolling mill. The passage takes only about a minute and, after rolling, the rod is immediately quenched to room temperature. This processing sequence helps produce the fine distribution of oxide particles in a fine grain structure. The table shows oxide particle size and grain size in CMCR rod, and the average diameter of the oxide particles, contrasted with the size of particles and grains in the conventional wire-bar rod. Comparison of the physical properties of the CMCR rod with those of conventional rod confirms the improvements to be expected from the improved structure (see table).

One of the most important properties for rod that is to be made into magnet wire is good annealability. The wire is usually passed through enameling towers, which have annealing ovens. Both temperature and length of time spent passing through the ovens are usually limited for high production and also to prevent overheating, yet the wire must be softened by the quick passage through these ovens. Therefore, it must be very annealable at low temperatures. Experience in processing CMCR wire has shown that it has better annealability than the conventional wire (Fig. 4).



Cast CMCR bar is rolled into rod in alternate oval and round passes, the preferred method of hot-working copper bar.

Testing also has confirmed the expected reduction in wire breakage during drawing. The number of breaks is twice as great with conventional rod as with CMCR rod and, since each break is due to an inhomogeniety, breaks usually signify that other less severe defects are present.

Thus, the CMCR rod, with its fine microstructure, is ideally suited for production of magnet wire. Surface and physical properties of the wire are superior to those of wire from the conventional process, and wire as small as 0.0025 inch diameter has been produced successfully.

The CMCR Process

The input to the process is electrolytically deposited copper plates 40 by 40 by ¾ inch thick, in stacks about 14 inches high and weighing 4000 pounds. These are removed from boxcars with fork trucks and deposited on a powered roller conveyor with automatic indexing provisions, which takes them to a vertical elevator with a roller bed (Fig. 5). On demand, the plate bundles are discharged into the top of a stack furnace. The lower level of the furnace has burners with variable firing rate to control melting at the hearth, which slopes toward a tap hole. The tap hole discharges into a transfer trough leading to a tilting holding furnace, which is needed as a buffer for molten metal since the exact flow rate of the stack furnace cannot be assured to be the same as that of the casting wheel.

The servo-controlled holding furnace discharges into a trough leading to a bottom-pouring tundish, or pot, containing a spout that reaches into the casting machine. A servo-controlled metering pin modulates metal flow through the tundish spout.

The casting machine has a 72-inch wheel with a groove in its rim closed by a flat steel belt during the part of the wheel rotation between pouring and extraction. A pool of molten copper is established and maintained in the groove. Water sprays cool the wheel and belt as the wheel rotates, and a solidified bar is extracted from the groove on the side of the wheel opposite the pouring side. Powered rolls guide the hot but solid bar in an arc that translates its motion to a horizontal axis for rolling.

A crop shear at this point cuts the bar into convenient scrap lengths until speed and temperature are suitable for rolling. (A slat conveyor removes the cut bars for storage until they are reloaded into the furnace.) When the bar becomes suitable, shearing is stopped and the bar proceeds through a conditioning machine to the rolling mill.

This conditioning machine removes the corners, forming radii suitable for optimum rolling, and wire-brushes the top, bottom, and sides to assure unblemished surfaces.

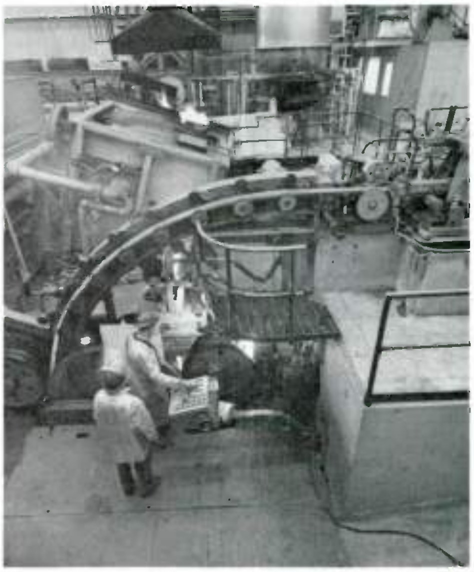
The rolling train is a 12-stand continuous close-coupled unit with 125 horsepower on mills 1 and 2 and 700 horsepower on mill 3, which consists of 10 stands. It is tooled for rod sizes of ¼, ⅜, 7/16, ½, and ⅝ inch. The final stand used varies from number 6 to 12, depending on the rod diameter being rolled. The roll pass schedule employs alternate oval and round sequences, which is the preferred method of hot-working copper bar that is to be drawn into wire.

On leaving the mill, the hot rod enters a transition tube in which it is cooled to room temperature and elevated to a coiling device. This is a center-fed powered flinger with a programmed variable speed for level laying of the rod in the basket. Outside diameter of the coil is 84 inches, and inside 30 inches.

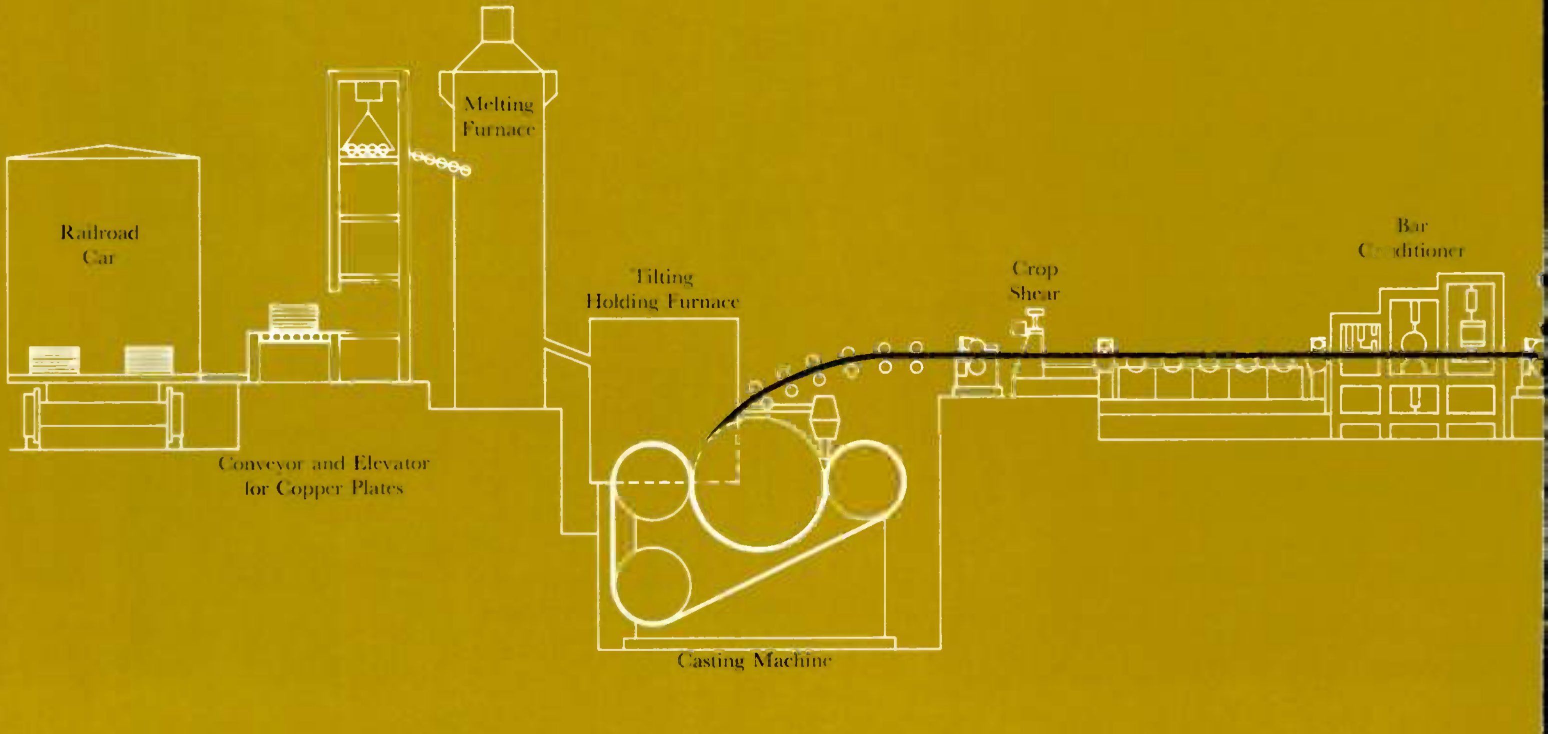
Control for Reliability

Product quality requires continuous operation, and reliability was recognized as the key to continuous operation. The necessary process assurance was designed into the system by means of on-line and off-line indicators, controllers, recorders, and servo systems that monitor and control the melting furnace, holding furnace, tundish level, metering orifice, casting speed, rolling speed, and surface finish. Rod size is readily controlled to commercial tolerance, and quality is high and consistent.

Although it was not known at the outset what each parameter needed to be, full-scale experimentation soon revealed



Bundles of copper plates *(upper left)* are conveyed to an elevator that charges them into the top of the furnace seen at top center. Molten copper is tapped from the furnace and led into a holding furnace that supplies it to the pouring pot as needed. Cast bar is drawn continuously from the casting wheel and guided into a horizontal axis for conditioning and for rolling in a continuous mill.

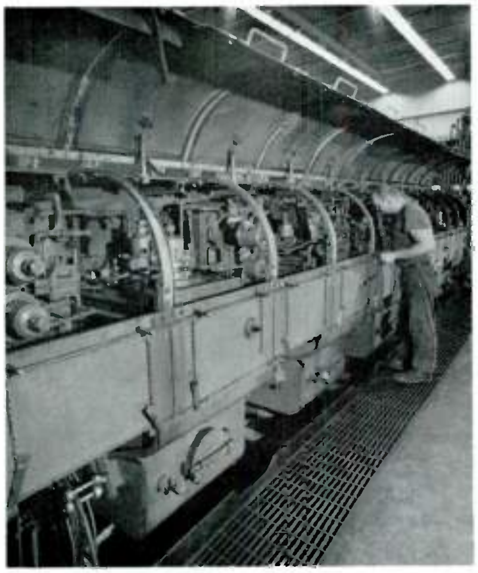


the acceptable limits. Production experience has confirmed the choices; CMCR rod has become the preferred material for drawing and coating operations at the Copper Wire Division.

Reliability proves to be a function of component selection and protection and of an adequate supply of replacement parts. High-temperature molten metal taxes refractories, and the high-temperature bar taxes the handling and processing elements of the system. Production experience has dictated the relocation of vulnerable components and more adequate protection for others. Expendable components are evaluated continuously for possible use of different materials to extend their life expectancies.

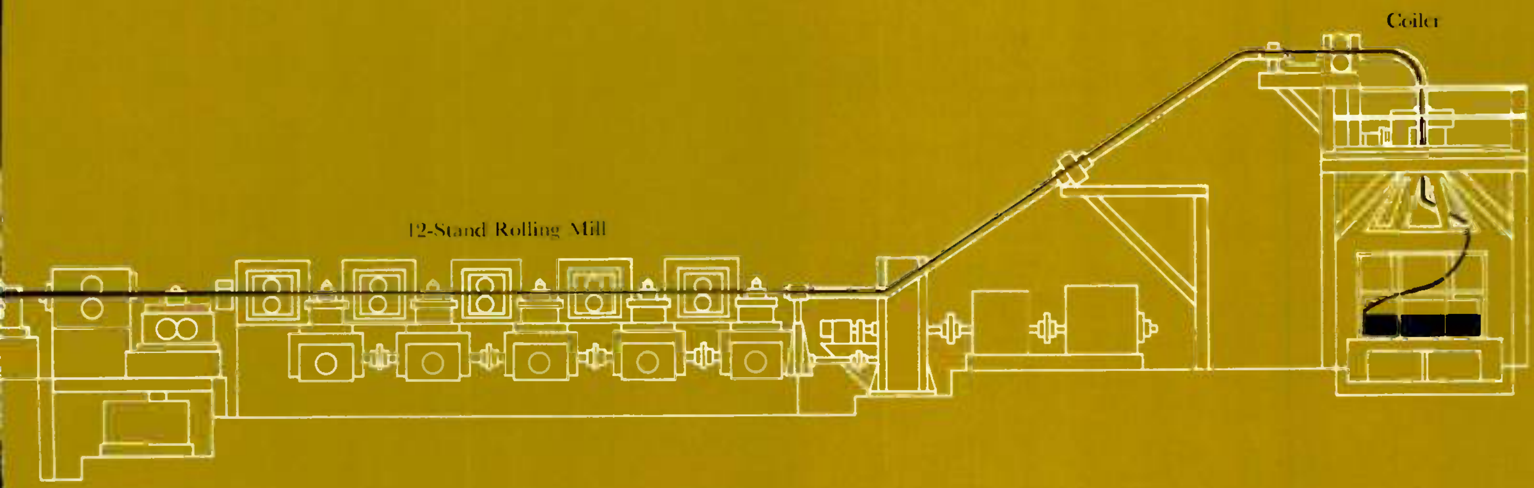
Conclusion

This giant step in rod-making has reduced rod costs, mainly by eliminating the large number of handlings required with the conventional small rod bundles. Even more gratifying is the improvement in wire products made from rod produced by the CMCR process.



Rolling train, shown here with its shield raised, consists of three mills with a total of 12 stands. It can produce rod ranging from ¼ to ⅝ inch in diameter.

After rolling, rod is cooled in its passage through a tube that elevates it to a coiling device, which lays it evenly in large baskets. When one is filled, it is removed and another put into its place without stopping the process. The rolling train is seen in the background and, behind that, the casting facilities and a railroad car in which copper plates are brought in for melting.



5—CMCR process begins with the loading of copper plates into a continuous furnace. Molten copper is poured into a casting machine and emerges as a bar. The bar is rolled into continuous rod of the desired diameter, and the rod is then coiled.

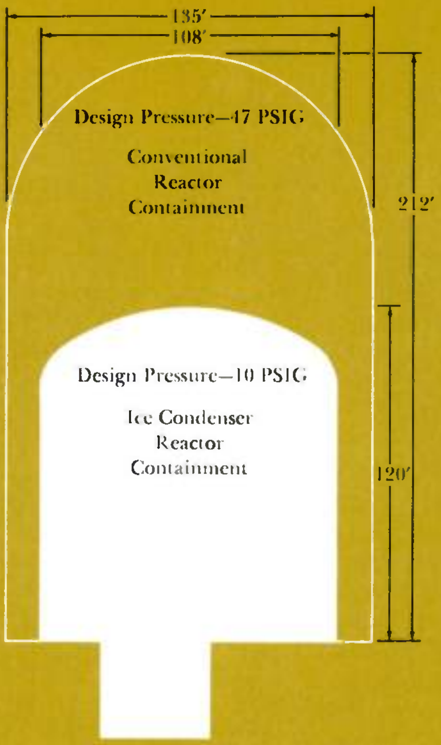
New Containment Design Lowers Nuclear Plant Capital Costs

A new concept in design will drastically reduce the size of a nuclear plant containment structure.

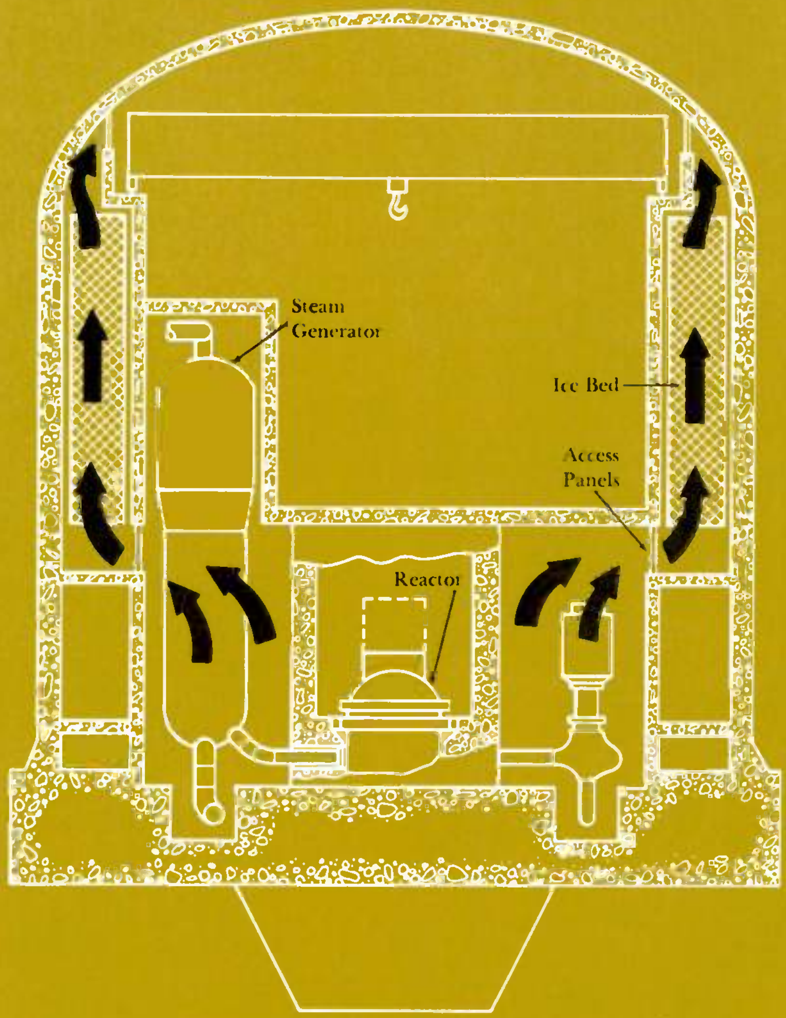
Ordinary ice, one of man's oldest known cooling agents, is about to become a vital element in the design of a new containment structure for one of man's newest engineering systems, the nuclear power plant. Its purpose: to serve as a heat absorber in the event of accidental release of steam within the containment structure. Its advantages: a smaller containment structure, designed for lower pressures, with resultant reduction in capital costs (see Fig. 1); rapid absorption of heat; and a virtually static system, which contributes to reliability.

While few systems of any kind are as carefully engineered for inherent safety as nuclear power plants, the nuclear reactors themselves are surrounded by massive concrete and steel containment buildings. These containment buildings are a barrier to prevent the release of radioactivity to the atmosphere even in the highly unlikely occurrence of some failure in the nuclear system. Since the only failure of any consequence would be the sudden rupture of some portion of the reactor coolant loop piping or other element, the condition to contend with is the sudden release of large quantities of steam, which must be held within the containment structure.

Until now this has been accomplished by building a silo-shaped or spherical structure, designed with sufficient volume and strength to hold the quantity of steam



1—*(Above)* Silhouette diagram of a conventional containment and an ice condenser reactor containment structure for a 1000 mw(e) nuclear plant illustrates the dramatic reduction in size made possible by the new concept.



2—*(Below)* This cross sectional diagram shows the general arrangement of an ice condenser reactor containment structure for a typical nuclear power plant.

that might be released. In the new design the ice is used as a condenser system to swiftly and safely condense any steam accidentally released within the containment structure.

Design of the Containment System

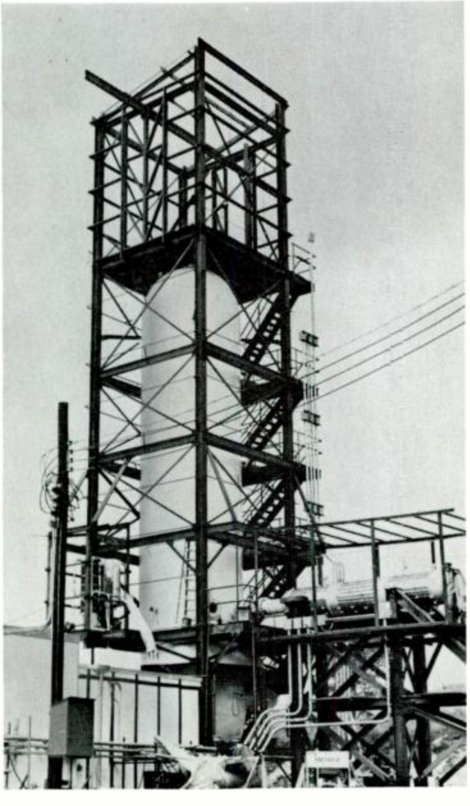
The new concept, known as the "ice condenser reactor containment system," involves the use of a cold storage compartment surrounding the nuclear steam supply system, as shown in Fig. 2. Ice is placed in the cold storage compartment within the reactor containment structure, which is of conventional reinforced concrete construction. The ice is kept frozen by standard refrigeration equipment.

If any increase in pressure occurs in the containment structure, the steam or hot air that caused the overpressure is admitted through the access panels at the bottom of the ice condenser compartment; it then flows through the ice condenser bed, where the heat is rapidly absorbed, and is released through the top access panels.

Condensed water from the steam is drained off at the bottom of the compartment. The bottom access panels merely swing outward toward the ice as a result of overpressure, admitting steam to the condenser chamber. Access panels at the top swing inward to the upper compartment, releasing the cooled air. The system is basically simple and effective and allows equilibrium conditions to be quickly restored to the reactor containment structure.

To prove the expectations on soundness, practicality and safety of the new ice condenser concept, a facility representing a full-scale section of a containment with an ice condenser was erected at the company's Waltz Mill Site nuclear complex, located some 30 miles southeast of Pittsburgh, Pennsylvania. The facility was completed in November 1966, and to date several tests have been performed with different internal arrangements and "blowdown" times.

3—*(Above)* The receiver vessel, shown during erection, is part of the test facility built to prove the validity of the ice condenser design.



4—*(Below)* In this view of the nearly completed test facility, the receiver vessel containing the ice condenser is the tall structure in the center of the photo. The boiler is at bottom right, connected to the receiver by piping.

Tests Confirm the Concept

The test facility, shown near completion in Fig. 4, is made up of two basic sections: a high-pressure boiler to provide the steam which might accidently be released within a reactor containment building, and a receiver vessel to represent a containment building with an ice condenser unit. The facility also includes a control room to record and control test temperatures and pressures, a commercial ice machine to produce ice for tests, and a cold storage room for long-term ice storage tests.

In operation, pressurized water and steam at a temperature matching reactor operating conditions is abruptly released from the boiler and admitted into the receiver vessel.

The ice in the vessel quickly condenses the steam, thereby limiting the pressure rise in the vessel to as low as 10 psi. Boiler temperature and pressure, steam flow rate, and ice configurations can be varied to represent a wide varity of hypothetical accidents. An elaborate system of temperature and pressure indicators and recorders provides test engineers with prompt test data.

Tests performed to date have demonstrated the effectiveness of this new containment concept and have confirmed engineering estimates of the performance. The ice condenser performs equally well over a wide range of conditions, including a variety of ice configurations and steam "blowdown" times ranging from 10 seconds to 45 minutes.

Continuing tests are aimed at optimizing the design of the ice condenser and its arrangement within the reactor containment building.

Electrical Systems for Hot-Rolling Mills… Faster, More Powerful, More Capable

E. H. Browning

Bethlehem Steel Corporation's new hot sheet mill typifies the giant strides that have been made in electrical power and control equipment in the past few years. Its size, power, and advanced computer control system provide efficient operation for Bethlehem and quality products for its customers.

More than two billion dollars, a large sum by any reckoning, was spent in the United States last year on new facilities for a single product—steel. As much or more probably will be spent this year. The money is being invested in all areas of the industry, from mining and smelting to forming and final processing.

Of all the processes, none has reached the technological development of the hot-rolling mill. The new mills are bigger, faster, and far "smarter" than those built just five years ago.

The changes that have taken place in those five years are nothing short of revolutionary, and they are well illustrated by the 80-inch hot sheet mill that recently went into operation at Bethlehem Steel Corporation's new Burns Harbor Plant at Chesterton, Indiana. This mill, and the others recently built or now being built or designed, represent far more than an exercise in technological virtuosity. In the words of Edmund F. Martin, Bethlehem's chairman and chief executive officer, the mill was installed for the sound business reasons of providing "the finest possible quality product for our customers and the most efficient operation possible for ourselves."

Probably the most striking characteristic of the recent development of hot-rolling mills is the spectacular growth in the scope and capability of the electrical system. An estimated 15 percent of the cost of a hot mill now goes for the electrical system; five years ago it was about 10 percent.

The additional money for electrical systems is being invested in greater power, increased system complexity, and controls that were not available five years ago. A finishing train, for instance, was driven by motors totaling about 45,000 horsepower in 1961; in 1966, horsepower had increased to as much as 82,000. In the same period, the delivery speed capability jumped from 2500 feet per minute to as much as 4200 feet per minute. In addition, an acceleration-deceleration mode of operation has replaced the old constant-speed operation.

This increased power, speed, and flexibility demand a more reliable and more capable control system, which is one reason why the process-control computer has made its most important steel-industry contributions in the hot sheet mill. Another reason is that quality control is more essential in hot rolling than it used to be because steel customers have become more demanding. The steel that comes from a computer-controlled mill is much more uniform and much closer to customer specifications. The producer benefits, too, by reducing the amount of product that is off-gauge, off-width, or off-metallurgy and that therefore requires costly scrapping or reworking.

Yet another reason why computer control is especially rewarding in hot rolling is its ability to match the mechanical and electrical flexibility of the new mills with its control flexibility. The mills are large, their operation is complex because of many variables, and a number of different products may be in process at once. Without a control computer, much scheduling effort is required to arrange the sequence of different product orders in such a way that the metallurgical and dimensional changes are small enough for human operators to cope with. The computer is not limited in this way, because of its vast ability to store instructions and to compute new rolling schedules rapidly, so it can make runs on the basis of order requirements instead of on the basis of ease of transition. The result is greater output and more efficient use of manpower by enabling operators to concentrate on making sure that each strip is rolled to superior quality.

The average hot-rolling mill computer in 1961 had a memory of 4000 to 8000 words. Because of the additional control and data-logging functions demanded of today's computer systems, memories have grown to 64,000 to 120,000 words. And, increasingly, more than one computer is being supplied for a rolling mill. One new 86-inch hot strip mill, for example, will have four small Prodac 50 computers supervised by a larger Prodac 550 computer.

Automatic control systems that have become generally available only during the past few years also help account for the increased amount of electrical equipment in the mill. They include automatic preset controls such as those for speed, position, and crop shearing; automatic roll changing; automatic looper and coiler systems; and automatic acceleration and deceleration.

Another factor is the present widespread use of thyristor power supplies. These solid-state systems were almost unknown five years ago but now are widely used in place of m-g sets for supplying adjustable-voltage dc power to main and auxiliary drives because of their efficiency, relative freedom from maintenance, and other advantages.[1]

Automatic gauge control systems also have been extended significantly. Five years ago, a strip mill had automatic gauge control on just two or three stands; today, six or seven stands have it.

Moreover, coil-handling facilities at the delivery end of the mill have become increasingly complex. Two or three coilers are needed because mills have become too fast for one. An automatic sequencing system directs the equipment that changes coilers; removes coils from the mandrels; and turns, bands, conveys, and stores the coils.

Burns Harbor Mill

The new 80-inch hot sheet mill at Bethlehem Steel Corporation's Burns Harbor Plant is one of the fastest and most powerful in the world, designed as it is for a delivery speed of 3750 feet per minute and with its various drive motors capable of supplying a total of 108,000 horsepower

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

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for metal reduction. It is the most completely computer controlled hot mill in operation, being controlled for its entire length by a Prodac 580 computer system. It is also the first in operation with the finishing train completely powered by thyristor power supplies; the 63,000-kw capacity of these power supplies and those for mill auxiliaries is the largest in the industry. Electric power comes from the mill's own substation, which could supply the needs of a city of 100,000 persons.

Another "first" was scored in the mill startup. Never before had a mill been started up under the complete control of its computer, but this one broke the rules. With the line under computer control, the first heated slab emerged from the furnace and passed through the roughing train. It then entered the Number 1 finishing stand, was successfully threaded in turn through the other six finishing stands, and was coiled. In view of the complexities of a highly automated mill of this size, such a startup is a considerable feat.

The hot-rolled coils and sheets produced are used directly in the production of such items as automotive parts, shipping containers, railroad cars, and agricultural implements. In addition, the mill supplies coils of steel for further processing in the plant's cold-rolled sheet and tin mill.

Products range in thickness from 0.047 to 0.500 inch and in widths from 20 to 75

1—Under the watchful eye of an operator, a slab is removed from a furnace in preparation for rolling in the 80-inch hot sheet mill at Bethlehem Steel Corporation's new Burns Harbor Plant. The entire rolling mill is under the direction of a Prodac 580 computer control system, from the slab depiler that charges these furnaces to the strip coiler at the delivery end of the mill. Overall length of the mill is about 2000 feet.

2—The heated slab passes through a scale breaker and then through the five-stand roughing train for initial reduction. The in-line computer calculates the rolling schedule for the slab on the basis of simple input information about the slab and the desired finished product. Such mill data as speeds and temperatures are registered for operators in the control pulpit, and the operators can communicate with the computer to initiate changes in mill operation.

inches. The mill is capable of producing coils weighing up to 1100 pounds per inch of width with a maximum diameter of 80 inches.

The slabs used range from 5 to 12 inches thick, 20 to 76 inches wide, and 12 to 32 feet long. After processing in the slab yard, they are transferred to one of three continuous heating furnaces, where they are heated to approximately 2300 degrees.

Heated slabs move on a roller table through the vertical scale breaker, where two rolls loosen the scale formed during heating. The scale is washed away by a high-pressure water spray and the slab enters the first of five roughing stands, which are also equipped with high-pressure water sprays.

The first two roughing stands are two-high mills, while the next three are four-high units. They remove all remaining scale, establish the finished width of the product, and reduce the slab to a suitable thickness for the finishing operation.

Work rolls in the roughing mills range in diameter from 43 to 48 inches, and their working surfaces are 80 inches in length. The last four roughing stands have vertical edging rolls that control the width of the steel.

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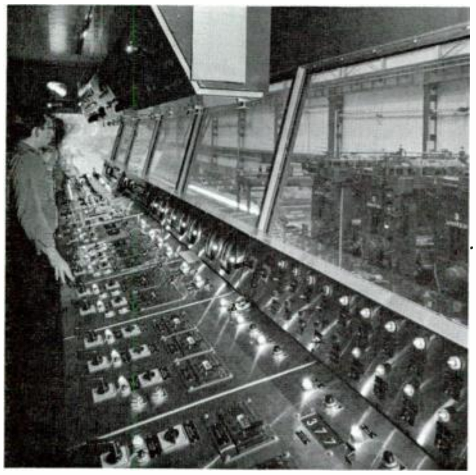

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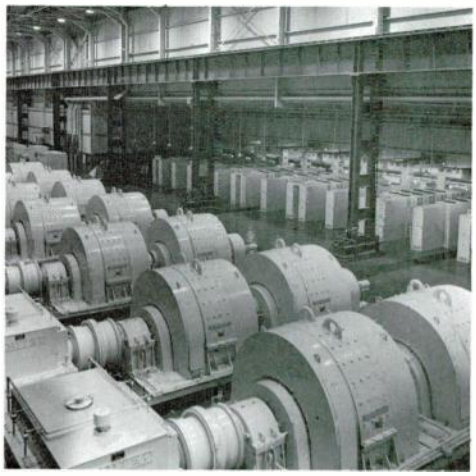

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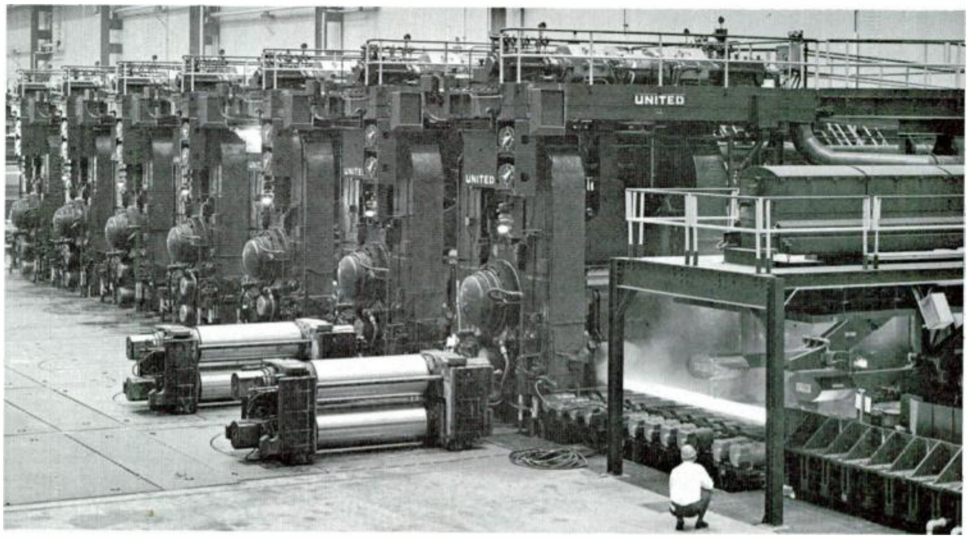

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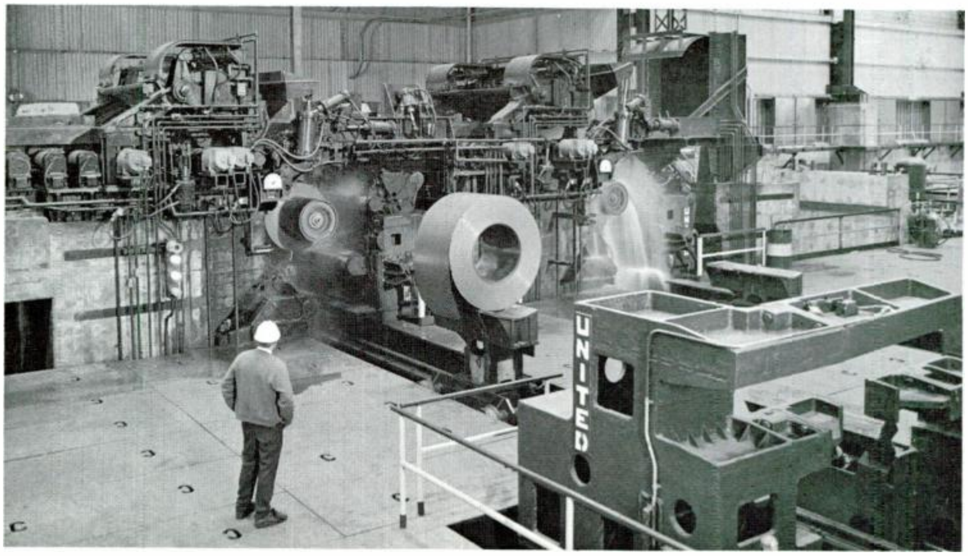


3—After rolling in the roughing train, a seven-stand finishing train rolls the hot steel uniformly to the final thickness. Total horsepower on the roughing and finishing trains is 108,000.

4—Each finishing stand is driven by a 9000-horsepower double-armature dc motor. Thyristor static power supplies that provide adjustable-voltage dc power for these motors are seen in the background. The thyristor power supply ratings total 63,000 kw.

5—Delivery speed from the finishing train is as high as 3750 feet per minute. Product thickness ranges from 0.047 to 0.500 inch, and an automatic gauge control system maintains close control of thickness. Work rolls are changed automatically by unique turntable devices seen at the side of two of the stands. All table rolls beyond the vertical scale breaker are driven by individual permanent-magnet dc motors.

6—Two high-speed coilers wind finished strip into coils. The mill's control computer selects the coiler to be used and also initiates the removal, banding, and conveying of the coils.

As the slab leaves the last roughing stand, it rolls onto a delay table that synchronizes its speed with the entry speed of the first finishing stand. The delay table also transports the slab to the crop shear, located just ahead of the finishing train, where the head end is sheared. It then passes into scale-breaker stands where rolls and high-pressure water sprays descale it.

Next, the slab enters the finishing train, which consists of seven four-high stands in tandem. The speed of the metal in the first finishing stands is relatively slow compared with that in the final stands, since speed increases in proportion to the reduction (and therefore elongation) being made. Rolling speed also is governed by the automatic control system to regulate the temperature of the metal.

Work rolls in the finishing stands range from 26½ to 28½ inches in diameter, while back-up rolls range in diameter from 56 to 61 inches. Like the rolls for the roughing stands, each finishing roll is 80 inches long.

Finishing-stand work rolls require frequent changing even under normal operating conditions, and roughing-stand work rolls also must be changed periodically. Consequently, automatic devices were included for changing all 18 work rolls in the finishing stands and final two roughing stands within six or seven minutes. Each stand has a roll-change turntable that contains two sets of parallel tracks, one on each side of the turntable center. The new pair of rolls is placed on one set of tracks, while the other set of tracks is aligned with the rolls presently in the mill stand. Two motorized rams push the work rolls from the stand onto the set of empty turntable tracks. The turntable is then rotated 180 degrees, bringing the new rolls into line with the stand, and the rams pull the new rolls into the stand.

From the last finishing stand, the strip is transported to the coiler over runout tables. Two rotating-mandrel coilers are used alternately so slabs can be processed in quick succession. The wound coil is automatically lifted from the coiler to a stripper car, which carries it to an "upender" that rotates it from a horizontal to a vertical position. The upender deposits the coil on a high-speed conveyor that transports it to a scale where it is weighed and banded. Coils scheduled for further processing in the cold-rolled sheet and tin mills are transported to those facilities, and those that are to be processed further in the finishing department of the hot mill proper move from the weigh scale to one of two "downenders" in the coil storage building. There they are rotated to a horizontal position and stored to await processing.

Control System

The Prodac 580 computer system has complete centralized control of the mill, tracking production flow from the time a slab leaves the depiler in the slab yard until the coiled strip reaches the scale on the delivery side of the coilers. Besides providing consistent, accurate, and economical control of the operation, it monitors and logs selected mechanical and electrical data to supply operators with detailed process information.

Input to the computer is minimal, consisting mainly of slab dimensions, grade of steel, any special rolling requirements, and desired finished dimensions. The computer calculates the rolling schedule for each product, employing its programmed mathematical model of the process, and makes the necessary setups in the furnace area, roughing and finishing mills, and coiler area. (The setups include roll openings, sideguide settings, edger openings, operating speeds of stands and tables, and action of cooling sprays.) The computer then initiates the process, tracking each slab by means of signals from sensors and initiating the proper sequence of operations for it. Control is predictive and adaptive, which means that the computer can update its operation to optimize results.

A high-performance speed-regulating subsystem in the control for each finishing stand includes provision for accelerating the mill. The mill is threaded at some lower speed and then accelerated to maximize throughput or to provide the required rolling conditions.

Each finishing stand also has its own automatic gauge control that takes account of such factors as strip acceleration and hardness to set the stand speed and screwdown settings to optimize the work done in each stand and to hold gauge accurately. Load-cell gauge meters in the stands measure gauge indirectly; they can be used alone to hold gauge constant, or with an X-ray monitor to obtain the absolute gauge called for.

The two special X-ray gauges on the delivery side of the seventh finishing stand can be traversed the full width of the strip. One is used to monitor and correct the load-cell gauge system, and the other checks strip profile. A back-lighted optical scanning device measures width at the delivery side of the last stand.

All finishing stands have provision for backup-roll bending with hydraulic actuators. Bending the rolls may be necessary to counteract the bending due to work forces and thus keep the strip's transverse flatness within the desired limits.

The computer also controls the temperature of the metal being rolled, holding it within specified limits throughout rolling and coiling. Temperature control is important during rolling because it affects gauge control, and during coiling because constant temperature is needed to assure uniform metallurgical properties throughout a coil of strip.

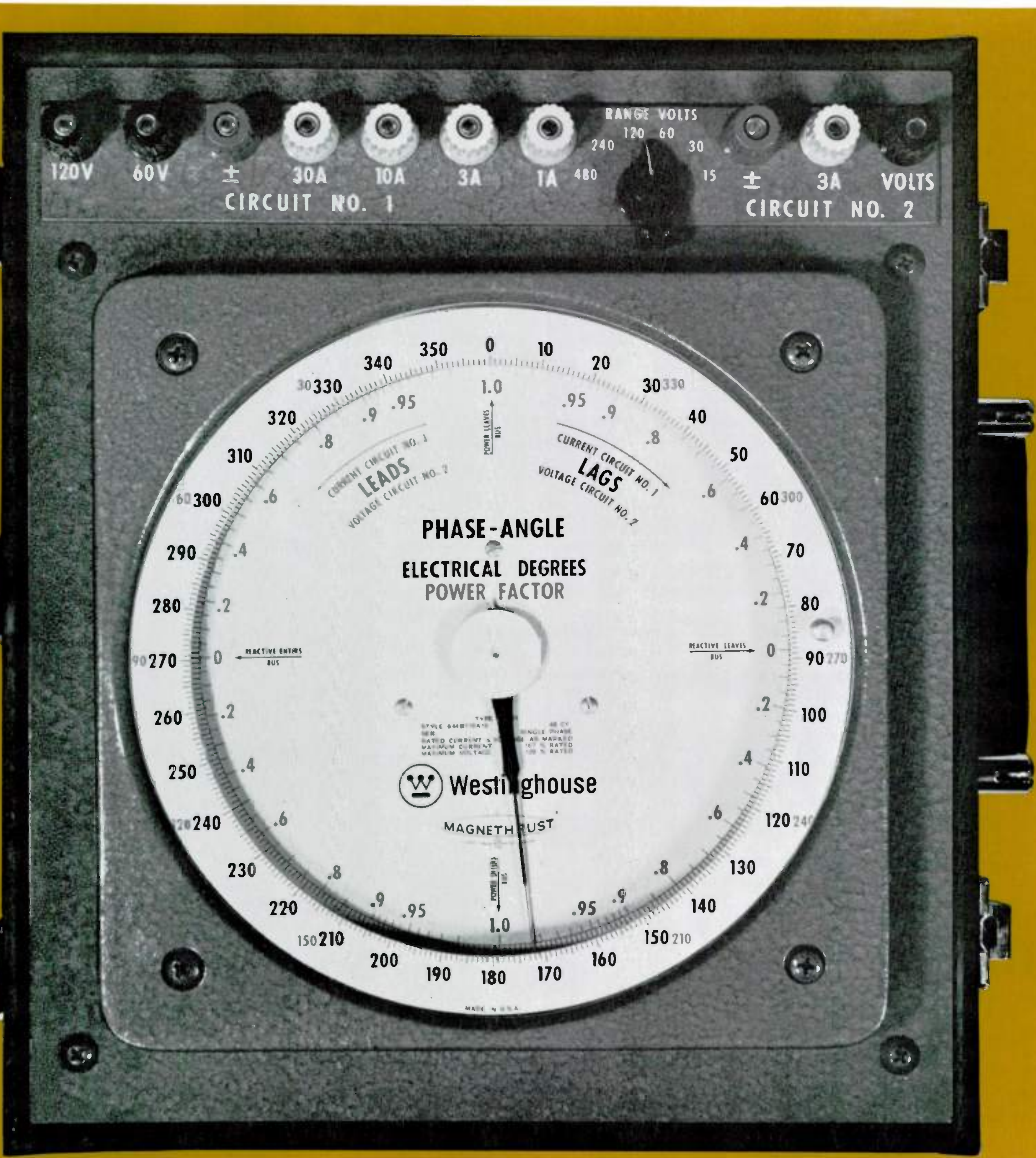
One way the computer controls strip temperature is by regulating the spraying of cooling water on strip and rolls. The other way is by regulating speed and acceleration. The strip loses heat by radiation and acquires heat by work input in rolling; thus, it is cooled by slowing the stands and runout tables, and heated (or heat loss reduced) by running faster. Constant delivery temperature is achieved by accelerating the mill at a rate that creates a work temperature input equal to the radiation temperature loss.

Conclusion

All the recent technological advances in hot-rolling mills are for the purpose of achieving better operation of the process. They have been brought about by increasingly stringent production requirements, and they are helping steel producers meet those requirements.

A Versatile Phase-Angle Meter for Electric Power System Analysis

T. L. Bourbonnais II
L. J. Lunas



This new portable instrument can be used to measure phase angle between a current and voltage, two currents, or two voltages. Vector relationships are given on a 360-degree scale.

Many devices on electric power systems—protective relays, watthour meters, instruments, and transformers, to name a few—require specific phase relationship between current and voltage for proper operation. These conditions must not only be checked for each new installation but must often be analyzed in cases of trouble or faulty operation. A versatile instrument developed for this purpose is a new phase-angle meter (Type PI-161), illustrated in Fig. 1.

The new phase-angle meter is a moving-iron type with a 360-degree scale. It was developed to meet the need for a portable instrument that can be used over a broad range of currents and voltages. The meter will measure phase angle between a current and a voltage, or between two voltages, or between two currents. Conventional counterclockwise vector notation has been incorporated in the 360-degree scale to facilitate identification of vector relationships. The scale has an effective length of about 20 inches so that scale resolution is about $1/16$ inch per electrical degree. Rated accuracy, which is easily readable, is ± one electrical degree when the instrument is operated at rated voltage, current, and frequency.

Instrument Mechanism

The mechanism for the 360-degree meter consists of a motor-type stator with distributed three-phase star-connected windings, energized single-phase through a phase-splitter circuit (Fig. 2). The moving element rotates freely within a separate polarizing inner-coil winding. Low-residual nickel-iron vanes on the moving element are magnetized alternately north and south by alternating current in the inner coil. The moving element seeks a position where the vanes develop maximum pole strength with relation to the rotating stator field. Thus, moving-element position is determined by the phase angle between the electrical quantity that energizes the stator field and the electrical quantity that energizes the inner polarizing coil. This assumes, of course, that both circuits are energized from sources of identical frequency. Otherwise, the moving element rotates in the same manner as a synchroscope.

1—Dial and scale arrangement of new phase-angle meter (Type PE-161) is convenient for determining vector relationships between quantities being measured.

Photo—Portable phase-angle meter is designed for use as a field instrument for checking relay connections and other applications where the relationship between current and voltage must be known.

To minimize bearing friction for improved accuracy and to provide longer bearing life with low maintenance, a magnetic-suspension bearing system of the type used in watthour meters is used rather than the conventional pivot-and-jewel system.

Rated Conditions and Accuracy

Rated accuracy applies when the inner magnetizing coil (*Circuit 1*) is operated as a current coil, and the stator field (*Circuit 2*) is operated as a voltage winding. However, both circuits can be operated from either voltage or current so that phase-angle measurements can be made between two currents or two voltages (at slightly reduced accuracy).

Both circuits are energized through internal multirange transformers. Thus, rated current for the inner magnetizing coil (*Circuit 1*) is 30, 10, 3, or 1 ampere. Series resistances and an auxiliary winding are included so that the current coil can also be operated as a voltage circuit at 120 or 60 volts.

A reduction in load current from rated values will cause an increase in lag reading, as shown by the current-influence curve (Fig. 3). However, current may be reduced to as little as 10 percent of rated value with reasonably good results. Current as low as 2 percent of rated provides a positive indication, but the lag error is large. Thus, it is possible to obtain a reading on the one-ampere tap with load current as low as 20 milliamperes. For some purposes in relay work, these large errors, when understood, would not prevent useful analyses. For example, if readings are taken on a balanced three-phase system in a differential circuit, the same error applies to each phase so that the measure-

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ments could provide a useful comparison for some purposes. If better accuracy is necessary at these low current levels, an external auxiliary current transformer can be used to step up the current to the required level.

The current coil has a maximum rating of 167 percent of rated current continuously, and is capable of carrying larger overloads for short periods.

The field winding (*Circuit 2*) has switch-selected voltage ranges of 480, 240, 120, 60, 30, and 15 volts. For use as a current winding, a 3-ampere current circuit is provided.

Voltage influence on the stator winding is relatively small. For example, a reduction of voltage by 50 percent causes only a 0.5-degree leading error when the current coil is operated at rated current. Voltages of 110 percent rated may be applied continuously. Thus, with the multiple choice of voltage ranges, an operating tap can be selected to minimize voltage influence.

Since the phase-splitter circuit used in the stator field is frequency sensitive, the instrument has rated accuracy only at the frequency for which it is calibrated. However, frequency influence is not great over the range of frequency variation likely to be encountered in normal system operation. From the frequency influence curve (Fig. 4), it will be noted that frequency influence depends upon both frequency and scale position.

Vector Relationships

Since the scale arrangement and pointer rotation correspond to conventional vector diagram notation, vector relationships can be determined directly from the scale reading. This feature is particularly useful when analyzing trouble.

Dial notation also clarifies direction of power flow and reactive flow. Several different conditions of power flow and re-

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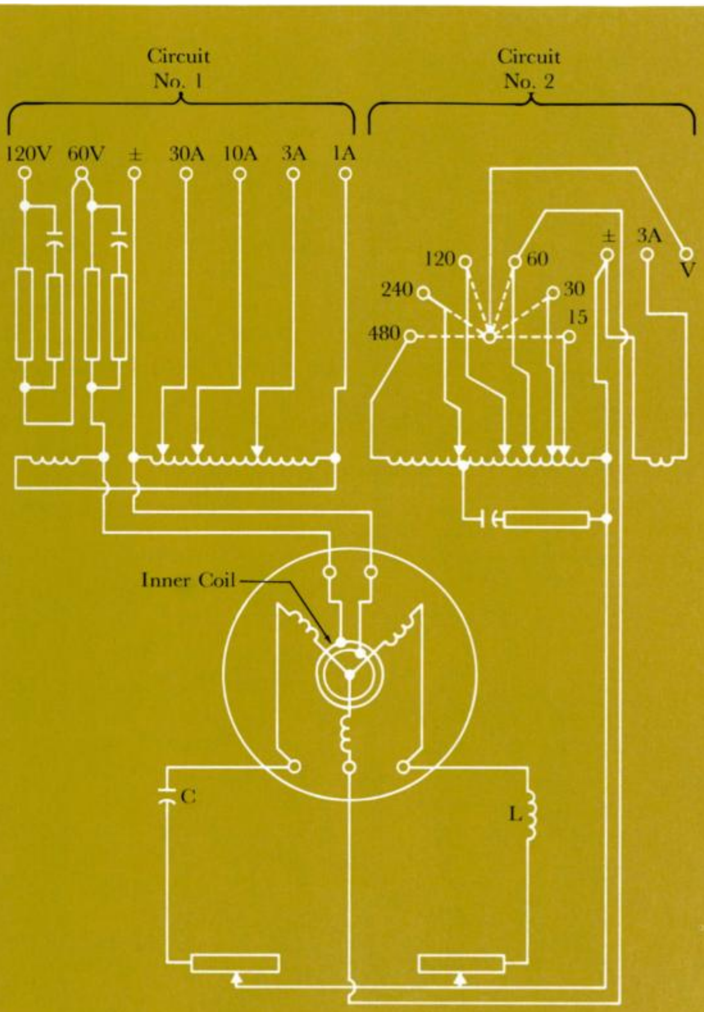

2—Current and voltage circuit arrangements are illustrated by internal wiring diagram of phase-angle meter.

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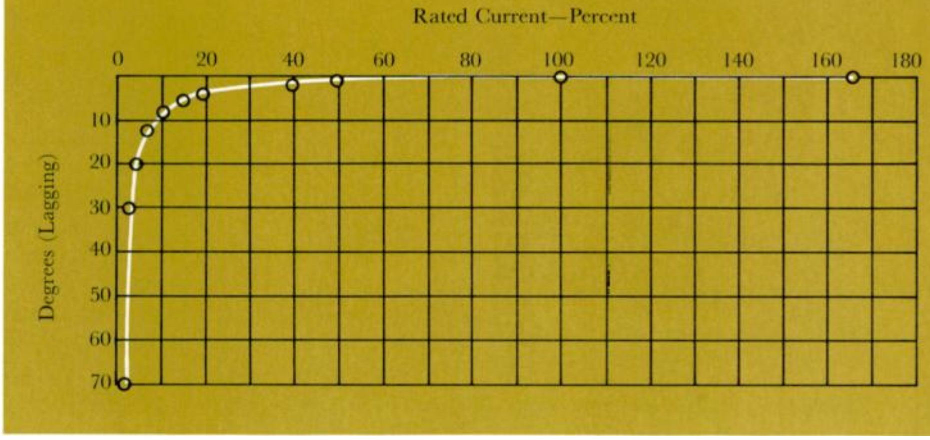

3—When less than rated current is applied, phase-angle meter indication will err in a lagging direction.

active flow, with the instrument indication for each example, are illustrated in Fig. 5. The upper half of the scale indicates power flow leaving the bus, while the lower half of the scale shows power flow in the reverse direction. Similarly, one quadrant of each half-scale corresponds to "lag" (of the current circuit behind the voltage circuit) and the other quadrant corresponds to "lead." Basically, the instrument is a single-phase power-factor meter with the scale marked in degrees. For convenience, a corresponding power-factor scale is also included, and marked in contrasting color.

The position that the pointer takes depends on the relative direction of the real and reactive power. If both are away from the bus, the reading is between 0 and 90 degrees; if both are into the bus, the reading is between 180 and 270 degrees. Similarly, other conditions read in other quadrants, with the specific indication depending on the relative magnitudes and directions of real and reactive power.

Applications

Phase-angle meters have been used for many years for checking connections of relays and instruments. Common applications that are frequently encountered include:

1) Checking polarity
2) Checking connections of directional relays
3) Checking differential relay circuits
4) Connecting transformers—for example, single-phase units in bridge-rectifier arrangements
5) Checking phase rotation
6) Phasing out busses
7) Checking synchronizing circuits
8) Connecting watthour meters, wattmeters, varmeters, power-factor meters, synchroscopes, etc.

Of various applications, checking con-

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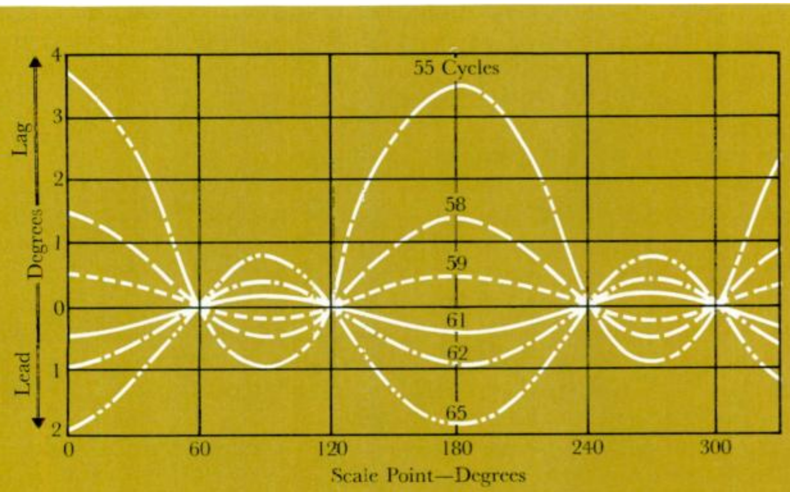

4—Frequency influence is a function of both frequency and scale position.

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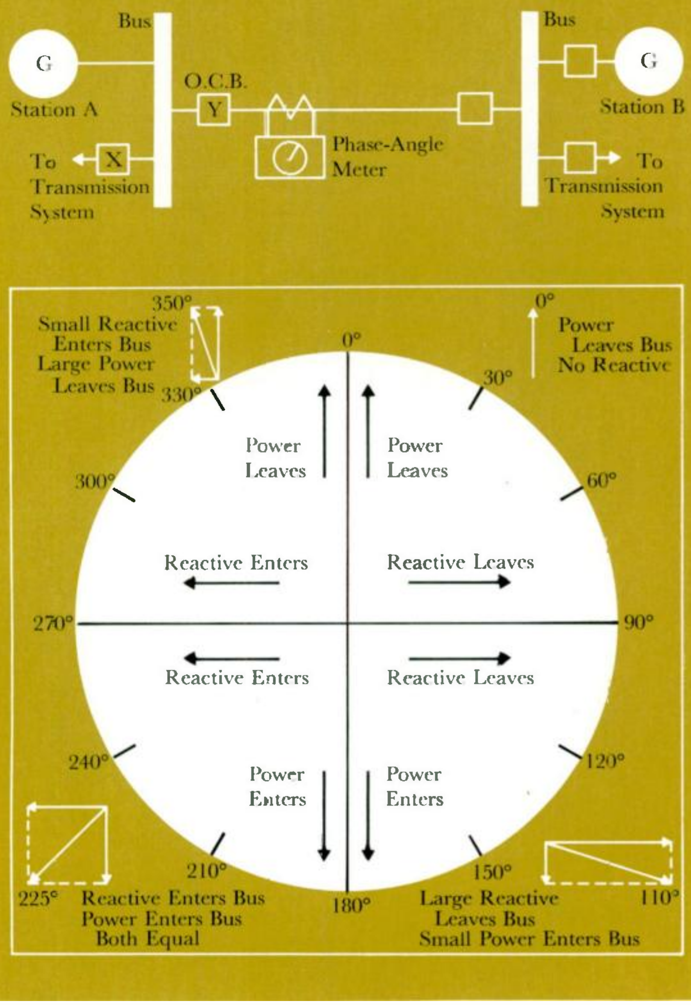

5—Power flow, reactive flow, and phase angle can be determined from 360-degree dial of the phase-angle meter, connected as shown to a transmission system.

nections of banks of directional phase relays is perhaps one of the most useful tasks for the phase-angle meter. However, a thorough understanding of instrument transformer polarities is required if the phase-angle meter is to be used to determine angular differences between specific currents and voltages. A proper vector analysis also requires complete knowledge of current and voltage phase relationships on the transmission line to which the relays are connected.

A Typical Relay Analysis

Directional relays develop their operating characteristics by comparing a line current with a line-to-line voltage. These quantities are selected from different phases so that (under normal system conditions) current leads voltage at the relay, usually by 90 degrees. Thus, relay operating torque is developed only during fault conditions when a fault produces a highly inductive load and causes current and voltage at the relay to approach an in-phase condition.

To illustrate a typical directional-relay connection, each of the three phase relays in Fig. 6 receives a current that leads an applied voltage by 90 degrees when current at the relay is at unity power factor in the tripping direction. For example, current in phase one (I_{x1}) leads voltage developed from phases two and three (V_{23}) by 90 degrees, and these quantities are applied to the phase one ($\phi 1$) relay.

To check these vector relationships, the phase-angle meter is connected to the current and voltage circuits of each relay (illustrated for relay $\phi 1$). The phase-angle meter should indicate a 90-degree current lead for a system load of unity power factor. Thus, it is also necessary to know the power factor of the system. This can usually be accomplished by arranging with the system dispatcher to adjust excitation at some time of the day for unity power factor. If readings for all phases do not conform to the intended phase angle between current and voltage, further analysis will show which relay connections need to be reversed, or how the polarity of current or potential transformers can be changed to obtain the necessary vector relationships.

Many Other Uses

Although only one application has been illustrated, the phase-angle meter can be used for analyzing the vector relationships of any directional or differential relay scheme.[1]

Other typical uses for the meter include the checking of connections of watthour meters, wattmeters, varmeters, and other meters or instruments that depend upon specific phase relationships between voltage and current. The instrument is also adaptable for use in synchronizing applications, phasing out systems by comparing potentials, and checking phase relationships in special connections such as Scott-connected transformers. Thus, the phase-angle meter can be a valuable tool for analyzing and solving power system problems.

Westinghouse ENGINEER **May 1967**

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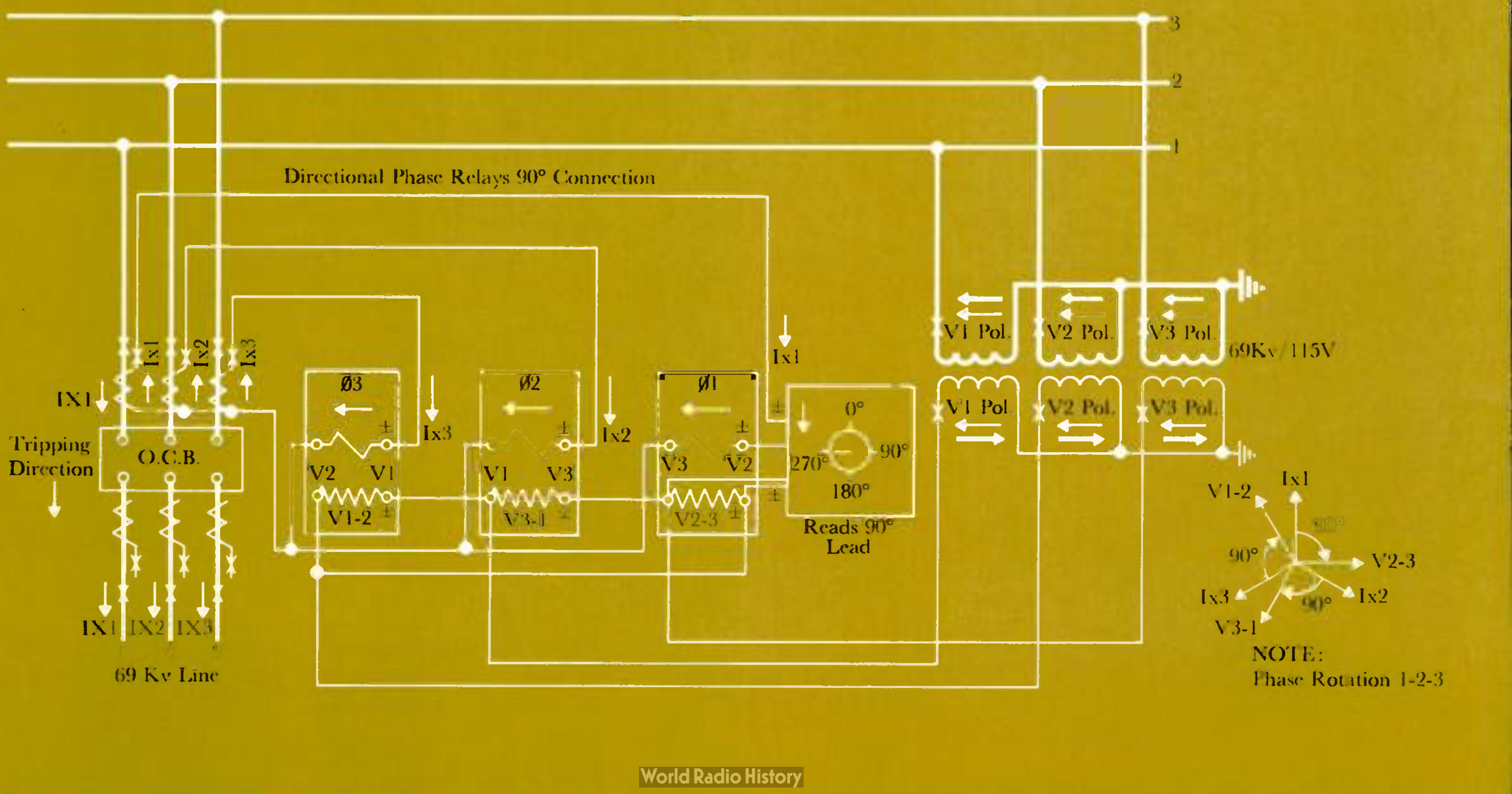

6—Analysis of current flow with phase-angle meter is demonstrated for typical directional relay scheme.

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[1] Bourbonnais II, T. L., and Lunas, L. J., "A Versatile Phase-Angle Meter for Power System Analysis," *IEEE Transactions* (Power Apparatus and Systems), Volume PAS-86/No. 6, June 1967.

Fast Induction Heating Speeds Hot-Spinning Process

Induction heating equipment enables Walter Kidde & Company, Inc., to heat a six-inch end section of a fire extinguisher shell to 2200 degrees F in just 45 seconds. This rapid heating makes it possible to shape 225 shells per shift per machine by hot spinning.

Spinning reduces the size of the open end of the shell and shapes the neck for the valve assembly. The shell is held in the spinning machine by a spindle and chuck and rotated at high speed while a turret, manipulated by a skilled operator, shapes the top and neck in about a minute and 20 seconds. The cylinder is then heat-treated again, the top is machined smooth, and the inside of the neck is threaded to receive the valve.

Five high-induction m-g sets supply power in the induction-heating system, which was supplied by the Westinghouse Industrial Equipment Division. The m-g sets have 3600-rpm squirrel-cage single-phase alternators driven by induction motors.

A variety of methods had formerly been used to heat the shell ends. A "hammer-necking" process involved putting an extinguisher shell into a forge, heating it, removing it, pounding it with a trip-hammer until cool, and repeating the process until the desired shape was reached. With this process, only eight shells could be made per hour. Next, a swaging operation with a four-segment die that vibrated the neck was tried. Most recently used, before induction heating, was a spinning machine with gas heating.

Induction heating equipment heats the open end of a fire-extinguisher shell to white heat in 45 seconds. The end is then quickly shaped to a neck by hot spinning.

Silicon Rectifiers Cut Costs of Arc-Air Gouging

Virtually all large steel castings require processing to remove risers, cracks, inclusions, and other defects. This has often been done by mechanical grinding or chipping but, more recently, electric arc-air gouging has come into use to reduce the time and effort required.

An innovation in power supply for arc-air gouging is the use of parallel-connected solid-state welder power supplies at the Coraopolis Works of Blaw-Knox Company, Coraopolis, Pennsylvania. They replace m-g sets that, while satisfactory power sources, required much more maintenance: brushes, bearings, and brush holders in the m-g sets had to be replaced regularly.

The silicon-rectifier power supplies require virtually no maintenance and therefore reduce operating costs for the company. Moreover, electrical power is used only when an arc is struck, while an m-g set's motor draws power all the time it is operating.

The power supplies are Westinghouse type WSH 500-ampere industrial arc-welder units, stacked in threes connected in parallel by half-inch copper bus bars. There are presently five such assemblies, and the company plans to replace all its remaining m-g sets for arc-air gouging with silicon-rectifier power supplies. The three rectifiers in an assembly can be operated at full power to produce 1500 amperes dc, or one or two can be partially or completely shut off, depending on the power need.

The steel castings processed range from 200 pounds to 25 tons in weight. They are used in such applications as earth-moving equipment, military tanks, and freight cars.

Solid-state welders are connected in threes to form power supplies for arc-air gouging.

Arctic Research Drift Vessel

The model of an Arctic research drift vessel in the photograph at lower left is based on a conceptual design developed for the National Science Foundation, Washington. The study was aimed at enabling scientists in the future to conduct longer and better research expeditions; National Science Foundation specifications called for quarters to house 45 men and space for several years' food supply. In addition to several laboratories, the vessel would include medical and recreation facilities, an electronic equipment repair and machine shop, a hanger for snow-removing equipment and aircraft, and a small nuclear reactor for internal power. The study was conducted by the Westinghouse Defense Center.

Arctic research drift vessel would permit longer and better-equipped expeditions.

Second Deepstar Deep-Diving Vehicle Under Construction

DS-2000, second in the family of Deepstar manned submersibles, is being built for various underwater operations, mainly scientific, at depths of 2000 feet. Its design is based on criteria derived from construction and operation of its predecessor, *DS-4000*, which has been in service since May 1966. That vehicle is now being used in undersea research by the U.S. Navy under a year's contract.

The pressure hull of *DS-2000* is cylindrical, in contrast to the spherical shape found in most smaller deep-diving vehicles. For work at 2000 feet, the cylindrical shape provides more internal volume per unit strength. The hull is 10 feet long and 5 feet in diameter; it is made from two hemispherical heads and a cylindrical midsection, all ¾-inch HY-80 high-strength steel. (See photograph.) The complete hull, including ports, hatch, and other penetrations, will be hydrotested under pressures found below 3000 feet of water to provide a minimum safety factor of 1.5.

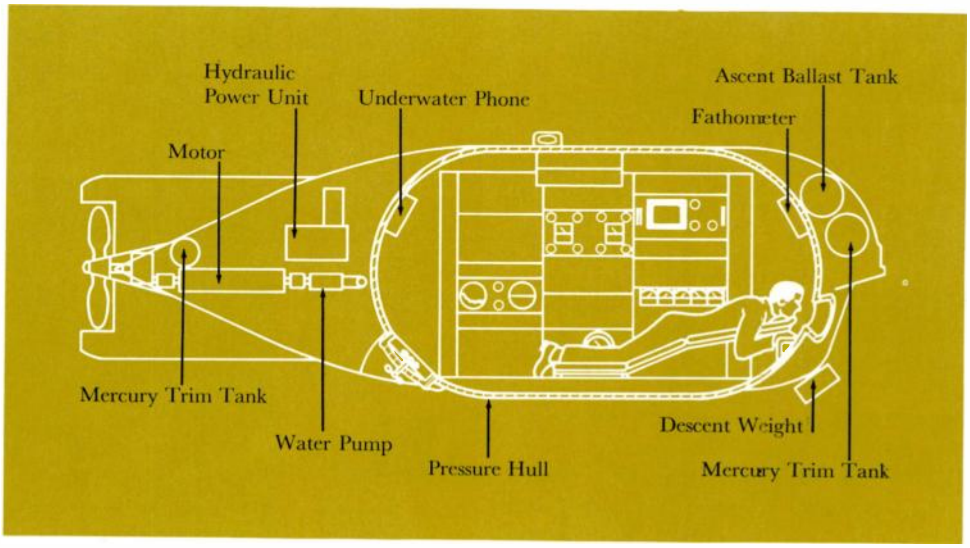
After pressure testing, the hull will be outfitted at the Westinghouse Underseas Division's Ocean Research and Engineering Laboratory near Annapolis, Maryland. Propulsion, control, and life-support systems will be installed, along with a fairing to give the vehicle a hydrodynamic shape, and a manipulator will be included for scientific sampling. The seven-ton submersible will begin diving tests by this fall.

Basic design criteria for all the Westinghouse submersibles emphasize safety, portability, maneuverability, versatility, and ease of launch and retrieval at sea. For maximum safety, the design includes use of a pressure-resistant, positive-buoyancy hull that does not require power to return to the surface. It also includes advanced life-support equipment, navigation aids, a means of tracking and locating the craft, and high reliability throughout all systems. All the Deepstar vehicles are small and light enough to be easily transported by truck, ship, or aircraft to minimize the time and cost of moving the vehicle from one job site to another.

DS-2000 will obtain its positive buoyancy from the displacement of the hull and from a foam material between hull and fairing. The foam is made of millions of microscopic hollow glass spheres embedded in an epoxy binder; its specific gravity is 0.60 to 0.65. In the event of a power failure, the crew can manually jettison the main batteries, dump the mercury in the trim system, and release much of the external scientific instrumentation including the manipulator.

To enable *DS-2000* to perform useful work, it will have a system for accurately controlling attitude, speed, and depth. Small water jets and a mercury trim system will be used to control the vehicle's attitude and to make fine adjustments in speed. Main propulsion, producing speeds up to three knots, will be provided by a single 26-inch propeller powered by an ac motor. Depth will be controlled by transferring oil into and out of the craft's ballast tanks.

For versatility and adaptability to a wide variety of work and environmental conditions, the vehicle will be equipped with certain basic instrumentation (such as cameras and lights) used in most operations. Additional internal rack space, electrical cable penetrations, power, and external forward mounting foundations will be provided for special equipment.



Pressure hull for *DS-2000* is made of two hemispherical heads welded to a cylindrical midsection (*left*). Hull material is ¾-inch high-strength steel. The manned submersible *(right)* will perform scientific work, construction, and salvage at depths to 2000 feet.

Airport Transportation System Will Take the Walking Out of Flying

Four unique passenger transfer systems at the new Tampa International Airport will eliminate the long wearying walk from terminal building to airplane when the airport complex is completed, probably in 1969. Eight air-conditioned vehicles in the system will run over elevated roadways on rubber tires to transfer passengers about 1000 feet from a central "landside" building to four "airside" locations.

Two vehicles on parallel roadways will serve each airside location, which will be devoted to the loading and unloading of passengers, baggage, and cargo and the handling and servicing of aircraft. Each of the driverless electronically controlled vehicles will be capable of carrying up to 100 standing passengers to their destinations in about 40 seconds—or at least 840 people in a single direction in ten minutes. This is equivalent to accommodating passengers discharged from the simultaneous arrival of four fully loaded intercontinental DC-8 aircraft.

The vehicles will operate in a passenger demand mode; when not carrying passengers, one will be in position in a foyer at the main landside building and the other in a foyer at airside. As a passenger approaches a vehicle, automatic sensing devices will open the vehicle doors. If the vehicles are in operation, the sensing devices will command the approach of the first of the two vehicles available and open the doors once the vehicle is in position. Then the vehicle will transport the passenger to his destination as smoothly and rapidly as an automatic horizontal elevator.

Pneumatic-tired guide wheels on the bottom of the vehicles will lock onto a steel I beam in the center of the roadway for operating safety. Vehicles will be 35 feet long and 9½ feet wide, have a 228-inch wheelbase, and weigh 21,500 pounds. Each will be powered by two 100-horsepower dc motors and will reach a top speed of 35 miles an hour after leaving its station.

The vehicles will have two sets of double-parting doors on each side, allowing passengers to get off on one side while others get on from the opposite side. Because the vehicles are reversible, they will not have to turn around at the ends of their shuttle runs. The systems will be supplied by the Westinghouse Transportation Division.

Stocking and Ordering of Turbine Parts Facilitated by Data System

Renewal parts for installed steam turbines have to be kept in stock at the turbine location, or at least readily accessible from the supplier, to assure maximum availability of the turbine. Yet, stocking unnecessary parts or more than is necessary is uneconomic. Consequently, a system has been devised to enable electric utilities to determine in advance the need for specific parts and the number of places where those parts are used.

With that information, a utility can stock parts adequately yet economically. The system also facilitates order processing and shipping of parts. Approximately 500 electric utility turbines, starting with units installed in 1947, will eventually be included in the program.

Key to the Large Turbine Division's renewal parts program is the application of a style number to each part listed in the instruction manual furnished with the turbine. The style number comes from the detailed drawings used to manufacture renewal parts. All identifying renewal parts information is applied to punched cards, and the card information is transferred to a master tape file for data storage. Printouts are made from the tape on a reproducible form, and copies are then bound in a renewal-parts data book and an interchangeable-parts book.

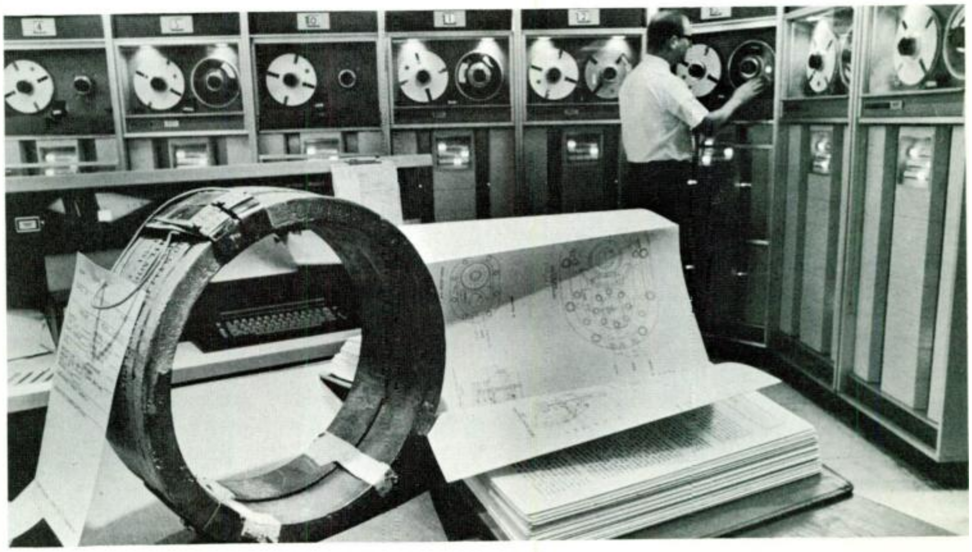
The interchangeable-parts book lists the units by serial numbers for a given electric utility system and contains the information on interchangeability of renewal parts for all of these units. The book can be expanded to include the units of two or more utility systems by selecting the appropriate tapes for processing.

The renewal-parts data book has the same descriptive terminology and item numbers shown in the instruction manual. It also lists recommendations for stock, which are based on the Large Turbine Division's reliability program.

This method of cross referencing simplifies determination of a renewal part's style number. Interchangeability is then established by locating the renewal part's style number in the interchangeable-parts book.

Thus, an electric utility can obtain complete ordering information from a single line entry in the renewal-parts data book, minimizing the time required to process an order. Order entry by teletype, using the style numbers, further reduces order handling time. Shipment also is fast because the manufacturing infor-

Information about steam turbine renewal parts is programmed on tape for storage and computer processing to assure ready availability of the parts. The information includes identification, interchangeability, stocking recommendations, and manufacturing data.

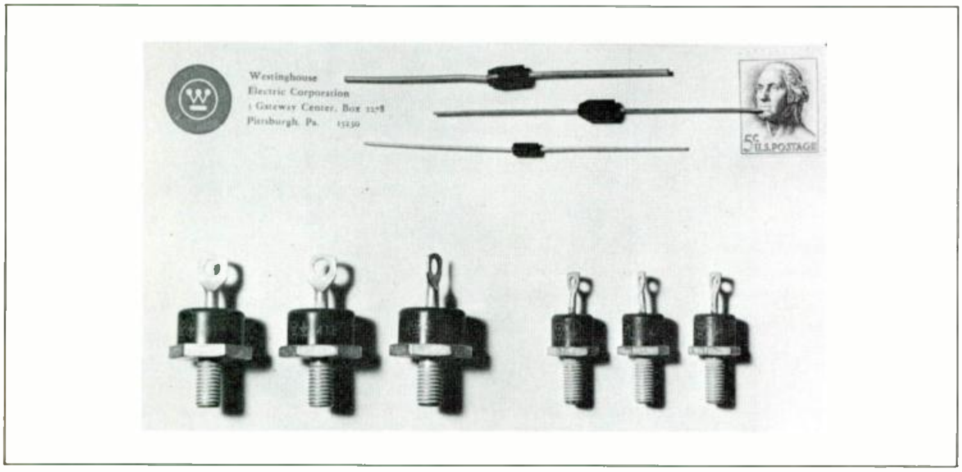


mation developed for each renewal part is programmed for computer processing and storage; the quick information retrieval thus provided starts the manufacturing cycle the day the parts order is received.

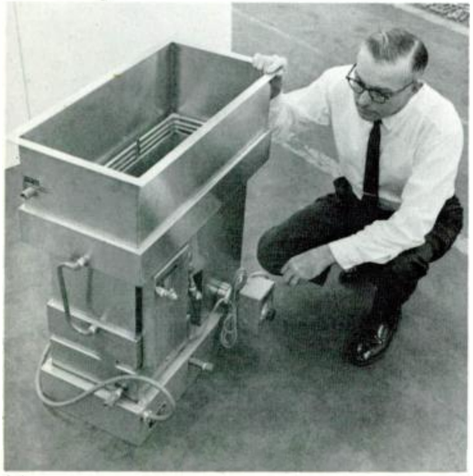
Products for Industry

Silicon rectifiers in a low-priced plastic-encased line can replace most popular Jedec devices rated from 1½ to 40 amperes, with peak reverse voltages up to 1000. Typical applications include television, hi-fi, power supplies, communication equipment, light dimmers, speed controls, and battery chargers. The rectifiers incorporate features usually found only in higher priced metal-cased rectifiers. *Westinghouse Semiconductor Division, Youngwood, Pennsylvania 15697.*

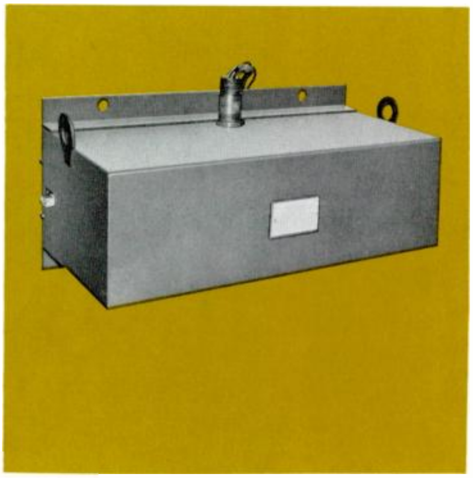
Ultrasonic vapor degreaser is a compact portable unit that uses Freon TF cleaning solvent. It is only 29 by 15 by 35 inches high, yet it is versatile enough to handle most solvent cleaning jobs. Each of the two 4.3-gallon tanks has inside dimensions of 10 by 10 by 10 inches. The ultrasonic cleaning tank has a magnetostrictive transducer providing an intensity of 12 watts per square inch. A separate ultrasonic generator feeds high-frequency energy to the transducer. Entire unit is made of stainless steel. It can be modified to handle other types of cleaning solvent. *Westinghouse Industrial Equipment Division, 2519 Wilkens Avenue, P.O. Box 416, Baltimore, Maryland 21203.*



Silicon Rectifiers



Ultrasonic Vapor Degreaser



Explosion-Proof Transformer

Explosion-proof transformer is for outdoor applications in corrosive atmospheres or under hazardous conditions (Article 500, Division 1, National Electrical Code). Its case is completely filled with a resin-sand mixture that has little shrinkage and high strength, so it can withstand extreme thermal shock and does not need a thick-walled case. The transformer is designed for three-phase 60-cycle operation at 600 volts and lower, and it has class F insulation, 115 degrees C rise. It is available for wall, floor, or rack mounting in output ratings of 9, 15, and 30 kva. *Westinghouse Specialty Transformer Division, Greenville, Pennsylvania 16125.*

New Literature

The When, Why, and How of Magnetic Shielding is a 36-page design handbook that discusses magnetic shielding in low-frequency applications. Illustrations, formulas, graphs, diagrams, and tables supplement the text in presenting useful theory and practical tips for designing and evaluating shielding. Topics covered include design parameters, choice and comparison of materials and shapes, heat treatment, and evaluation. *Copies available from Westinghouse Materials Manufacturing Division, Blairsville, Pennsylvania 15717.*

Westinghouse Industrial and Power Tube Technical Guide is a 32-page book presenting a complete up-to-date listing of electronic tubes. It includes an interchangeability listing that covers the most significant American tube manufacturers. Specifications, base diagrams, and electrical characteristics for 740 tube types in 19 basic categories also are presented. Some of the tubes included are radio-frequency oscillators and amplifiers, audio-frequency amplifiers, gas and vacuum rectifiers, ignitrons, thyratrons, and special-purpose sensing and control tubes. Helpful technical information is provided about the function, construction, and application of each tube category. *Copies available from Westinghouse Electronic Tube Division, P.O. Box 284, Elmira, New York 14902, at $.50 each.*

About the Authors

The ESS, *E*mplaced *S*cientific *S*tation, as conceived in a preliminary study for NASA by Westinghouse, is described in this issue by **Dr. Russell D. Shelton** from NASA's Marshall Space Flight Center, and **Vernon B. Morris** and **Dr. Ernest J. Sternglass** of Westinghouse.

Dr. Shelton is Chief of the Nuclear and Plasma Physics Branch of the Research Projects Laboratory, Marshall Space Flight Center, Huntsville, Alabama. He is responsible for activities in the areas of ion, plasma, nuclear and radiation physics. Dr. Shelton is the technical director of the Emplaced Scientific Station program for NASA.

Dr. Shelton joined NASA in 1958 and has worked in the areas of nuclear and electric propulsion, radiation shielding and effects, and satellite experimentation. He also assists in the supervision of research contracts on thermal neutron spectrometry, electrical propulsion, and shielding studies for space vehicles. He has participated in the scientific planning of nuclear weapons tests.

Dr. Shelton received his BS degree from Eastern Kentucky State College in 1947, and his MS and PhD degrees from the University of Tennessee in 1950 and 1953. He has taught physics at the above universities and also at Texas Christian University, the Illinois Institute of Technology, and the University of Alabama.

V. B. Morris, program manager for the Emplaced Scientific Station project at Westinghouse, is in the advanced programs group of the Systems Operations Division. For the past several years, he has directed planning and development programs for post-Apollo scientific instrumentation and lunar base communication systems. Before moving into this activity in 1962, he was engaged in telemetry system design, development, installation, and operation for a number of weapons programs. Morris is a graduate of Johns Hopkins University with a BS in Chemical Engineering.

Dr. E. J. Sternglass studied electrical engineering at Cornell University and obtained his BSEE in 1944. After serving in the Navy, he joined the U.S. Naval Ordnance Laboratory to do research and development work in physical electronics until 1949, when he returned to Cornell for graduate work in engineering physics.

On receiving his PhD in 1952, Dr. Sternglass came to the Westinghouse Research Laboratories, where he has since been engaged in both theoretical and applied work in the areas of electron physics, imaging devices, radiation physics, space instrumentation, and nuclear particle structure. Dr. Sternglass served as scientific director of the ESS program.

Edwin G. Noyes, making his third appearance on these pages, this time joins **John W. Skooglund** to discuss under-frequency operation of large steam turbine generators.

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

Skooglund graduated from Penn State University in 1951 with a BSEE and immediately joined Westinghouse on the graduate student course. In 1952, he became a member of the Electric Utility Engineering Department and then attended the Westinghouse Electrical Design School. After completing Design School, his first assignment involved test work at the Tidd 500-kv test project.

Skooglund spent two years in the Army Signal Corps and returned to the Electric Utility Engineering Department in 1956 as Assistant Sponsor Engineer.

He continued his education at the University of Pittsburgh and earned his MSEE in 1958. He became a Sponsor Engineer in 1958 with responsibility for special utility problems originating in the New York City area and Westinghouse International Company.

He became Advisory Engineer in 1966, and has recently spent much of his time working in the areas of power system stability and generator excitation systems.

R. E. Fromson's professional interests center around better ways of making things by use of better manufacturing systems and methods, a penchant illustrated by his development of adaptive control for the electrochemical machining process several years ago.

Fromson earned his BSME at Case Institute of Technology in 1938, his MSME there the following year, and has since completed MIT's Program for Senior Executives. He joined Westinghouse on the graduate student course in 1940, and his first permanent assignment was to Headquarters Manufacturing Engineering. Since then he has served as Manager of Manufacturing at the Small Motor Division, Works Manager at Bryant Electric Company, Manager of Facilities and Methods at Headquarters Manufacturing Planning, and Manager of Advanced Technology at the Industrial Equipment Division. He has been Manager of Manufacturing Technology and Planning at the Copper Wire Division since last year.

D. R. James graduated from Cambridge University, England, in 1965 with a BA in natural science (physics and metallurgy). He joined Westinghouse on the graduate student course and settled in the Copper Wire Division as a process engineer, working on metallurgical process development. James is a member of the Institute of Metallurgists, a British professional society.

E. H. Browning has spent his professional career applying electrical equipment and systems to the metals industries. He joined Westinghouse on the graduate student course in 1942, after graduating from Johns Hopkins University with a BE in EE, and found his first assignment in the metal-working section of the former Industry Engineering Department. After a two-year interruption for service in the U.S. Navy, Browning returned to the section and became its manager in 1953.

Browning moved to Buffalo when the Industrial Systems Division was formed in 1964. He served as Manager, Hot Rolling Mills, until early this year when he assumed his present position of Manager, Metals Industry Systems Department.

T. L. Bourbonnais II and **L. J. Lunas** join forces to describe a new phase-angle meter. The development of this instrument is an excellent example of a customer engineer working with a manufacturer's engineers to provide an answer to a definite need.

Bourbonnais, presently a Consultant with the Engineering Department of E. I. duPont de Nemours & Company, first became interested in phase-angle meters when he worked for the Idaho Power Company (1948–1951). He could not find an instruction manual for phase-angle meters in English, French, German, or Russian, so he decided to write his own. The result was the book, *Relay Testing,* a manual for relaymen published by Idaho Power Company and DuPont. During the writing, he found that existing instruments had many limitations, so in a subsequent IEEE paper he described his concept of the ideal phase-angle meter and its application.

Bourbonnais graduated from Michigan State College in 1943 with a degree in Electrical Engineering. He spent 1943 until 1946 in the U.S. Army, working in telephone and radio station construction in the Pacific Theater. The next year was spent doing engineering work on various types of plant construction. The last assignment led to his going to work for the Idaho Power Company, where he worked on system relay engineering. He moved to DuPont in 1951 to become a transmission consultant for the Savannah River Plant (operated for the AEC by DuPont). He assumed his present position in 1956.

Lunas came to Westinghouse from the University of North Dakota with a BSEE in 1926. After attending the Company's Electrical Design School, he chose electrical instruments as his field and has spent his entire career in instrument design engineering and supervisory work. Lunas is presently an Advisory Engineer in the Instrument Engineering Department, where he concentrates on new development problems. He obtained a MSEE degree from the University of Pittsburgh in 1939 and a Professional EE degree from the University of North Dakota in 1941.

Not a swiss cheese but a stainless steel core support plate for the pressurized-water reactor being installed in the 490,000-kw power plant of the Connecticut Yankee Atomic Power Company at Haddam Neck, Connecticut. The plate is seen here after rough machining. Instead of drilling and boring the holes, engineers devised a trepanning technique employing a hollow cutter. Trepanning saved much machining time on this foot-thick plate and also helped maintain the close tolerances required.