Westinghouse ENGINEER

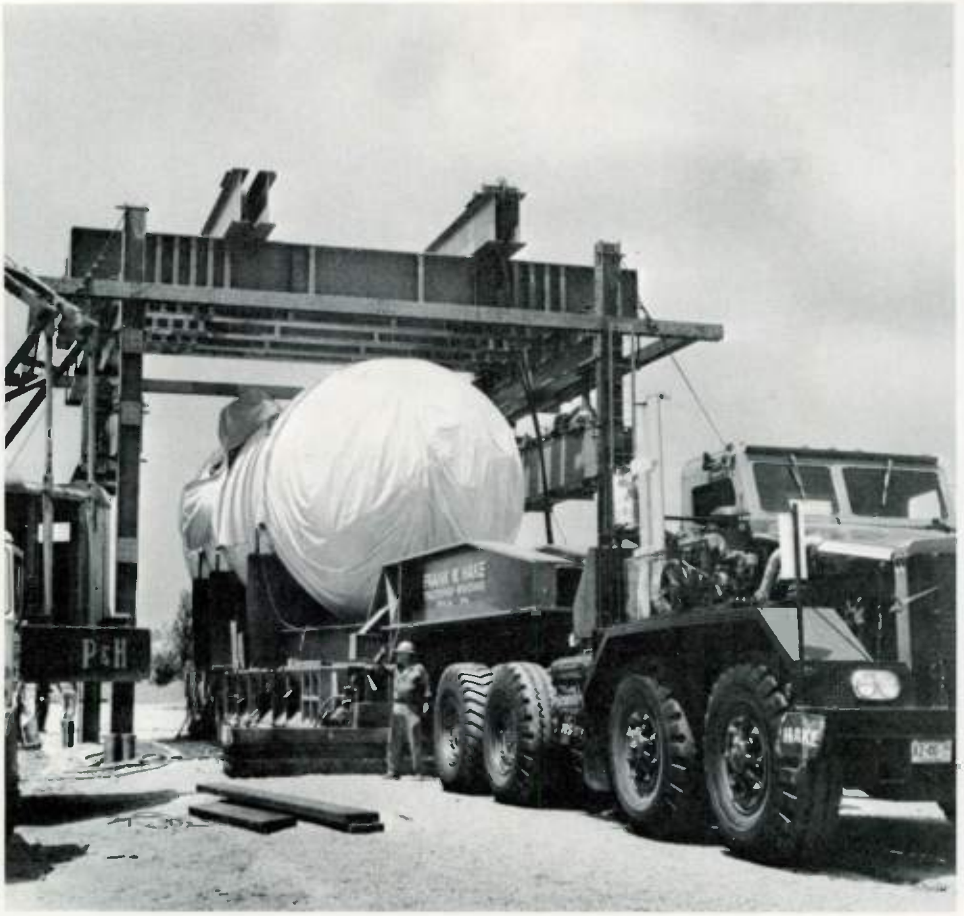
November 1968

Reactor Vessel Shipment Sets Size Records

A 321-ton nuclear reactor vessel recently had the distinction of being the largest piece of nuclear equipment ever shipped overland and the widest load ever carried by an American railroad. The vessel, 20 feet 2 inches in diameter and 40 feet long, was shipped by Westinghouse to Hartsville, South Carolina, for installation in the nuclear generating unit being built for Carolina Power & Light Company at its H. B. Robinson plant.

The vessel began the 3100-mile journey at the Chattanooga, Tennessee, plant of Combustion Engineering, Inc., which manufactured it for Westinghouse. It rode a 72-foot flatbed trailer secured to a reinforced barge. Traveling day and night, the barge moved down the Tennessee, Ohio, and Mississippi rivers to the Gulf of Mexico. From there it crossed Florida on the Okeechobee Waterway and moved up the Atlantic coast through the Intracoastal Waterway to a dock at Georgetown, South Carolina.

There the trailer was rolled off the barge and pulled by a tractor about three-fourths of a mile to a specially built rail siding (see photograph). A huge lifting tower then transferred the vessel to a special 12-axle high-capacity flatcar.



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Cover design: The 130-foot radio telescope, recently installed at the California Institute of Technology's Owens Valley Radio Observatory, is described in this issue. Cover artist Tom Ruddy shows the huge telescope on its high desert site.

A New Radio Telescope for the Owens Valley Observatory

Bruce Rule
Geo. F. Gayer

Use of the interferometer array of large steerable antennas for radio astronomy began with the California Institute of Technology's two 90-foot dishes at its Owens Valley Radio Observatory ten years ago. The 130-foot antenna is the first step toward a more sensitive interferometer array at this same site.

The dedication of the 130-foot radio telescope at the California Institute of Technology's Owens Valley Radio Observatory (OVRO) in October completed the first phase of a major expansion program. This program, recommended by the Panel on Astronomical Facilities of the National Academy of Sciences,[1] comprises an eight-antenna interferometer array to be built at the Owens Valley facility. Such a system would make OVRO the world's most powerful and flexible radio observatory for the study of radio sources in and beyond our galaxy. This first antenna for the OVRO array was made possible by a grant from the National Science Foundation.

The planned interferometer would be able to resolve objects 1/30 of the size of those resolved with OVRO's existing 90-foot telescopes (See *Owens Valley Radio Observatory*), and it would be able to detect objects with radio strengths only 1/20 of those presently observed. Until additional 130-foot telescopes are completed, the new unit will be operated in conjunction with the two existing 90-foot antennas.

The basic design of the new 130-foot antenna was done at Caltech, assisted by C. W. Jones Engineering. The detail design, manufacture, partial assembly and test were done by the Westinghouse Marine Division at Sunnyvale. The antenna was erected at the site by the Westinghouse Electric Service Division.

Radio Telescopes

Radio telescopes are a relatively recent development, and extend astronomy into the range of radio wavelengths. Many of the techniques used in radio telescopes are similar to those used with optical telescopes in which star images are reflected from a parabolic light mirror to the mirror's focal point to be observed or photographed. Similarly, radio waves are caught in a huge aluminum reflector and focused on a radio receiver positioned at the focal point of the reflector. As with optical reflectors, resolution is proportional to the ratio of aperture (diameter) to signal wavelength—and therein lies the fundamental difference between radio and optical telescopes. Since the wavelength of light is only about 20 millionths of a inch, the 200-inch optical reflector on Mt. Palomar provides a resolving power of about 10 million and can discriminate objects in the sky with a diameter of only 0.023 seconds of arc (the eye can detect about one minute of arc). However, a typical radio wavelength (such as radio propagation from ionized hydrogen, the basic constituent of interstellar matter) is 21 centimeters, so that the resolving power of the largest steerable paraboloid radio reflectors (such as the 250-foot Jodrell Bank telescope in

[1] *Ten-Year Development Program for Ground-Based Astronomy in the United States* ("Whitford Report").

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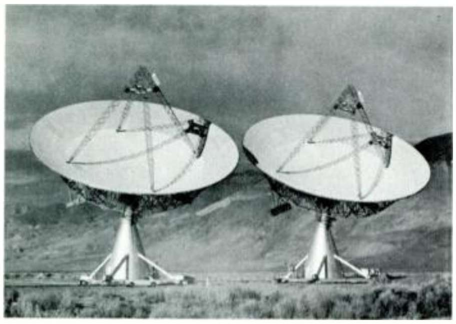
Owens Valley Radio Observatory



The Caltech Radio Observatory, sponsored by the Office of Naval Research, has been operational since December 1958. Located 250 miles north of Pasadena in Owens Valley, the observatory is shielded from man-made radio and television signals by two of the nation's highest mountain ranges—the Sierra Nevada and the White Mountains. With a high plateau desert-like climate, the OVRO site requires no special protection against rain, snow, or sleet.

Another favorable aspect of the Owens Valley location is that it is only about 350 miles north of the 200-inch optical telescope on Mt. Palomar. This makes it easy to duplicate radio telescope observations with optical views.

The OVRO installation was the first interferometer array of large steerable antennas and consists of two 90-foot dishes that are positioned on one of two 1600-foot rail tracks —a north-south leg and an east-west leg which form an "L."

The new 130-foot telescope now installed is the first unit of a planned eight-dish interferometer array which will also move on a rail system in the form of an inverted "T;" a 7500-foot east-west track aligns with the existing east-west track of the 90-foot dishes; a north-south track will extend three miles northward from the midpoint of the east-west track.

Radio astronomers at the OVRO observatory have already made significant contributions to the young science of radio astronomy. For example, they have precisely located and participated with the Mt. Palomar 200-inch optical telescope in identifying more radio sources than any other radio observatory; they have played a major part in the discovery of "quasars," helped identify the most distant galaxy known, determined that a majority of distant radio sources come in pairs, analyzed in detail the Van Allen radio belt around the planet Jupiter, detected and measured hitherto unseen cold hydrogen clouds in the arms of our Milky Way galaxy, made detailed maps of the galactic magnetic field, and produced the first radio map of the planet Venus.

England) is about 15 minutes at the 21-centimeter wavelength; thus, unless extremely large reflectors or multiple arrays are used, radio telescopes can discriminate objects no smaller than several minutes of arc. Obviously, individual radio reflectors will always be severely limited in resolving power because of the cost and mechanical limitations of building larger radio reflectors.

Interferometer Arrays

To overcome the severe limitation in resolving power of individual radio telescopes, two or more steerable antennas can be used in an interferometer array. For some measurements, the effective aperture of the interferometer is equivalent to the separation between antennas.

A two-element interferometer is shown in Fig. 1. Two large steerable reflectors are spaced distance *d* apart. For an incoming radio signal, the path difference ϕ from the radio source can be expressed:

$$\phi = d \sin \theta$$

where θ is the angle between signal path and the perpendicular to the baseline. When signals from the two antennas are electronically combined, a signal maximum occurs when path difference ϕ equals some integral number of wavelengths because signals will be in phase; similarly, signal minimums will occur when path difference causes signals to be 180 degrees out of phase. Since the path difference (ϕ) is much greater than wavelength (λ), a sinusoidal signal pattern is produced as the antenna tracks a radio source across the sky. Thus, a single sighting produces ambiguous results, and many observations over a wide range of antenna spacings are required to determine θ precisely. The intricacies of interferometer techniques are beyond the scope of this article, but with these techniques, radio astronomers have measured dimensions and shapes of radio sources with great precision. Additional antennas operated in orthogonal fan arrays, such as the proposed eight-antenna array for Owens Valley, would permit astronomers to discern additional details of radio sources.

The 130-Foot Reflector

The shape of a paraboloid reflector is given by the basic relationship, $x^2 = 4ay$, as shown in Fig. 2. The focal length (a) of the 130-foot antenna is 52 feet, so that the antenna paraboloid shape is $x^2 = 208y$, and the f-ratio (focal length/aperture) is 0.4. Initially, the receiver will be supported at the prime focus. Future Cassegrain configuration may use a smaller hyperboloid reflector just below the prime focus and move the receiver to the apex of the dish parabola.

Unlike typical aircraft or industrial structures, the stiffness and accuracy requirements of a radio telescope reflector do not scale directly with size, but are determined by signal wavelength. In all orientations of pointing, the structure must withstand stresses due to wind load, tracking movement, temperature, or other environmental effects without distorting beyond these signal wavelength limitations.

For sharp focusing, the reflector surface should conform to the desired paraboloid shape with deviations no greater than $\pm 1/10$ of the shortest wavelength (λ) to be received. Since the OVRO telescope is being designed to receive radio wavelengths as short as 5 centimeters (the range from 1 to 6 kMHz), the accuracy criteria for the first order setting by West-

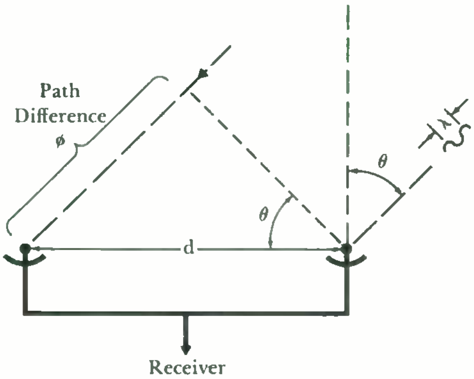


Fig. 1—Interferometer principle is used for accurate angle measurement by radio telescopes. Since path difference (ϕ) is much greater than wavelength (λ), many measurements with various antenna separations (d) are necessary to resolve ambiguity.

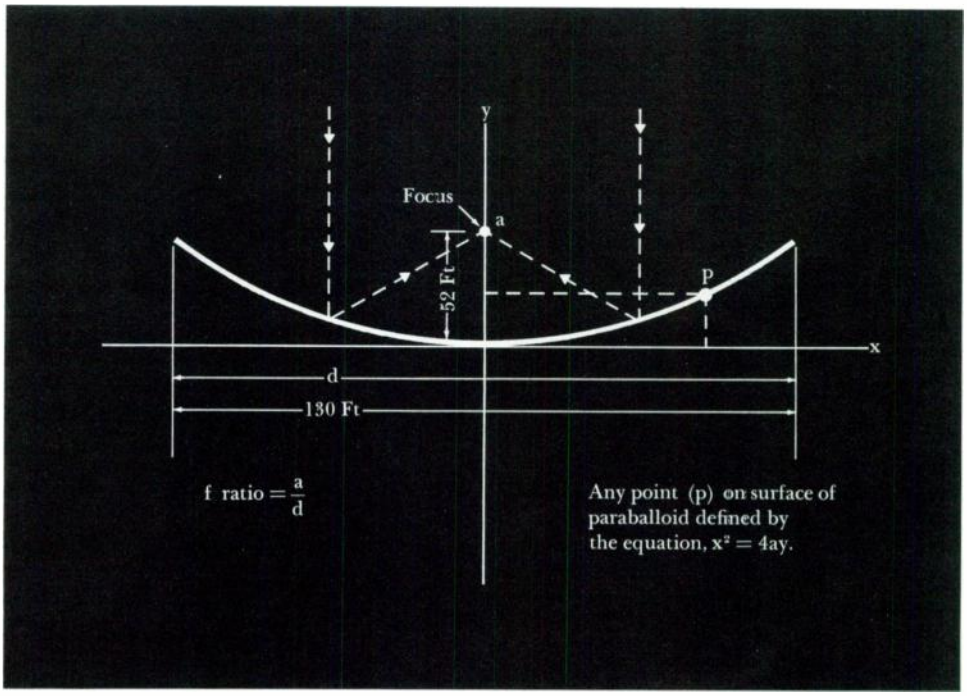


Fig. 2—The shape of the paraboloid radio antenna structure is defined by the basic formula for a parabola.

inghouse are $\pm\frac{1}{8}$ inch in the center of the reflector and $\pm\frac{3}{16}$ inch at the outer edge. Final adjustment of the reflecting surface panels by Caltech astronomers will provide finer tuning, hopefully to reach even shorter wavelength performance criteria.

The supporting structure for the reflector surface panels is formed by 36 radial trusses fabricated from $4\frac{1}{2}$-inch diameter seamless steel tubing. There are 672 joints in each truss with the most complicated joint consisting of 14 members coming together at a single point. Caltech had the 120,000-pound dish structure checked for deflection and stresses by JPL-CIT on the modified STAIR computer program. Westinghouse added basic precision cast crosses at each joint to allow full penetration welding, which added stiffness and strength with only a slight weight increase; Westinghouse also developed a computer program to calculate the lengths of some 2400 tubes, and to produce plots for the 53 cams needed to burn the joints on a production basis, thus eliminating tedious layout drafting. Shippable pie segments of trusses were shop fabricated on a fixture with an optical check of $\pm\frac{1}{32}$ inch.

The reflector surface, mounted on the supporting structure, consists of 852 panels of 0.080-inch aluminum surface, riveted on Z-bars developed by Caltech and built by Rohr Aircraft. The panels have 936 adjusting screws to permit final tuning of the surface to $\pm\frac{1}{16}$ inch of the optimum parabola. Rosett springs on the adjusting screws support the corners of four adjacent panels and allow for stresses due to temperature changes and to gravity forces during antenna movement. Initial adjustment was made by sighting on these junction points with a theodolite positioned at the apex of the parabola. Final tuning will be done by Caltech astronomers using radio star sources.

Telescope Mount

Steerable radio telescopes use one of two basic types of mounts, each of which has certain advantages and disadvantages compared to the other.

The conventional equatorial (or polar axis) mount used with optical telescopes has its principle axis parallel to the earth's so that the telescope can "unwind" in opposition to the earth's rotation, permitting the telescope to track a star from east to west as it moves (apparent motion) across the sky (Fig. 3). The declination axis, at 90 degrees to the polar axis, provides sky coverage in the north-south direction. The fundamental advantage of this type of telescope mount is that its drive and control coordinates are aligned with the celestial coordinates of the stars (right ascension and declination). There is no observing "dead zone" except at the North Pole. This equatorial mount is also used on many radio telescopes, but its application to the larger reflectors is complicated by gravity and by the severe wind loading on large radio reflectors.

The other basic form of radio telescope mount is the azimuth-elevation configuration, or the familiar "gun mount." A vertical ground axis provides for azimuth rotation of an alidade structure that supports the elevation axis. The principal advantage of the azimuth-elevation mount is that it can support great weight, and it provides solid ground support against high wind loads. The azimuth-elevation mount can provide complete sky coverage except for a "dead zone" at zenith (directly overhead). Its fundamental disadvantage is that its azimuth-elevation coordinates must be converted to celestial coordinates (right

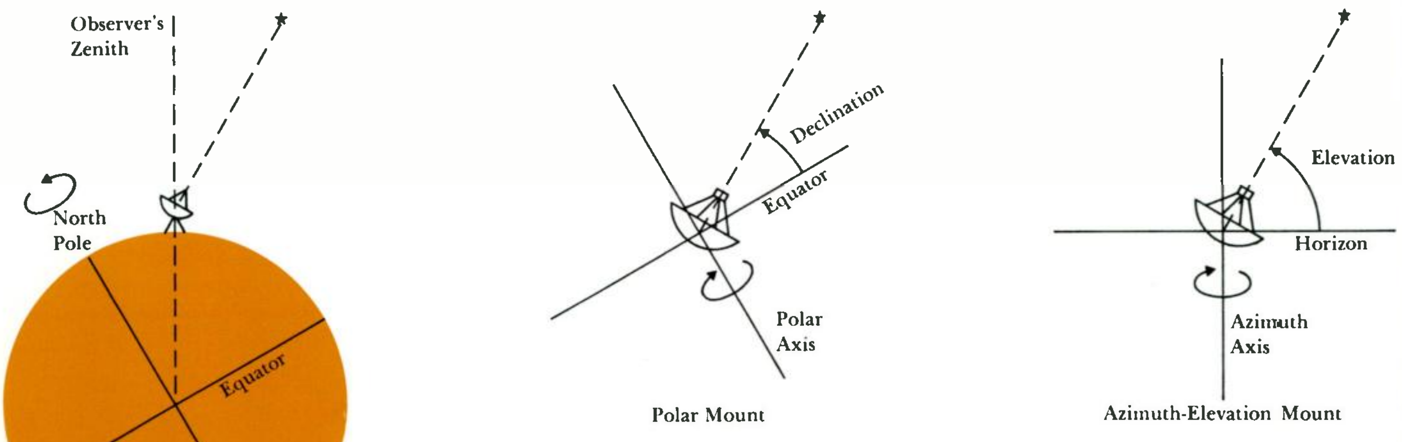


Fig. 3—Two basic types of mount are used with steerable radio telescopes: A polar axis mount has its principal axis aligned with the earth's poles to facilitate star tracking. The antenna is elevated to the star's declination and the antenna rotates in opposition to the earth. Star tracking is more difficult with an azimuth-elevation mount because elevation of the star increases, reaches a maximum, and then decreases; azimuth rotation is not constant because the elevation axis is not aligned with earth's axis. However, the azimuth-elevation mount does have the advantage of providing very solid ground support for the antenna.

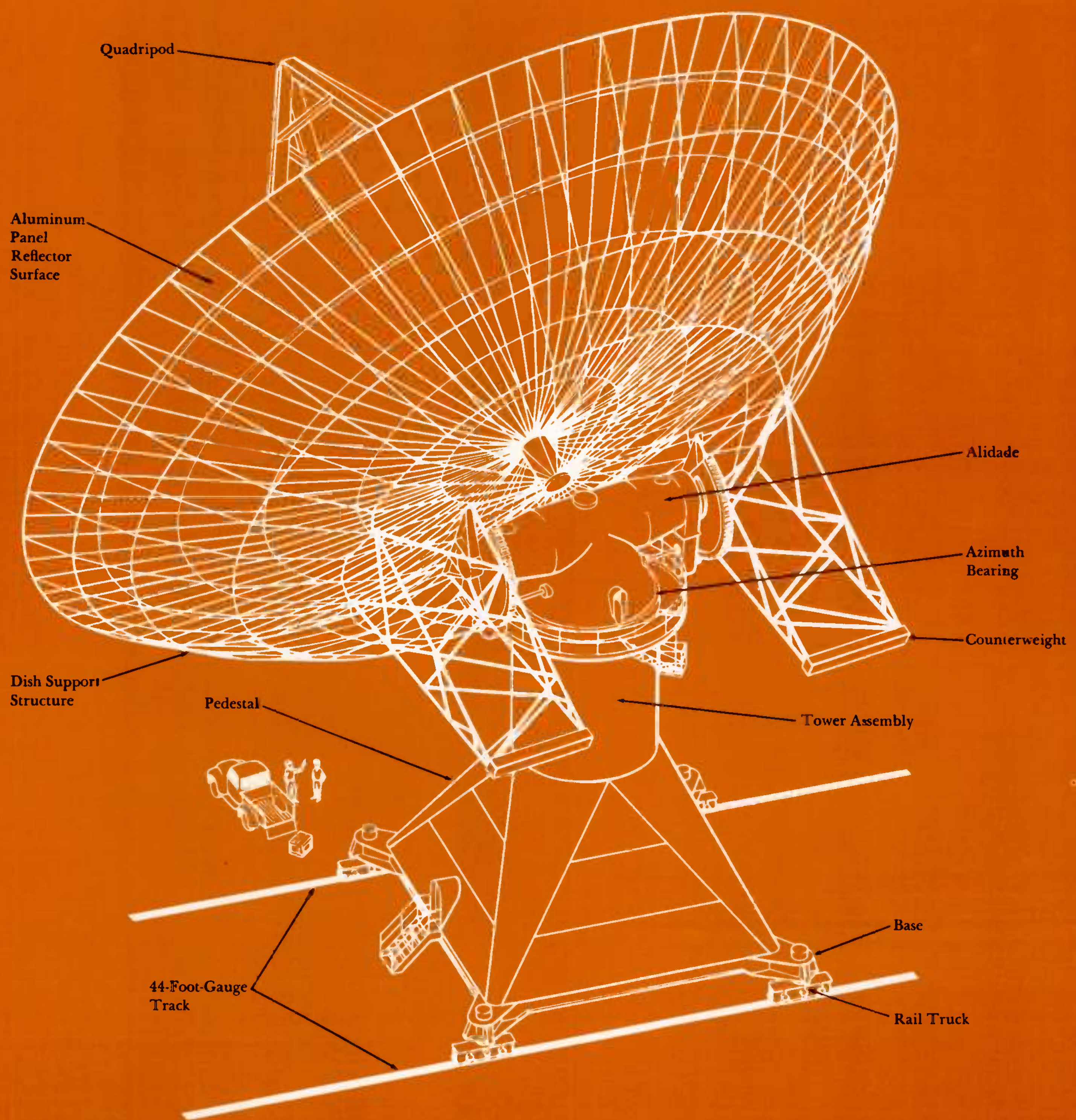


Fig. 4—Basic components of OVRO telescope are shown on this line sketch.

ascension and declination) for tracking celestial targets. This conversion can be accomplished by an analog conversion (or slave) computer, or with a programmed digital computer. Since digital computer costs are relatively fixed, digital computer conversion becomes economic only for large-scale antenna programs. An additional complication is the variable-rate drive requirements for both azimuth and elevation axes because the conversion is nonlinear.

For the 130-foot OVRO telescope, Caltech designers and astronomers chose a fully steerable azimuth-altitude mount. Conversion to celestial coordinates will be done on a digital computer program developed at Caltech. The complete mount consists of the counterweighted dish supported by an alidade mounting, pedestal, base, and four rail-mounted base trucks (Fig. 4). The entire mobile assembly weighs 941,000 pounds.

The dish is pivoted in elevation on two spherical roller bearings (SKF 230/600) at each end of the 32-foot-wide alidade. Elevation drive of the dish and counterweights is through two 180-degree gear segments (216 inches in diameter with 11-inch face width) and two 18-inch diameter pinions extending from rigid Western Gear boxes mounted beneath the alidade ends. The alidade turns in azimuth on a 155-inch diameter roller bearing (Messinger "X"), the largest of this type ever built. The azimuth bearing has an integral 180-inch diameter spur gear, driven by two pinions. A third pinion exerts an adjustable preload (to prevent backlash) through a hydraulic system built into the differential gear drive between the other two pinions. Encoder readouts are mounted at the centers of the azimuth and one elevation bearing for digital control application.

The azimuth bearing and alidade are mounted on a tower assembly, supported by the pedestal and base. The tower assembly, pedestal, and base are fabricated from welded large plate and structural steel. The tower assembly components include stairs, piping, electrical apparatus, azimuth counterweights, cable wrap up, and gear reducers.

Erection of the antenna at Owens Valley was complicated by the amount of field fabrication that was required because of common carrier shipping limitations of such large parts. The two principal assemblies requiring field fabrication were the dish and pedestal. All components had to be aligned optically, both during shop fabrication and assembly at the site.

Observation from this antenna and the seven others that will eventually compose the array will usually be done from variable or fixed positions. With fixed antenna positions, interference plotting is done by the array as the earth rotates. The trucks supporting the new OVRO antenna can also be moved with onboard power to provide another mode for interferometer measurements of radio sources.

The entire antenna assembly can move along the 44-foot gauge tracks at a normal speed of 50 feet per hour (with a maximum possible speed of 60 feet per minute). The rails will be straight (not level) to within ± 1/8 inch, and plans are to eventually computerize the controls for automatic hydraulic leveling of the base during mobile operation. Leveling will be accomplished with the hydraulic support cylinders on the base corner trucks.

The hydraulic support cylinders are supplied by a 1500-psi oil system, and are presently used to transfer trucks from the north-south to the east-west tracks. To change from one track to the other, the antenna is positioned at the track intersection, and the hydraulic cylinders are raised to support the structure on three trucks while the fourth is turned to run on the other track. Turning all four trucks requires only about 20 minutes.

Environmental and Operational Requirements

The 130-foot radio antenna is designed to operate in the temperature range of −15 degrees F to +130 degrees. The antenna

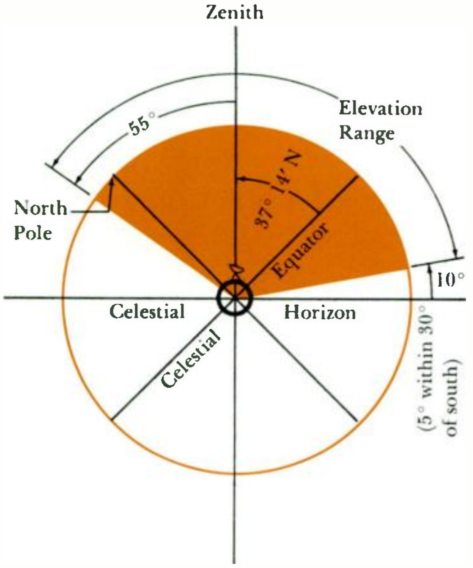
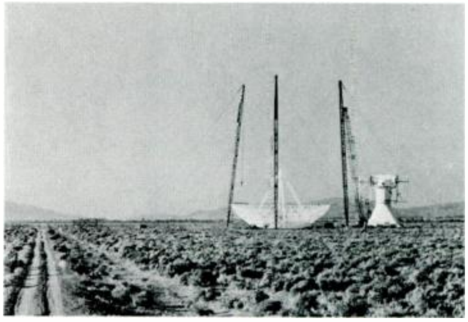


Fig. 5—The elevation range of the 130-foot OVRO telescope is from 10 degrees above the horizon (except for ±30 degrees of South where it is 5 degrees) to 55 degrees past zenith.



Because of common carrier shipping limitations of such large parts, the erection of the antenna at Owens Valley required extensive field fabrication from factory-assembled components. The two principal assemblies requiring field fabrication were the dish and pedestal. The dish with quadripod (less aluminum surface) was hoisted by three 195-foot legs, the base and tower on the trucks moved under it, and the dish lowered so that its back support pads bolted to the counterweight structure. Elevation and azimuth gearing were aligned, and alidade orthogonality was checked optically on the azimuth bearing. Aluminum dish segments were bolted in place and adjusted optically to establish the best parabola. Rigidity tests on the azimuth and elevation drives were rechecked to shop test values to assure alignment and final correct mechanical assembly.

will be operable for observational use in winds up to 30 miles per hour. The highest accuracy of ±⅛ rms of surface shape is limited to operation in winds of 0-20 mph, and accuracy degrades by a factor of four in 20-30 mph winds. At 40 mph, the dish is slewed to the stow position (pointing to zenith) and chocked to the rails. No operation is permitted above 40 mph up to the design survival wind of 90 mph.

The operating azimuth range is 420 degrees each side of North. Elevation travel is from 10 degrees above horizon to 55 degrees past zenith (Fig. 5), except in the range of azimuth bearing 30 degrees each side of South where elevation travel is extended to five degrees above the horizon. This additional elevation range is made possible by the asymmetrical structure of the back side of the dish. The OVRO site latitude (37° 14′) allows the telescope to reach approximately two degrees past the celestial North Pole when pointed South.

Elevation and azimuth drive accuracy, based upon 0.10 degree beam width and the possible future 3-centimeter radio wavelength, is 5 seconds of arc for short-period smooth tracking and a maximum of 20 seconds of arc at any position. Bearing rotation speeds are 0 to ±4 degrees per minute track (in azimuth) and ±15 degrees per minute slew.

A New Window to the Universe

Since 1933, when Karl Jansky, a young Bell Telephone Laboratory engineer, first picked up signals from outer space, radio astronomy has grown to become an advanced science. All celestial bodies, from our own planets to the furthermost known galaxy some 10 billion light years away, emit vast amounts of electromagnetic energy—part in the visible portion of the spectrum but much in the radio range. Thus, radio waves offer astronomers another range of wavelength (some 10,000 times greater than the short optical spectrum) with which to study the universe, literally opening a "huge new window to the universe."

Although some of the more powerful radio sources may emit energies as high as 10^{35} watts, the great distance of these sources diminishes their radio energy to some 10^{-7} watt by the time it reaches earth. The new OVRO interferometer will provide radio astronomers with a much more sensitive tool for detecting and measuring these minute celestial signals. Astronomers hope to obtain many answers to questions that have arisen from previous observations with less sensitive telescopes—and probably will encounter even more unanswered questions. Such a diverging series does not seem so strange when we consider that astronomers, unlike scientists in other disciplines, can only study their infinite subject from almost infinite distances.

Westinghouse ENGINEER **November 1968**

Solid-State Reclosing Systems

W. A. Elmore

A new family of solid-state reclosing relays minimize maintenance requirements, simplify external wiring, and provide flexibility in circuit-breaker reclosing systems for transmission line or distribution feeder applications.

Continuing improvements in solid-state circuitry and techniques provide increasing incentive for reappraisal of the role of mechanical devices in circuit-breaker reclosing systems. Conventional reclosing relays consist of an assortment of motors, latches, cams, gears, clutches, microswitches, stepping switches, and multiple-coil elements. These relays work well, without excessive maintenance and with infrequent malfunction, but solid-state circuitry has the potential of further decreasing maintenance requirements and malfunctions. Other reasons for developing solid-state reclosing systems are the accommodation of more sophisticated logic in the reclosing sequence, greater flexibility, and simplification of external wiring.

With those objectives in mind, a family of solid-state reclosing relays have been or are being developed in many variations of single-shot and multiple-shot, with and without selective reclosing, and with and without synchronism-check and dead-line/live-bus or live-line/dead-bus control. These various functions are accomplished with a variety of solid-state relays that can be Flexitest-case mounted or rack-mounted.

One-Shot Reclosing

The significant factor in the success of a reclosure on a transmission circuit is the speed of tripping. The faster the fault is cleared, the less the fault damage and degree of arc ionization, the less the shock to the system on reclosure, and the greater the likelihood of reenergization without subsequent tripping. Thus, the probability of reclosing success is maximized if reclosure is attempted *only* following a high-speed pilot trip (simultaneous tripping of circuit breakers at both ends of a faulted section). Conversely, since nonpilot-system trips for end-zone faults occur sequentially, a successful high-speed reclosure may be impossible because the fault is never deenergized.

Experience has shown that, with properly designed reclosing systems, the vast majority of successful transmission line breaker reclosures (particularly in high-lightning-level areas) are accomplished on the first try. Thus, many users believe that the small additional percentage of successful reclosures achieved by multiple operations does not warrant additional breaker operations, so a single-shot reclosing relay can be justified on many transmission circuits.

The logic of a single-shot reclosing relay locks out reclosing on the first breaker trip so that, if the reclosure is unsuccessful and a second breaker trip occurs, the reclosing relay cannot initiate a second reclosure attempt. However, if the initial reclosure is successful, a reset timer in the reclosing relay completes its cycle (3 to 30 seconds) and the reclosing relay resets to its normal state.

The logic diagram for the single-shot solid-state reclosing relay is shown in Fig. 1b. The single-shot relay is designed for either Flexitest case mounting (SGR-51) or with components mounted in a 19-inch chassis designed for rack mounting (SGRU-51).

Greater flexibility in one-shot reclosing is provided by solid-state relay SGR-52, which is similar to the SGR-51 relay except that a *reclose initiating* function is added (Fig. 2, diagram). Also, a 0 to 2 second reclosing *delay* is included, and provision is made for a *reclose blocking* input. (SGRU-52 provides these same relay functions in a 19-inch chassis for rack mounting, Fig. 2, photo.)

When a pilot trip occurs, a contact closes to initiate reclosing. This contact may be on a relay in the output auxiliary (SRU); in an electromechanical pilot system, the contact may be on the breaker failure initiating auxiliary (62x). If the reclosing delay timer is set at zero, the CR relay closes its contacts at approximately the same time as the 52bb switch closure in the breaker closing

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Single-Shot Reclosing

The differences between developing relay control logic with conventional electromechanical elements and with solid-state circuitry can be illustrated for single-shot reclosing systems.

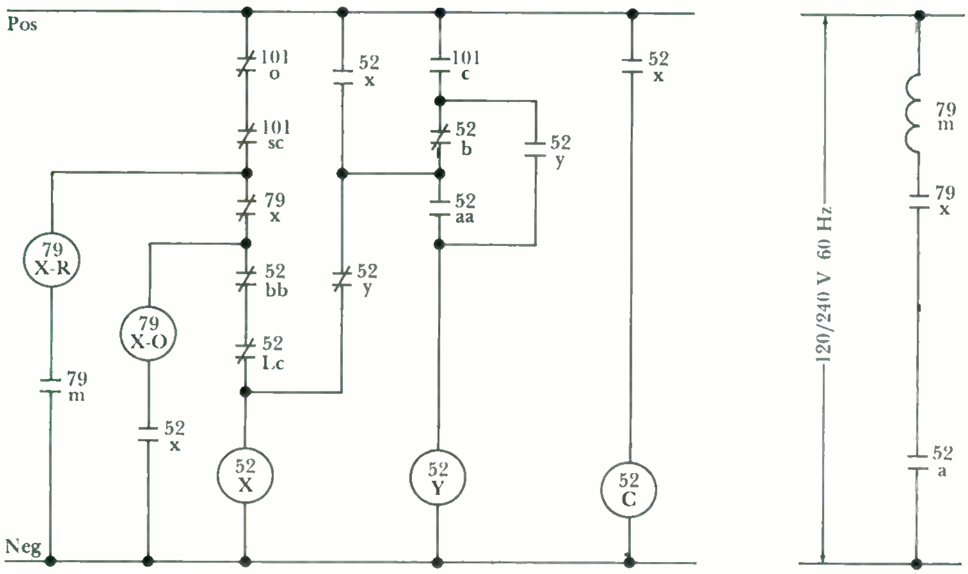
A conventional reclosing control circuit (SGR-12) is shown in Fig. 1a. When the breaker is tripped by protective relays, reclosing is initiated by energizing the 52X operating coil through the preclosed 79x contact, the circuit breaker auxiliary contact (52bb), and the latch check switch (52Lc). (The 101o and 101sc contacts remain closed following closure of the breaker by the control switch.) When 52X closes, the breaker close coil (52C) is energized and the operating coil of the reclosing relay (79X-O) is energized to open the 79x contact in the close circuit and close the 79x contact in the reclosing motor (79m) circuit. If the breaker remains closed, the circuit breaker auxiliary contact (52a) remains closed and the reclosing motor is energized. After a preset time interval, its contact (79m) energizes the reclosing relay reset coil (79X-R), resetting the 79x contact in the close circuit and opening the 79x contact in the motor circuit, thus readying the control circuit for the next breaker trip. If circuit breaker closing is not successful, the reclosing motor (79m) is not energized, the 79x contact in the close circuit is not reset, and the circuit breaker is locked out.

The logic diagram for the solid-state control circuit (SGR-51) that accomplishes the reclosing function is shown in Fig. 1b. With the control circuit in its normal (at rest) state, the sequence for a reclosing operation begins when the 52bb contact (in the breaker closing circuit) closes due to a protective relay trip. With the output contact CR preclosed, the closing circuit of the breaker is immediately energized. As the breaker recloses, the breaker auxiliary switch (52b) opens, which removes negative from the input and provides a positive voltage to the SINGLE-SHOT. The SINGLE-SHOT produces a short-duration 1 output when and only when an input is applied, whether the input is of short duration or sustained. This serves the same purpose as the 52X auxiliary relay in the conventional control circuit by providing an output pulse only during the closing stroke of the breaker.

The SINGLE-SHOT output *sets* the FLIP-FLOP, deenergizing the CR relay and opening its contacts. The 0 output from the FLIP-FLOP to the AND, together with the 1 input due to the open 52b contact, initiates the RESET timer. If reclosure is successful, the timer completes its cycle and *resets* the FLIP-FLOP, restoring the CR relay to its normal state.

If reclosure is not successful, the 52b contact closes when the breaker trips, removing the 1 input from the AND to stop the RESET timer. The CR relay remains locked out until the FLIP-FLOP is cleared.

1a



Legend:

101 Manual Control Switch (C—close; O—open)

86 Locking Out Relay

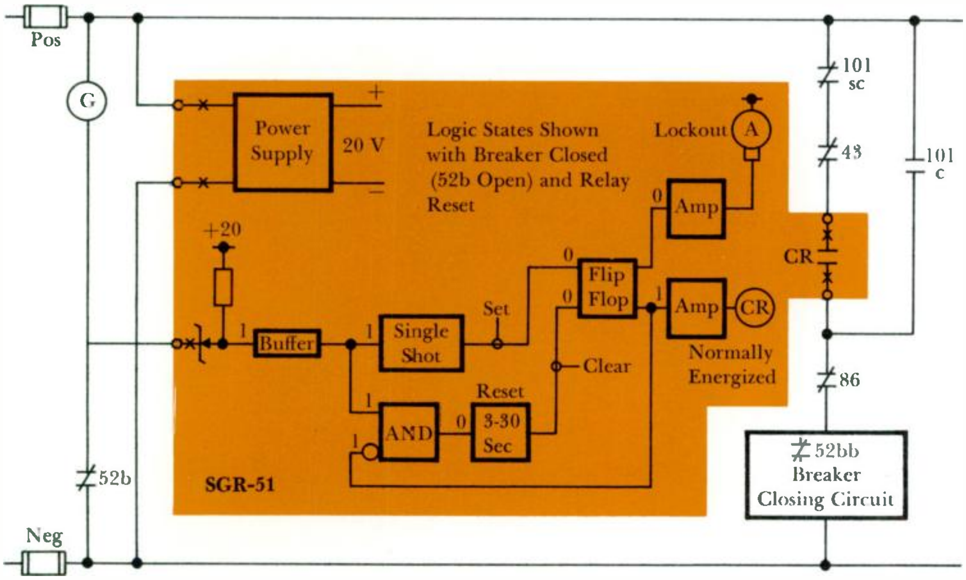
79 Reclosing Relay (X—auxiliary; M—motor)

52 Circuit Breaker (X—auxiliary; C—close; Y—anti-pump; Lc—latch check; a and aa—auxiliary contacts closed when breaker closed; b and bb—auxiliaries closed when breaker open)

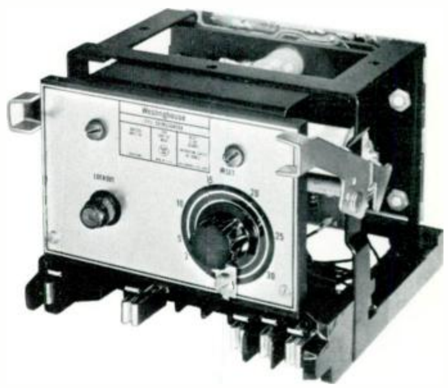
43 Selector Device

Negation

1b



SGR-51



circuit, thus producing no intentional delay in reclosing.

However, a further consideration with high-speed pilot tripping is the minimum time required for deionization of the arc at the fault after the breaker opens. From a 1963 IEEE Committee Report[1] the minimum deionization time (t, in cycles) based on operating experience can be expressed:

$$t = 10.5 + kV/34.5$$

Thus, if the inherent minimum reclosing speed of the breakers involved will result in a dead time less than t cycles, a reclosing delay must be incorporated in the reclosing system. To keep the delay device in the protected environment of the control house and achieve the most accurate type of timing device, this time delay should be accomplished in the reclosing relay rather than in the breaker. Thus, for EHV applications where intentional delay is required, the SGR-52 relay is provided with a 0 to 2 second timer.

The reclose blocking function is necessary for such conditions as out-of-step tripping or breaker failure transfer tripping. The *block* input to the reclosing relay predominates over the *initiate* input and prevents reclosing even though the pilot system may be calling for reclosure. To avoid resetting criticality between *initiate* and *block* inputs, a timer (.2/60 in Fig. 2, diagram) provides a continuing block signal for 60 milliseconds following removal of the blocking input.

Two-Shot Reclosing

Experience has proven that the probability of successfully reenergizing a faulty line improves with the number of reclosing attempts. A two-shot reclosing relay (SGRU-54) can provide one high-speed reclosure on pilot trips and one time-delayed reclosure on all relay-initiated trips (Fig. 3). For EHV applications, the initial reclosure can be delayed to allow the necessary dead time for arc deionization. The time-delayed reclosure can be supervised by an external relay, such as a synchronism check relay (CVE), which can be further equipped with dead-line/live-bus and live-line/dead-bus (CVE-1) control if the particular application dictates. If synchronism check is not used a reclosing timer (2 to 20 seconds) is controlled solely by the circuit breaker auxiliary switch (52b) input.

Another use for a two-shot relay is to partially equalize the reclosing duty on circuit breakers in configurations that use two breakers for each transmission line, such as breaker-and-a-half or ring bus arrangements. This is done by setting the reclosing relay for one breaker to reclose at high speed on pilot trips and to have a fairly long second reclosing time delay; the reclosing relay for the adjacent breaker is set to have short-time-delay reclosing only. For a high-speed pilot trip, both breakers trip and the first breaker recloses at high speed. If this reclosure is unsuccessful, the second breaker provides the second reclosure. If the second reclosure is also unsuccessful, both reclosing relays are locked out. The second reclosing relay is locked out by its own logic circuitry, while the first relay is locked out by an inhibiting signal from the second relay.

If the second reclosure is successful, the reclose inhibiting input to the first relay is removed following reset of the second relay in 3 to 30 seconds, allowing the first relay to reclose the first breaker after time delay (2 to 20 seconds).

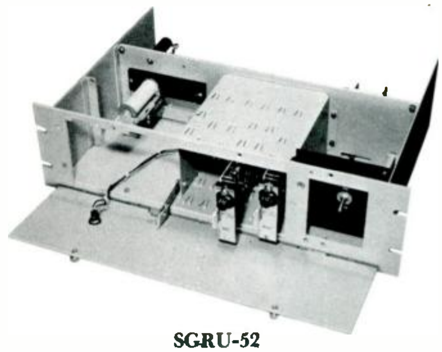
The time-delayed reclosures may be supervised by a synchrocheck relay, and, if desired, by dead-line/live-bus and live-line/dead-bus auxiliary relays.

Three-Shot Reclosing

On distribution circuits exposed to tree damage and where an unsuccessful reclosure generally means a customer outage, multiple reclosures are warranted. On transmission circuits, multiple reclosures allow additional refinements in control and provide automatic circuit restoration much faster than could be accomplished manually. Therefore, solid-state relays for three-shot reclosing are provided in two forms, one for distribution feeder applications (SRC-1) and one for subtransmission and transmission applications (SCR-2). Both types use in-

[1]"Arc Deionization Times on High-Speed Three-Pole Reclosing," *IEEE Transactions*, Special Supplement, 1963, p. 236.

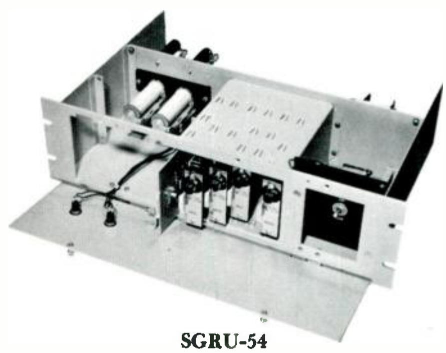
2



SGRU-52

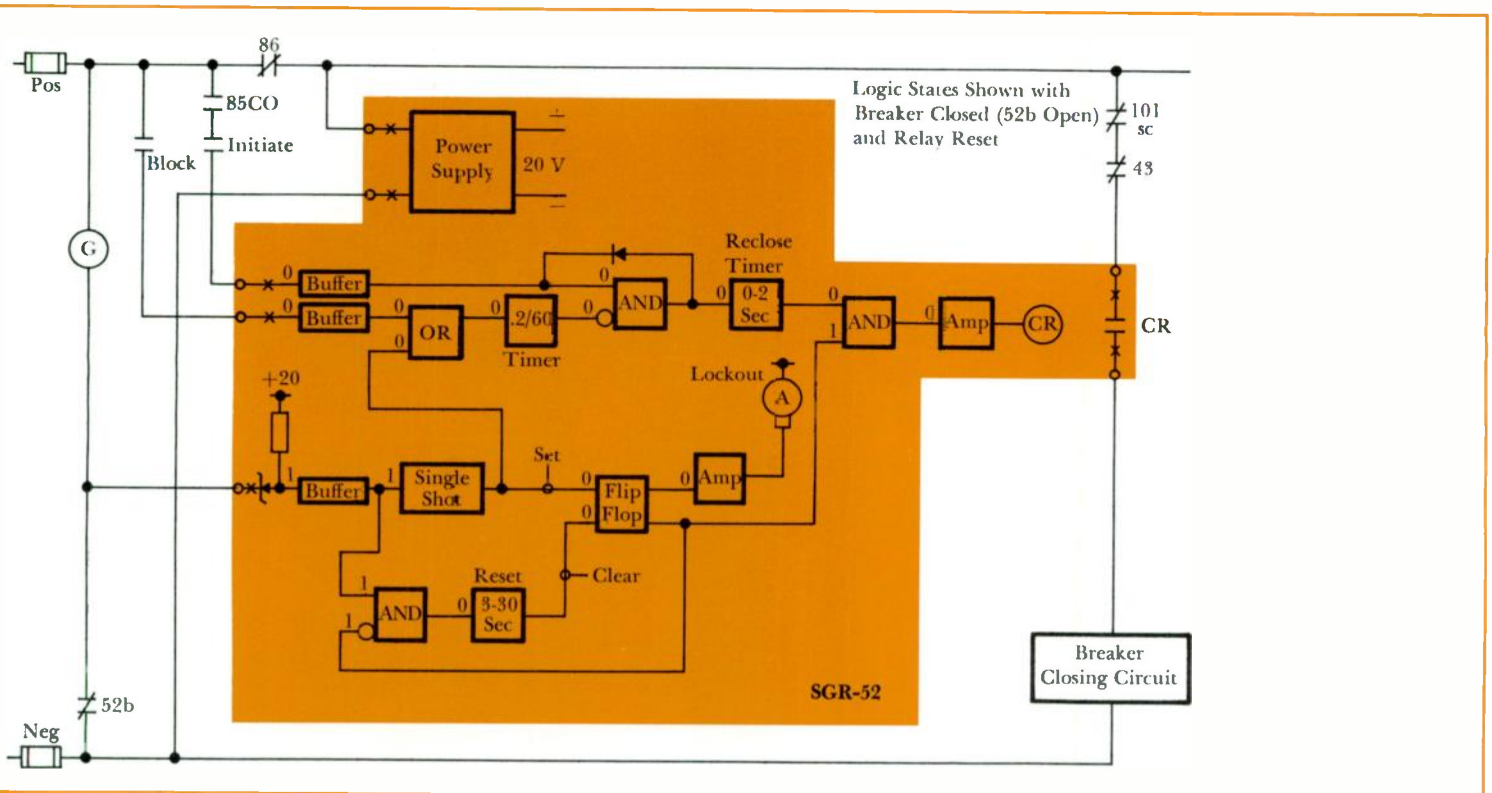
The SGR-52 solid-state relay provides single-shot reclosing and includes "initiate" and "block" functions to provide greater flexibility in controlling reclosing.

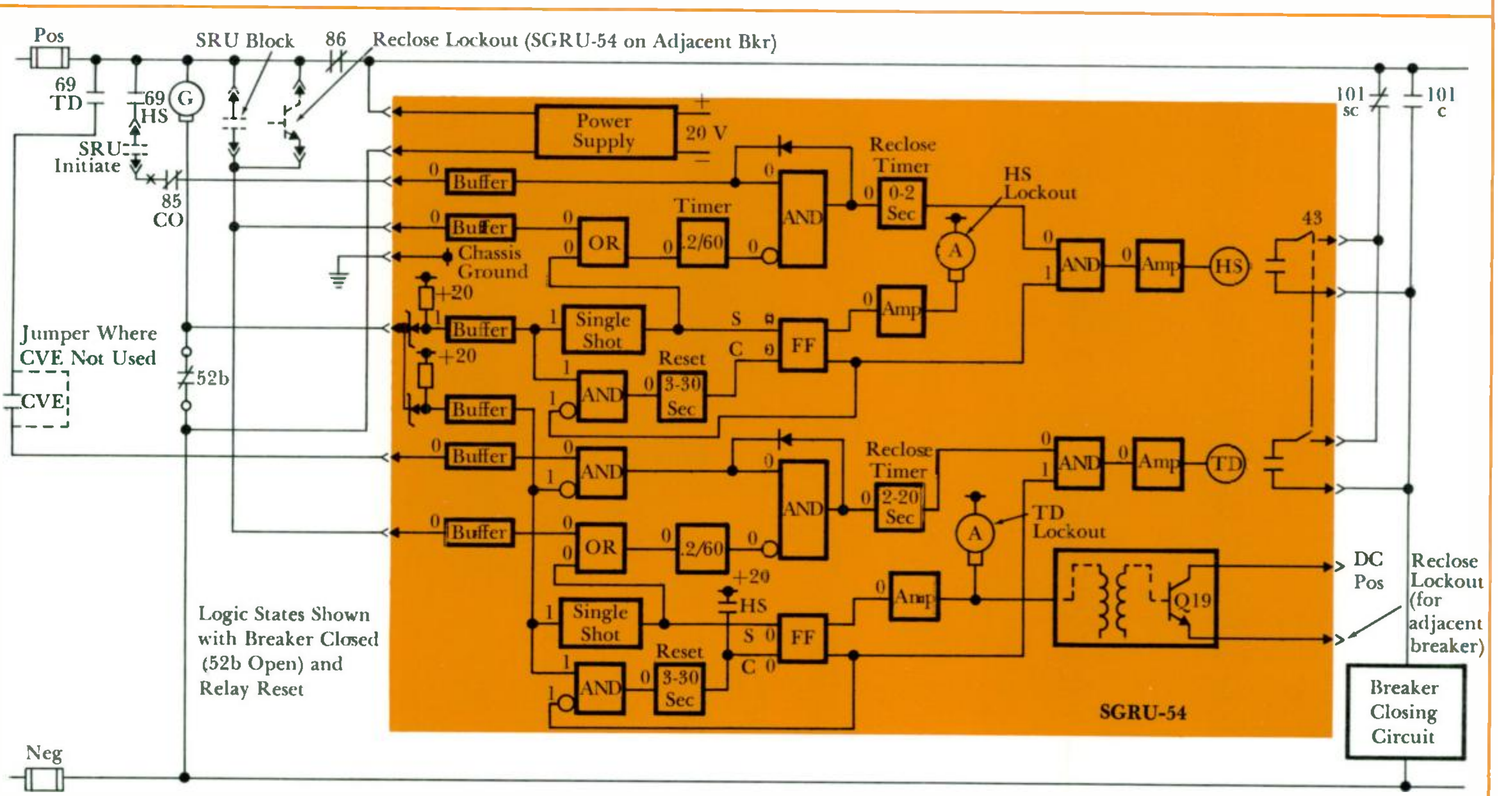
3



SGRU-54

The SGRU-54 is a two-shot reclosing relay, providing one high-speed reclosure on pilot trips and one time-delayed reclosure on all relay-initiated trips.


Pos
86
85CO
Initiate
Block
Power
Supply
20 V
Logic States Shown with
Breaker Closed (52b Open)
and Relay Reset
101
sc
43
G
Reclose
Timer
Buffer
Buffer
OR
.2/60
Timer
AND
0-2
Sec
AND
Amp
CR
CR
Lockout
A
+20
Buffer
Single
Shot
Set
Flip
Flop
Amp
Reset
Clear
AND
3-30
Sec
Breaker
Closing Circuit
SGR-52
52b
Neg


Pos
SRU Block
86
Reclose Lockout (SGRU-54 on Adjacent Bkr)
69
TD
69
HS
G
SRU
Initiate
85
CO
101
sc
101
c
Power
Supply
20 V
Buffer
Reclose
Timer
0-2
Sec
HS
Lockout
Buffer
Timer
OR
.2/60
AND
Chassis
Ground
A
43
AND
Amp
HS
+20
Buffer
Single
Shot
Amp
Jumper Where
CVE Not Used
+20
Reset
FF
52b
CVE
Buffer
AND
3-30
Sec
Buffer
AND
Reclose
Timer
AND
Amp
TD
2-20
Sec
AND
Buffer
OR
.2/60
TD
Lockout
A
DC
Pos
Reclose
Lockout
(for
adjacent
breaker)
+20
HS
Q19
Amp
Single
Shot
FF
Reset
AND
3-30
Sec
Logic States Shown
with Breaker Closed
(52b Open) and
Relay Reset
SGRU-54
Breaker
Closing
Circuit
Neg

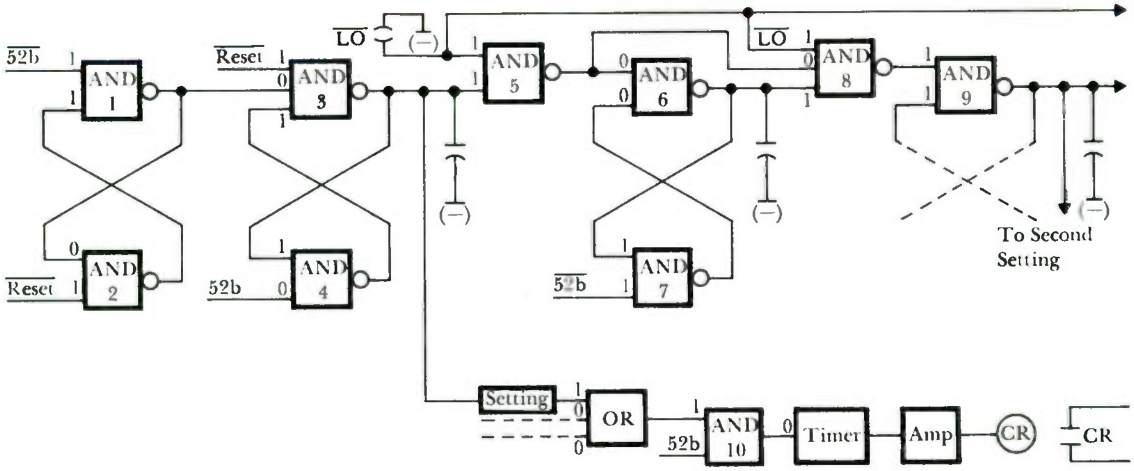
tegrated circuit components for sequencing (Fig. 4). Two distinct types of relays are required because of the differing needs of distribution and transmission systems. For example, distribution circuits have lateral fuses that should be protected, but transmission circuits do not. Transmission circuits practically always have generating sources at each end that must *never* be tied together when out of synchronization while distribution circuits are generally radial.

Distribution Circuits—On distribution systems where coordination with fuses is necessary, it has been a long-standing practice to protect the fuse on the first trip with an instantaneous tripping element on the substation breaker and to remove control by that element after the first trip. This arrangement allows the fuse to blow before a second breaker trip if the fault is beyond the fuse. Thus, the outage area for permanent lateral faults is minimized and the benefits of reclosing are provided for temporary faults.

The SRC-1 relay for distribution application (Fig. 5) contains circuitry for blocking instantaneous tripping after a preselected number of trips and optionally provides fault detector supervision of reset to allow fast resetting following a successful reclosure. For resetting to take place, the fault detector must be reset, the breaker auxiliary switch (52b) must be open, and the integrated circuit sequencer must not be in the reset state.

In heavily forested areas and in areas of high lighting incidence, where frequent repetitive faults are expected, long reset times on reclosing relays are intolerable. But the reset time must be well in excess of the maximum relay operating time, or pumping may take place. To accomodate these two conflicting requirements, an instantaneous overcurrent relay set above maximum load current and below minimum fault current is used to supervise reclosing relay reset. If reset cannot take

4



Logic Diagram for Solid-State Sequencing

This representative section of counting chain illustrates the use of integrated-circuit components for sequencing. The logical states are indicated for the breaker closed and relay *reset* condition. When the breaker is tripped by protective relay action, the 52b input to AND 10 becomes 1, allowing the capacitor in the TIMER to charge at a rate established by the SETTING resistor. After the preset time, the CR relay is energized to close the CR contact in the closing circuit of the breaker. In the meantime, AND 4 output has changed to a 0 because of the 52b input changing to 1. This keeps AND 3 output in the 1 state as the output of AND 1 clamps to a 1 state.

Opening of the 52b switch as the breaker closes produces a 1 output at AND 4, clamping AND 3 to a 0 output, driving AND 5 output to a 1 state, AND 8 to a 0 state, and AND 9 to a 1 state. The reclosing relay is then prepared for the second reclose timing operation if the 52b switch closes again. Similar action continues with AND 6 changing to a 0 output when 52b closes, changing AND 8 to a 1 output and so on, through comparable circuitry below and beyond AND 9, until either all three reclosures have been exhausted (unless the fault was temporary) or until lockout takes place, as established by setting, for less than three reclosures. For example, to set the relay for one reclosure, the upper input to AND 5 and AND 8 is held to a 0 state so that lockout will occur after the second trip due to the inability of AND 8 output to change to 1.

Following a successful reclosure the reset timer provides a momentary 0 input to AND 2 and AND 3, etc., restoring each element to its "normal" state.

place until the breaker is closed and there is no fault current flowing, a very short reset time can be used, thus lowering the probability of lockout for repetitive faults.

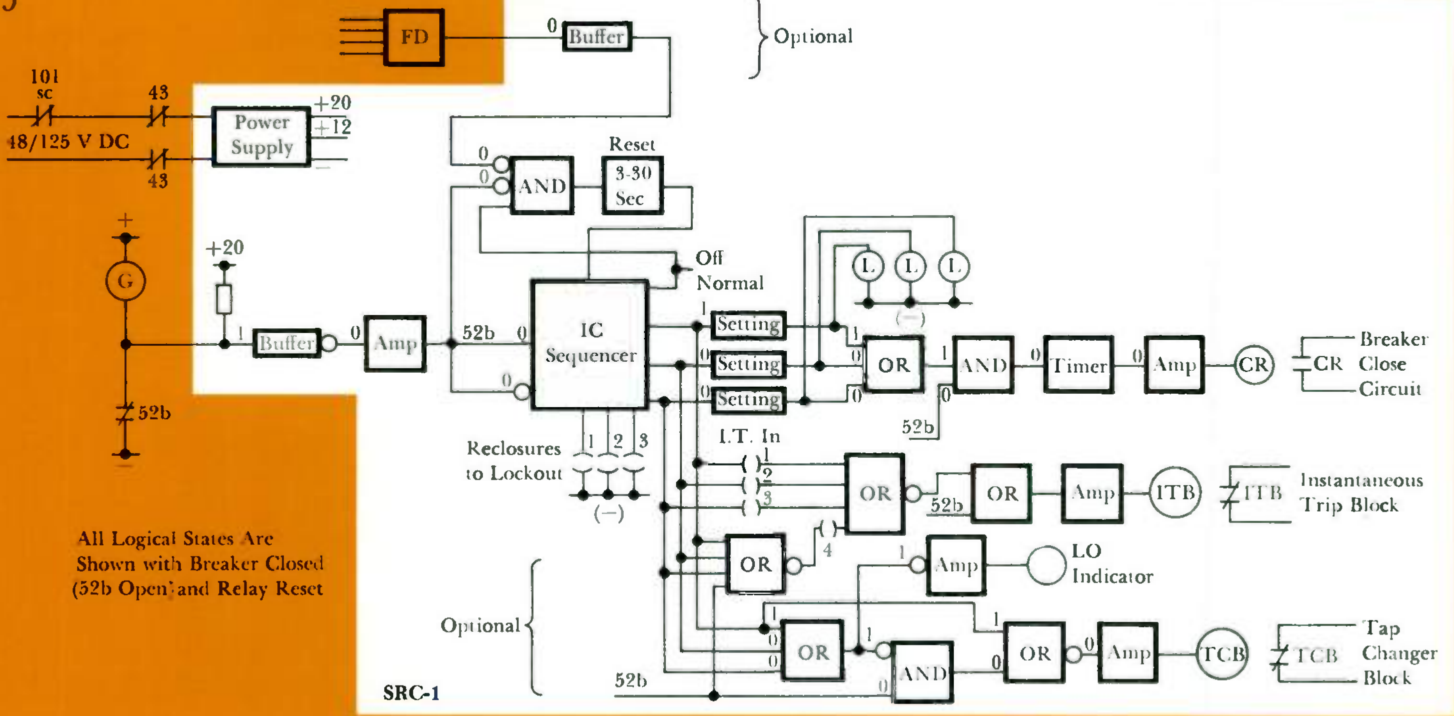
To avoid load tap changer operations during feeder faults and yet permit fast stepping for serious departures from desired regulated voltage, the reclosing relay has an option for blocking operation of a load tap changer during a reclosing sequence. This is a significant requirement only if the tripping time for a fault can exceed the tap changer control time.

Screw connector settings are provided to allow selection of the number of reclosures (1 to 3) and the number of trips for which instantaneous tripping is permitted (1 to 3). If a screw connector is placed in position 4, instantaneous tripping is reinstated (by deenergizing the *instantaneous trip block* relay, ITB) if the reclosing relay is locked out, and the breaker is manually closed.

Transmission Circuits—The SRC-2 reclosing relay is designed for subtransmission and transmission line applications. It contains high-speed reclosure initiating and blocking circuitry and provision for external synchronism check relay supervision of time-delay reclosures. Optionally, it permits intermediate lockout, allowing a final reclosure under synchronism check supervision.

Unattended substations that are not equipped with supervisory control can be effectively augmented by a reclosing scheme that locks out on a permanent fault prior to having exhausted all of its reclosing shots. With an attended (or supervisory controlled) substation at the other line terminal, manual reclosure can be attempted following lockout whenever the operator judges that the fault no longer exists. If his estimate is correct and the closure is successful, a synchronism check relay operates, in conjunction with the reclosing relay in the intermediate

5



Logic diagram for SRC-1 solid-state relay, which provides three-shot reclosing for distribution feeder applications.

lockout condition (i.e., with one remaining reclosure) at the unattended station, to restore the second line terminal to service. This procedure is effective for multiterminal lines where several unattended stations without supervisory control are disconnected for line faults.

The SRCU-1 and SRCU-2 relays incorporate all of the features of the SRC-1 and SRC-2 respectively, but are built on 19-inch chassis for rack mounting. The SRCU-2 optionally includes the synchronism check and the dead-line/live-bus and live-line/dead-bus control features. It also includes an optional *inhibit* input to prevent reclosing during such situations as reception of a transfer-trip signal from a remote station.

External Wiring

External wiring for the reclosing system is minimized by sensing breaker position entirely through the use of the "green light" breaker auxiliary switch (52b). In the past, a contact (52X) has been integrated into some reclosing schemes that closes during the closing operation of the breaker and is open at all other times. While this provided a distinct input to the reclosing relay to indicate that the closing circuit was sealed and further action by the reclosing relay on that shot was not required, it also produced problems. For example, many breakers are not equipped with a mechanism having a spare contact that can be used only for this function. Furthermore, the cost of the wiring from the switchgear to the control house can be significant when the reclosing relay is mounted a considerable distance from the breaker. Thus, a saving in wiring cost is possible through the use of a 52b contact already committed to the normal green light control, as opposed to using a spare 52b contact. This is made possible in the SGR group of solid-state relays through the use of a capacitor that charges when the breaker is open and provides a short-duration discharge during the closing stroke of the breaker when the 52b switch opens. This discharge provides the necessary lockout function, previously performed by the closing of the 52X contact. In the SRC group of relays, the need for this is obviated by more extensive logic.

All solid-state relay designs described use a 52b switch input and require no other indication of breaker status. Control is accomplished by removal of negative rather than the application of positive to avoid dependence on green lamp filament integrity.

Solid-State Reclosing Relays

Functions	*SGR-51 (Flexitest)* *SGRU-51 (rack)*	*SGR-52 (Flexitest)* *SGRU-52 (rack)*	*SGRU-54 (rack)*	*SRC-1 (Flexitest)*	*SRC-2 (Flexitest)*	*SRCU-1 (rack)*	*SRCU-2 (rack)*
Instantaneous one-shot reclosing	√						
First shot reclosing with time delay				0-1 sec		0-1 sec	
Initiated first shot reclosing with time delay		0-2 sec	0-2 sec		0-1 sec		0-1 sec
Initiated second-shot reclosing with time delay			2-20 sec	15-120 sec	15-120 sec	15-120 sec	15-120 sec
Internal reclose lockout switch	√	√	√			√	√
Initiated third-shot reclosing with time delay				15-120 sec	15-120 sec	15-120 sec	15-120 sec
Instantaneous trip lockout after any preset trip or when closing in from lockout				√		√	
Optional tap changer block when sequencing				√		√	
Optional intermediate lockout to allow final reclosure through external synchronism check relay					√		
Optional synchronism check and dead-line/live bus or dead-bus/live-line units with intermediate lockout control							√
"Inhibit" input to restrain all reclosing as long as input persists							√

All relays:
1) Use 52b switch controlling green light for all breaker status supervision.
2) Have all external circuits buffered against transients.
3) Have internal 20 volt (and 12 volt when required) power supply.
4) Assume lockout state when direct current is applied.
5) Have instantaneous reset following completion of desired reset time interval (3 to 30 seconds).
6) Have indicating lights to show status.
7) Have output relay for energizing close circuit.
8) Have continuously adjustable calibrated pots for setting from the front of the relay.

Conclusion

This family of reclosing relays provides a wide selection of functional characteristics in both the Flexitest and 19-inch rack-mounted configurations. Effective use is made of solid-state components, which should, with the greatly reduced number of moving parts, decrease the amount of maintenance effort that has traditionally been allocated to reclosing relays, and also make available some features not achievable with mechanical elements.

Computer Time Sharing Makes Numerical Machine-Tool Control More Effective and More Economical

Frank Carr

For maximum benefit from numerical control, the part programs that direct the machines often have to be prepared by a computer. Time-sharing services make large and capable computers accessible to any user while requiring him to pay only for the time he uses.

Numerical control of machine tools greatly enhances a plant's ability to compete profitably by lowering operating costs, improving cash flow, improving product quality, and permitting more accurate cost estimates and shorter delivery. Moreover, a plant employing numerical control usually requires no more total investment than one with conventional machines because numerical control reduces the number of machine tools required, reduces work-in-process inventory and stores inventory, improves scheduling, and reduces floor space requirements.

While numerical control has thus created new opportunities for manufacturing management, it has also created some needs. Probably the most pressing need is for efficient and accurate preparation of the part program—the set of instructions that, in the form of a paper tape, is read by the numerical control unit controlling the machine tool.

Now, however, time-sharing computer services have been created to give numerical control users access to central computers for preparation of their part programs. The Westinghouse Camp (computer aided machine programming) Services extend the advantages of numerical control by making available larger computers than the user could afford to maintain himself, thereby greatly reducing tape preparation time and achieving more efficient utilization of the user's numerically controlled tools.

The Part-Programming Problem

A part programmer (the person who prepares the part program) writes a manuscript with symbols that, when transcribed to the paper tape, will be understandable to the machine-tool numerical controller. To do so, he translates information contained in engineering drawings of the desired part into the appropriate symbols and adds additional process information such as materials, tooling, and machine-tool specifications.

Although numerical control reduces the manufacturing cost of a single piece, the part programming required becomes a setup cost that must be absorbed by the number of pieces in a lot. For example, if a $25 cost reduction per piece can be achieved by using numerical control on a given part but the cost of preparing the program is $250, there must be a requirement for more than 10 pieces in the lot to achieve any economic advantage. If the cost of part programming can be reduced, the economic lot size also is reduced. More parts can then be produced with numerically controlled machine tools, and that in turn influences economic decisions to acquire such tools.

Computers have been used successfully to reduce the cost of part programming. A part programmer using a computer doesn't write his manuscript with the symbols understood by the numerical controller; instead, he writes in a higher-level "language," which is then translated by the computer to the sets of symbols understood by the controller. (The language is called "higher-level" because the part programmer writes fewer statements in preparing the manuscript.) Using computers in this fashion reduces the cost of preparing part programs to approximately one-third that of manual programming, although cost varies, of course, with the complexity of the part. For very simple parts, there would be no saving and more likely an increase in cost; at the other extreme are many parts that are so complex it is virtually impossible to prepare their programs manually.

Improvement in tape reliability is another significant advantage of using the computer in part programming. For example, hand or desk calculation in manual programming carries with it a high probability of errors in manuscript preparation when trigonometric functions are required to calculate point locations on rotated lines, circles, and matrices. The subsequent keypunching of the data to tape by the part programmer also is subject to a high probability of error, and both types of error are difficult to detect. When using a computer, however, the part programmer has fewer statements to write and far fewer and simpler calculations to make, if any. Errors are fewer, and many of those that do occur (such as omissions or logical errors) can be detected by the computer. Moreover, the punching of the manuscript to cards for computer input is usually done by keypunch operators under supervision, where the normal attention to input data preparation reduces the probability of errors and increases the probability of detecting any that do occur.

However, there are also problems with computer part programming. As in manual programming, many different tapes can be punched to produce parts to the same design: some tapes will produce good parts and some bad ones; one will produce parts most efficiently (that is, with the shortest cycle time) and all the others less efficiently; and some are generated with less part-programming effort than others.

The computer program that yields the lowest per-unit total cost for writing the parts program, running the manuscript on the computer, and manufacturing the part is necessarily complex and requires the use of a very large computer to store the program and run it efficiently. Yet the running time for a manuscript on such a computer is short—less than a minute. Consequently, few companies can justify acquiring such a computer for numerical control alone; many, however, *can* afford to pay for the small amount of its time that they need.

Even when a large computer is available to a company, it must be shared with other users. And sharing can mean as much as a three-day delay in getting results back. The user may save part-programmer time, improve tape reliability, and lower tape cycle time, but his lead time suffers.

Such problems have kept computer programming from fulfilling its potential. The result of the problems is that more

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tapes are still prepared manually than with the aid of computers.

Time-Sharing Computer System

The ideal solution to the problems of computer part programming can be stated quite simply: give the numerical control user access to a large computer when he needs it, give him the results he wants as soon as the computer is through working on his problem, and charge him only for the amount of time he uses. Add the requirement that the user should have a terminal on his premises for access to the computer, and one has pretty well described what the user should find in a remote computer time-sharing service.

Time-sharing services available today range from the processing of individual sales transactions for wholesalers to remote entry of large batch-processing programs for such applications as part programming. They include simple inquiry of random-access files and special programs to help solve such problems as discounted cash flow calculations.

Westinghouse has been operating a real-time time-sharing system since 1962 when it opened its first Tele-Computer Center in Pittsburgh. Since then, more computers have been installed and the associated teletype network expanded to 40 lines with more than 500 teletype terminals. The latest addition is an RCA Spectra 70/46 time-sharing computer, and from five to ten additional computers of that type will be installed in satellite Tele-Computer Centers in various parts of the country. They will be used principally to satisfy the growing need for "conversational computing." That term means a form of remote computer time sharing that differs basically from batch processing: the computer is programmed to guide the user by asking questions or telling him what to do next at his terminal (which is usually of the keyboard type).

Remote Part Programming—The machine-tool user avails himself of the Westinghouse computing power through the Camp Services provided by the Manufacturing Information Services Department, Westinghouse Information Systems Laboratory. The approach of the Camp Services is to tailor the language to

Campoint in Action

The user of Campoint, one of the Camp Services part-programming languages, begins with an engineering drawing or sketch of the part to be programmed (Fig. 1). He selects one or more convenient reference points, from which he dimensions the machining points or the patterns of machining points. Patterns such as straight lines, circles, and matrices are readily identified, since all pattern points are generally referenced from a single point in the pattern.

The part programmer then fills out the input data sheet with the specific information for the machining operations (Fig. 2). As shown, a series of points and patterns can be described within a defined pattern and executed at selected places in the program. Also, defined patterns can be included within other defined patterns and executed independently or as a part of the parent defined pattern.

To gain access to the Campoint system, the user dials it from his teletype terminal and announces himself to the computer with the proper account number and password. The terminal can have a built-in telephone for dialing and communicating with the time-sharing computer, or it can have an accoustic coupler that couples the terminal to an ordinary telephone as shown in Fig. 3.

The user then specifies a part identification number, and the Campoint system requests him to enter a control word (Fig. 4). The user responds by entering a command word such as "Line" or "Circle." The system then asks the user to enter the additional information required to fully define the line or circle. When he does, the system asks if the input data is "OK." If it isn't, the entire sequence is repeated to give the programmer the opportunity to make corrections before proceeding to the next line of input.

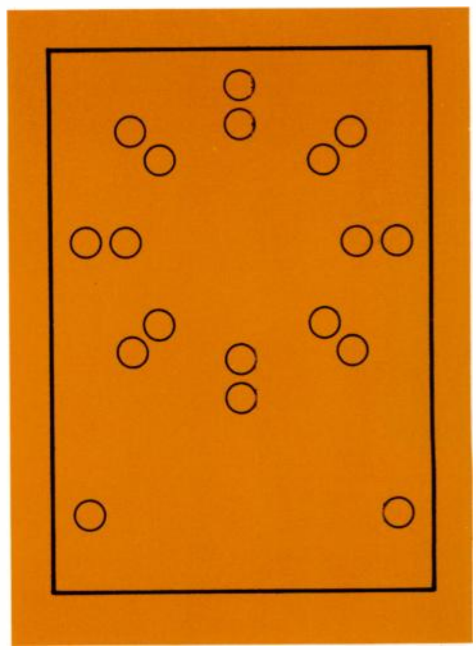
When the input step is complete, the system prints the input data in tabulated form. If there are errors in the input, the table is followed by diagnostic messages (Fig. 5). The programmer then uses the editing features to correct his input on-line and get another pass immediately.

The Campoint system then processes the input data, calculates the coordinates of all machining points, and lists them at the user's terminal (Fig. 6). The system asks if the user wishes to edit any of the input; if he does, he uses the editing procedures described above as often as necessary.

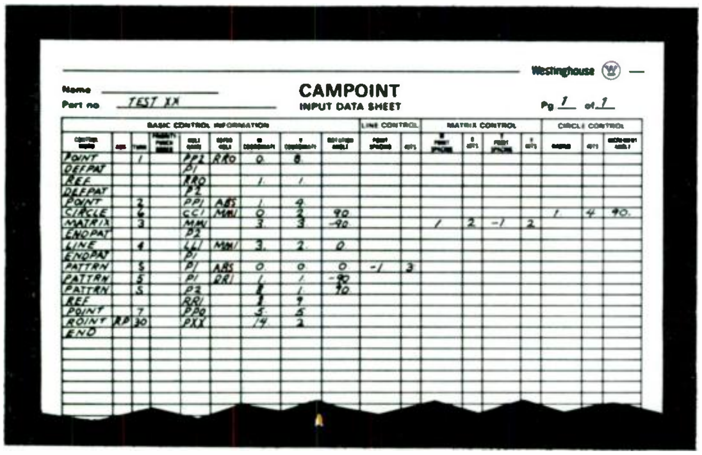
The system next asks if the programmer wishes to use the optimizing feature. If he does, the optimizing section reorders the machining points given in the previous list in such a way as to minimize the time required to machine the part and, thereby, improve machine-tool utilization (Fig. 7). The system also prints out the time (in seconds) required to machine the part with the input machining sequence (nonoptimized) and with the optimized sequence. In the example shown, optimized time was 33 percent less than nonoptimized time.

After optimization, the system prints (at the terminal) a verification listing of the output characters as they will appear on tape, except that the functions are spaced for readability. It then punches a paper tape in the EIA (Electronic Industries Association) format required by the user's machine tool; for most tools, that tape is ready for direct use. The tape is identified on the leader by readable characters that spell out the part number, drawing number, or any similar identification the user wishes.

1



2



3

4

```
ENTER CONTROL WORD—LINE 4
CIRCLE
ENTER AUX—TUR—PRTY—HOLE NAME—REF PT—X-COORD—Y-COORD—(ANG)
0
2
0
BHC
P1
5
5
ENTER RADIUS—HITS—INCREMENT
2
4
90
OK?
```

5

```
                    *** CAMPOINT ***

        WIEDEMATIC—WESTINGHOUSE CONTROLS

              LISTING OF PARTS PROGRAM

   PART NO  TEST #1                        CUST. ACCT. NO. 1

                                                 LINE CONTROLS
         COMMON TO ALL CONTROLS                  CIRCLE CONTROLS
                                                 MATRIX CONTROLS
 C   A  T  P   N   R    A     O      A    LINE-SP  HITS
  T   U  U  P   A   E    B     R      N   RADIUS   CHT  INCREMT
   L   X  R  O   M   F    S     D      G  X-SPACE  XHT  Y-SPACE  YHT

POINT      1    1  PP1  PP1  1.      1.
POINT      2    2  PP2  RR1  1.      1.
END

***** REFERENCE ERROR *****
THE POINT NAMED PP1 HAS BEEN REFERENCED TO ITSELF.
***** REFERENCE ERROR *****
THE POINT NAMED PP2 AND REFERENCED TO RR1 IS ILLEGALLY REFERENCED
IN THAT THE POINT RR1 HAS NOT BEEN PREVIOUSLY DEFINED
```

6

```
                    *** CAMPOINT ***
         WIEDEMATIC—WESTINGHOUSE CONTROLS
              LISTING OF PARTS PROGRAM

   PART NO. 312G550                     CUST. ACCT  NO

                                                 LINE CONTROLS
      COMMON TO ALL CONTROLS                     CIRCLE CONTROLS
                                                 MATRIX CONTROLS
 C   A  T  P   N   R    A     O      A    LINE-SP  HITS
  T   U  U  P   A   E    B     R      N   RADIUS   CHT  INCREMT
   L   X  R  O   M   F    S     D      G  X-SPACE  XHT  Y-SPACE   YHT
REF              P0       1     1
REF              P1   P0  9     9

LINE        5    LN1  P0  2     2             1       6

CIRCLE      2    BHC  P1  5     5             2       4   90
MATRIX      1    GRD  P0  2     2             5       2   4        2
END
                  ABSOLUTE POINT LOCATIONS
      AUX    TURRET    PPO    NAME    X-COORD     Y-COORD
  1           5               LN1     300 0000    300 0000
  2           5                       400 0000    300 0000
  3           5                       500 0000    300 0000
  4           5                       600 0000    300 0000
  5           5                       700 0000    300 0000
  6           5                       800 0080    300 0000
  7           2                       700 0000    500 0000
  8           2                       300 0000    499 9999
  9           2                       700 0000    500 0002
 10           2                       300 0000    499 9997
 11           1               GRD     300 0000    300 0000
 12           1                       800 0000    300 0000
 13           1                       300 0000    700 0000
 14           1                       800 0000    700 0000
```

7

```
OPTIMIZE?
Y
NON-OPTIMIZED TIME = 351.4900
OPTIMIZED TIME = 211.4300

                       ABSOLUTE POINT LOCATIONS
  AUX      TURRET     PPO     NAME     X-COORD        Y-COORD

   1          5                LN1     300.0000       300.0000
   2          1                GRD     300.0000       300.0000
   3          5                        400.0000       300.0000
   4          5                        500.0000       300.0000
   5          5                        600.0000       300.0000
   6          5                        700.0000       300.0000
   7          1                        800.0000       300.0000
   8          5                        800.0000       300.0000
   9          1                        300.0000       700.0000
  10          2                        300.0000       499.9997
  11          2                        300.0000       499.9999
  12          2                        700.0000       500.0000
  13          2                        700.0000       500.0002
  14          1                        800.0000       700.0000
```

the machine tool and the computer to the language. That is, the part programmer uses the language that makes it easiest for him to solve his problem, and Westinghouse uses the computer and communications system that processes the data at the lowest cost.

Campoint, one of several Camp Services languages, is an example of what can be accomplished to minimize the part programming problem by using a conversational time-sharing computer system. (See *Campoint in Action*, page 176.) Campoint is a powerful programming language that gives users of point-to-point machines a means of greatly reducing their tape preparation costs: cost reduction (compared with manual tape preparation) is conservatively estimated at well over 50 percent. Campoint also achieves more efficient utilization of the large variety of two-axis machine tools that can be programmed with it (such as punch presses, drills, inspection machines, spot-welding machines, circuit-testing machines, assembly machines, riveting machines, point drafting machines, and terminal wiring machines).

The language allows the part programmer to define patterns of points, lines, circles, matrices, and previously defined patterns. The complex patterns can easily be labeled for later reference, and the programmer can translate, insert, or rotate them through an angle and let the computer perform the detailed calculations that provide the point information required to produce the tape for his machine. Most of the causes of errors generally associated with those functions are consequently eliminated. The nature and simplicity of the information required on the input data sheet used in preparing the Campoint manuscript also reduces the probability of error, and errors that do occur are easily detected. The probability of errors occurring during keyboard input is reduced because of the immediate line-by-line editing feature.

The net effect is to reduce the time necessary to prepare the tape, increase tape reliability, and reduce the cost of tape preparation. Those improvements over present practices apply both to numerical control users who employ computers in a batch mode and to those who do manual programming.

Program Quality—Campoint has a number of helpful features that other programs lack. Examples are its full capability for using symbolically defined points, lines, circles, matrices, and patterns; its flexibility in defining independent patterns of random points and in nesting patterns within patterns; and its comprehensive on-line diagnostics and editing capability. Capacity is virtually unlimited in terms of part-program size and tape length. The powerful optimization feature results in efficient utilization of machine tools, and the areas over which optimizing is to be carried out can be specified.

The simple language used permits use of lower skills and eases part-programmer training. Also, the computer itself acts as a teaching device by continually asking for information.

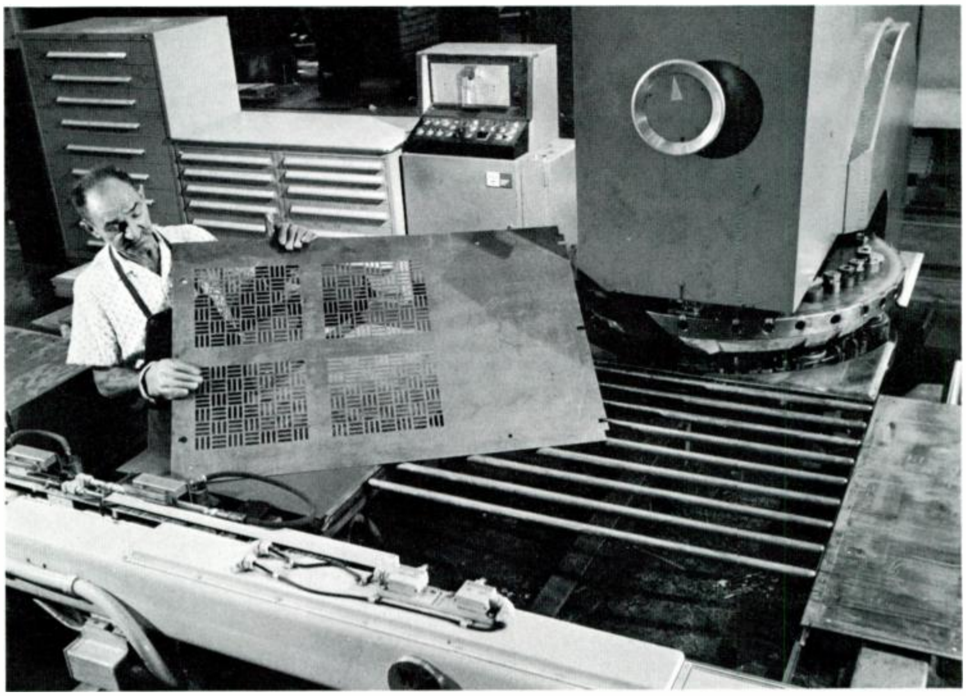
Manufacturing Technology

The Campoint system just described applies a computer to simplify the processing of *geometrical information* for part programming. Additional opportunities for work simplification abound in part programs involving *manufacturing technology*, such as feeds and speeds, depth of cut, and material and tool specifications.

A Camp Services system that simplifies the processing of manufacturing-technology information as well as geometrical information is Campfive. It is a powerful five-axis point-to-point language available to customers as Campoint is—through remote terminals. Campfive is an extension of a system used by Westinghouse for the past seven years.*

Several input features simplify preparation of the input manuscript. For

*D. C. Cumming and C. M. Knarr, "The CAMP II Numerical Control Programming System," *Westinghouse ENGINEER*, May 1963, pp. 70-5.



Paper tape produced by the Campoint system of remote computer time sharing is read by numerical controllers to operate machine tools in the most efficient manner. Here, a tape in the Westinghouse Model 20 controller in the background operates a Wiedemann "Wiedematic" turret punch press (NC-4050). The press automatically punches such complex patterns as the ventilation grille and edge notches in this sheet-steel part for a switchgear cabinet.

example, the part programmer has the following alternatives for inputting data required for the speed function: he can input the speed of either the cutting tool or the workpiece directly in revolutions per minute; he can input the diameter of the cutting tool and its maximum allowable surface speed in surface feet per minute; he can input the diameter of the cutting tool and the tool material classification (such as high-speed steel, carbide, or ceramic); and he can input a factor to account for fixture rigidity. The part programmer also has a number of alternatives for inputting data required for the feed function: he can input the feed directly in inches per minute or inches per revolution; for milling cutters, he can simply input the diameter of the cutter; for counter-boring cutters, he can simply input the number of flutes; and for drills, spot-drills, boring cutters, reaming cutters, and turning tips, he can specify the feed in either inches per minute or inches per revolution.

When speed-torque capability curves are supplied by the machine-tool builder, the user can input information from them plus a material specification that gives the horsepower required to remove one cubic inch of material from the workpiece; with that data, Campfive calculates the maximum depth per pass for milling cuts. For single-point operations with large ratios of machining depth to cutter diameter, the part programmer can specify multiple cuts for a single machining operation. Campfive then calculates the maximum depth of penetration, after which it retracts the cutter to remove chips and repeats the process until the specified machining depth is reached.

Campfive is a unique combination of conversational time-sharing and remote batch processing. During the keyboard input stage, for example, the part programmer can make corrections or changes in his input statements if he discovers an error or decides to change the sequence of machining operations. However, the completed manuscript is run as a batch processing job. It must, therefore, be scheduled in with other jobs, but, because it is short, it is given a high priority and usually is run the same day. The necessary scheduling is done automatically by the computer.

If the program detects errors during processing, it gives the part programmer an error listing at his terminal. The programmer makes his corrections and submits the job to be run again until all errors have been corrected. An average of three runs must be made because of the complexity of the part programs Campfive is used for and the length of the manuscripts.

The conventional computer method, with its problems of scheduling and making corrections, requires an average of five elapsed days to get a good tape. Campfive reduces the time to one day, and does so at lower total cost—including use of the computer, communications system, and terminal.

Remote Terminals

With most other time-sharing services, the only terminal available is a keyboard printer type (resembling a typewriter). Although that type is satisfactory for many applications, numerical control imposes additional output requirements such as punched tapes and perhaps graphic plots of the cutting tool path. Moreover, the volume of printed output may be so great as to require a medium-speed or high-speed printer. Meeting those requirements adds to the cost of a terminal, and often the equipment simply isn't available.

Camp Services, however, provide a range of terminals with features to meet individual customer needs. For example, the user may choose a low-cost keyboard-printer terminal with a tape punch, or he may choose a higher-priced terminal system that has in addition a graphic plotter and medium-speed printer. For lowest cost, he can choose just the basic keyboard-printer and have the completed tapes, lengthy printouts, and graphic plots delivered to him by courier service from the satellite Tele-Computer Center.

Integrated Information Systems

Part programming, as described in this article, actually is only the *central* piece of an information system for numerical control. The basic *inputs* to the information system are the decisions a design engineer makes in designing a new part and the consequent determinations by the manufacturing engineer on how the part will be manufactured (for example, what machines, tooling, and fixtures will be used). Camp Services now extend into those areas to a degree, as illustrated by Campfive, and the penetration will be increased. A cathode-ray-tube graphic display terminal will be added to the line of Camp Services terminals to make it simpler for the engineer and draftsman to input geometrical information into the system.

The *output* end of a numerical control information system is usually considered to be the tape that drives the machine-tool controller. However, the controller itself is an information-handling machine made up of digital and analog elements. It doesn't have to operate from tape input; instead, the instructions can be stored in a random-access memory such as discs or drums. Then, when the instructions are required by the machine tool, a process-control computer reads them and controls the machine tool directly. That computer not only can use the previously prepared part-program instructions but also can modify the instructions on the basis of other information picked up during machining. (For example, by measuring where the tool is cutting, the computer can make an adjustment for tool deflection.) At the same time, the computer can be used along with additional data collection devices to gather information on quality control, tool wear, machine availability, and expected job completion times—all of which can be used to increase shop production. It is expected that a computer of that type will become available as a Camp Services terminal, since many of the data processing functions that have to be performed can be most effectively carried out on a large time-sharing computer with programs that will be too expensive for individual companies to want to develop.

Such input and output additions will provide a more fully integrated information system for numerical control.

Simple Diode Rectifier Controls High Power

Robert M. Hruda

Varying the filament input of the new power control diode regulates the power delivered by the device from 0 to about 500,000 watts. That control capability plus inherent fault-protection and self-adjusting capability enable the power control diode to perform many control jobs better and less expensively than other devices can.

The devices used in industry to control electric power precisely are often bulky, complicated, and expensive. Yet they have been needed since the beginning of electrical applications because so many uses of electric power depend on precise control. Now, however, a relatively small and simple diode rectifier has been developed to act as a giant variable resistor and thereby control vast amounts of power.

Besides being a control element, with minor refinements the diode can also provide fault protection, self-adjusting capability, and a number of other application advantages. Moreover, the power control diode is compact and inexpensive in comparison with the devices it can replace, and it does not affect the line power factor.

The Diode As Control Element

The control diode is similar to any other diode rectifier in that electron current travels from its filament to its anode but cannot travel in the reverse direction. The tube has no grid; instead, current flow is controlled by regulating the amount of electrons available from the filament itself by simply varying the filament power input. As a consequence of that kind of regulation, the characteristic curve of volts versus amperes has two sections (Fig. 1). Up to the emission limitation, the curve follows the familiar diode line (*A*); beyond the emission limitation, there is little further increase in current (*B*).

That characteristic is the secret of the diode's ability to control huge amounts of power. How it works can best be illustrated by a typical application, dielectric heating. In such a heating system, a rectifier power supply converts ac power from the main into dc power and delivers it to an oscillator. The oscillator generates radio-frequency power that goes to the heating load.

Normally, the power for such a system is controlled at the input side of the power supply. If the power level is low, a variable transformer might be used; if it is a little greater, either an induction regulator or a saturable-core reactor could be used. A somewhat more sophisticated unit might use phased-back thyratrons or silicon controlled rectifiers that conduct current during only a portion of each cycle. In all of those methods, the quantity being controlled is the amount of ac current being rectified in the power supply.

In a system employing the power control diode, however, the power supply is designed to produce full output when it is turned on—it is not variable. The control diode is inserted between power supply and oscillator (Fig. 2). The input to the diode filament controls its emission, which, in turn, determines the voltage drop between filament and anode (as illustrated in Fig. 1). Thus, the diode acts as a high-power resistor between the power supply and the load. Typically, a change of only four watts of filament power results in a load change of one kilowatt.

In spite of that large output capability, the control diode takes up little space. A saturable-core reactor, for instance, controlling that much power might be as bulky as a large desk and weigh as much as 500 pounds; in contrast, its control diode counterpart takes up only two cubic feet, including the insulation space and the water jacket. And the steel alone in the reactor probably costs more than the diode.

Also, saturable-core reactors and induction regulators are not very fast acting, while a control diode typically has a time constant of 0.15 second. (That is, the current can be reduced from a given level to $1/e$ of that level in 0.15 second.) A typical time constant for reactors is one second; for induction regulators, a typical value is ten seconds.

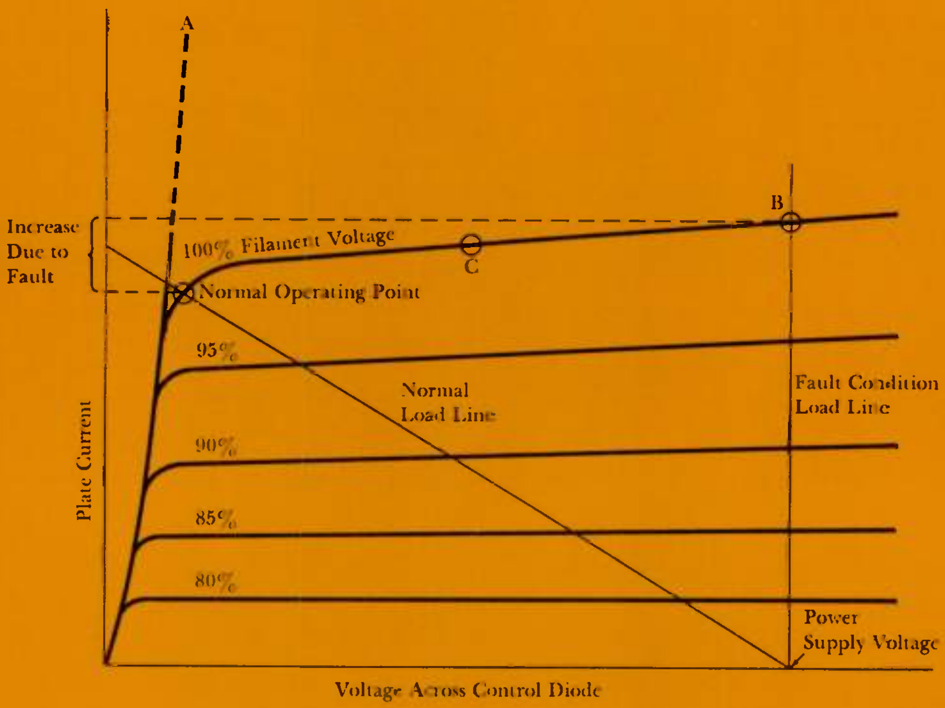
Fault Protection

Although the diode's primary function is power control, it can also be used to perform other important functions including system fault protection. When the filament is set for a certain amount of emission current, by the diode's very nature it conducts essentially the set current no matter how much the load increases. However, in a typical application the considerable voltage applied between anode and filament draws a small additional amount of emission from the filament. (This is known as the Schottky effect.) Thus, the actual current curve slopes slightly upward (perhaps 10 to 15 percent) as shown in Fig. 1. The additional emission permits sensing of a fault condition by an overload relay in the circuit, and thereby operation of a circuit breaker.

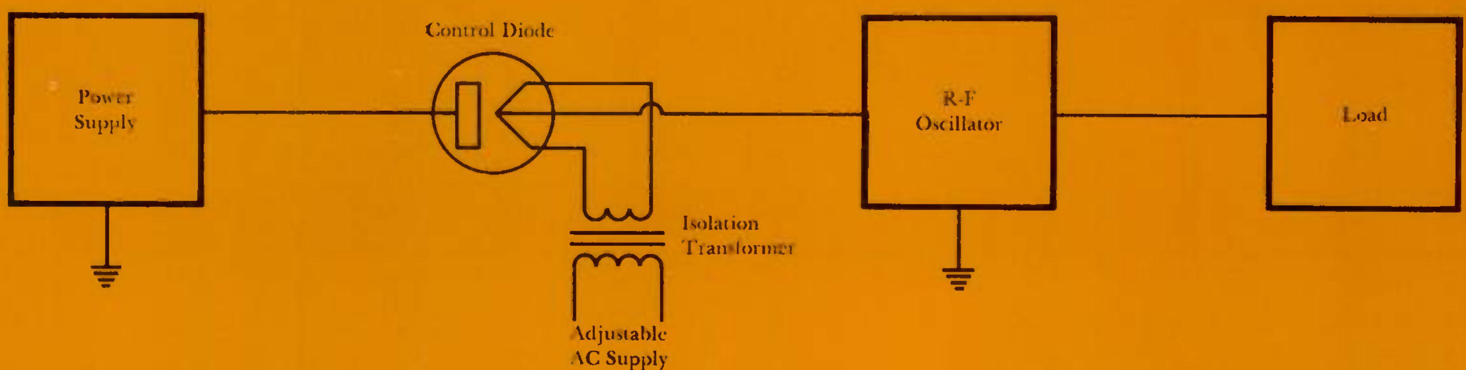
To illustrate, consider a dielectric heating installation consisting of a 15,000-

One application of control diodes is in this high-frequency test facility. The rf amplifier, which operates at 13.6 MHz on a 1.2 MW input, is used to season and test high-power copper-anode transmitting tubes at the Westinghouse Electronic Tube Division. The control diodes limit fault current through the tubes, preventing damage to the tubes and also allowing arcs to clear without shutting down the equipment.

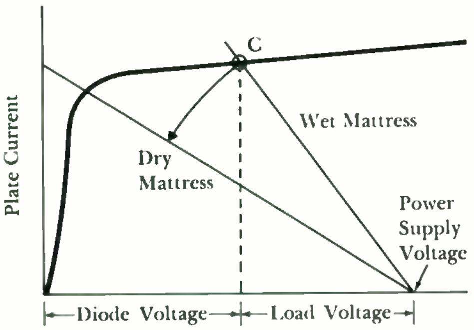
Robert M. Hruda is a Senior Design Engineer at the Electronic Tube Division, Westinghouse Electric Corporation, Elmira, New York.



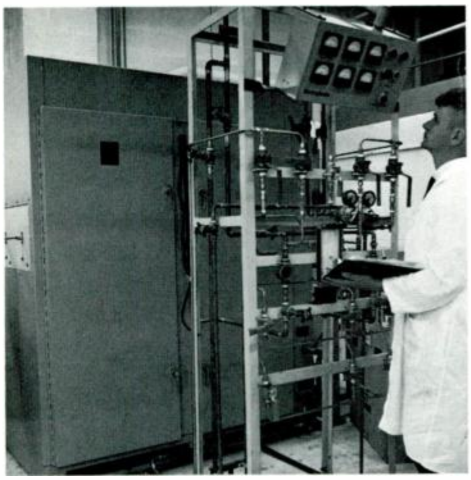
1—Characteristic curves (volts versus amperes) for the control diode show how the amount of power conducted by the diode is controlled by regulating the voltage input to the filament. Since conduction is limited by the filament emission limitation, even a serious electrical fault in the system increases current flow only a little (but enough to actuate a circuit breaker if power interruption is necessary).



2—Control diode in a typical application regulates the amount of power fed to an oscillator and its r-f heating load. Input to the diode's filament determines the voltage drop between diode and load; therefore, regulating that input regulates the power supplied.



3—Self-adjusting capability is exemplified in dielectric heating process for drying foam rubber mattresses. The heating load diminishes as the mattress dries, causing the control diode to automatically deliver a higher proportion of the voltage across it to the load. The result is uniform delivery of the highest power consistent with process safety, and consequent fast drying.



High-power r-f generator in background includes a control diode for stepless power control from 10 to 100 percent of rated output. The 125-kW Westinghouse type 125K67 generator is used at the Electronics Division, Dow Corning Corporation, Hemlock, Michigan, to heat graphite workpieces (enclosed in bell jars) for vapor deposition of silicon. The resulting silicon-carbide coating provides a very hard surface on the workpieces. Initial products of the facility are susceptors—devices that carry electronic components through manufacturing steps—but the process is applicable to other products as well. The control station in front of the generator enables an operator to monitor and control the flow of gases and r-f energy to the work stations.

volt dc power supply, a control diode, an oscillator, and the load. Arcing-over of the load, the oscillator, or some other component would be a short circuit; that is, zero ohms. The load line goes straight up in such an event, which in effect means that an infinite amount of current is demanded from the power supply. If the control diode is not used, the only thing that might limit the amount of current drawn is the negligible impedance within the power supply itself. The overload relay functions eventually, but often not before some damage has been done to the system.

With the control diode in the circuit, fault current is limited to only slightly more than the normal operating current (point *B* in Fig. 1). The increase in current is just enough to enable the circuit breaker to function. If the fault is transient or self-correcting, the overload relay need not function at all—the control diode absorbs the entire power supply output for the duration of the fault, thus minimizing the fault damage and the amount of downtime.

Self-Adjusting Capability

Another useful feature of the control diode is its ability to compensate for changes in operating conditions. Setting the diode to operate at the proper point past the knee of the characteristic curve (as at point *C* in Fig. 1) causes it to adjust its operation to suit a variety of load conditions.

An example is the drying of a foam rubber mattress by dielectric heating. The mattress contains a lot of water when it first enters between the electrodes; since the water has a great deal of resistance and capacitance, there is a heavy load on the dielectric heater. But by the time the mattress comes out, all the water is gone and so the load on the heater is relatively light. The result is a touchy control situation: if too much power is fed to the heater initially, rubber cells will be destroyed, steam will blow the mattress apart, or the rubber will melt. Yet, if the heater control is set unnecessarily low, the drying process takes longer than is necessary and therefore more production space is needed.

The problem is solved by using the control diode set at the safe condition out past the knee of the characteristic curve (Fig. 3). At the beginning of drying, the power supply voltage is divided between load voltage and diode voltage as shown. The load line swings counterclockwise as the mattress dries and the load tapers off; load voltage increases as a consequence, while diode voltage decreases. That progressive delivery of more voltage to the load (the dielectric heater) results in uniform power input to the mattress, allowing it to be dried faster than could safely be done with other control methods.

Dielectric heating of plastic is another example that illustrates the self-adjusting capability of the control diode. A piece of plastic starts as a good insulator, but, as heat goes into it, it becomes more and more conductive and so the heat flows in faster and faster. The heat must be stopped right on the dot or the plastic will burn up. Therefore, the timer on the heating cycle has to be extremely well defined. By using the control diode set at the knee of the characteristic curve, the voltage delivered to the r-f generator is reduced as the plastic heats. The otherwise steep rate of rise of heating thus is lessened, and the timing is made more flexible. The result is a much more uniform product.

Other Applications for the Power Control Diode

The preceding examples illustrate only a few of the control diode's application possibilities; it has the design flexibility to be modified to fit many other needs. For instance, rectifying and control functions could be combined by replacing solid-state or mercury-vapor rectifiers with control diodes set to operate just past the knee of the characteristic curve. Such an arrangement could eliminate an L-C filter, since it would produce almost ripple-free dc power from three-phase ac input. The point of these few examples is that the control diode can do many control jobs better and less expensively than they have been done before.

LE Flowmeter—A New Device for Measuring Liquid Flow Rates

Calvin R. Hastings

The LE (Leading Edge) Flowmeter can accurately measure liquid velocities and discharge in pipelines and canals, measure the speed of ships, and monitor the currents of the oceans.

Venturis, flow nozzles, and orifice plates have long set the standard for measuring discharge (volume rate of flow) in pipelines, and the pitot tube has long been used for measuring velocities. But those devices, based on Bernoulli's equation that relates pressure difference to velocity difference, restrict flow and measure it in one direction only. Moreover, all but the pitot tube require an initial calibration before being used to measure flow.

Increasing operating costs of water handling facilities have greatly increased the need for more accurate and more economical means of measuring discharge. A recently developed device that meets that need is the Westinghouse LE Flowmeter, an acoustic device. Moreover, greater demand for precision of navigation calls for more accurate measurement of ship speed. And a deeper concern for beach erosion begs for improvement in current-measuring devices. The advantages of the LE Flowmeter are the absence of projections into the flow stream when used to measure discharge, thereby eliminating any restriction to flow, rapid response to changes in flow, a linear system characteristic that eliminates the need for calibration, accuracies better than one percent of maximum flow, and a basically unlimited dynamic range.

Operating Principle

The LE Flowmeter is based on the principle that the rate at which sound travels from one point to another depends on the velocity of sound in the medium separating the points and the velocity of the medium along the path joining the points. That principle and a simplified block diagram of the LE Flowmeter are illustrated in Fig. 1 as applied to the measurement of discharge in pipelines or open channels. Two identical sources simultaneously emit sound pulses into the moving liquid. The pulse moving in the direction of liquid flow travels between transducers A and B in less time than does the pulse moving in the opposite direction. Transit times are given by the expressions

$$t_{AB}=\frac{L}{C+V_{\text{path}}} \text{ and } t_{BA}=\frac{L}{C-V_{\text{path}}}, \quad (1)$$

where t_{AB} is the transit time in the direction of the flow, t_{BA} is the transit time in the direction opposite flow, L is the acoustic path length that separates A and B, V_{path} is the average value of the component of liquid velocity along the acoustic path, and C is the velocity of sound in the medium whose flow is being measured.

The difference in transit times provides the expression

$$\Delta t=\frac{2LV_{\text{path}}}{C^2-V^2_{\text{path}}}. \quad (2)$$

For virtually all applications of interest, C^2 is much greater than V^2_{path}, thereby allowing for simplification of the above relationship to

$$\Delta t=\frac{2LV_{\text{path}}}{C^2}. \quad (3)$$

Thus for known values of C and L,

$$V_{\text{path}}=\frac{C^2\Delta t}{2L} \quad (4)$$

and the measured velocity is a linear function of Δt, requiring no calibration of the system.

The LE Flowmeter measures the difference in transit times (Δt) between the two pulses by measuring the differences in arrival times at the transducers. The Δt measurements are made at the leading edge of the received pulses to provide immunity to the acoustic phenomena of refraction and attenuation that affect all but the leading edge of the pulse. From that technique, the system derives its name—LE (Leading Edge) Flowmeter.

In most applications, the acoustic path is at an oblique angle with respect to the direction of the actual flow velocity as illustrated in Fig. 1. In some special cases this angle is zero. However, it can never be a right angle for in that orientation $\Delta t = 0$ for any value of V_{dia}. The relationship between the average velocity along a diameter (V_{dia}) and the component of velocity (V_{path}) measured by the LE Flowmeter is also shown. Calculation of discharge is explained later.

Factors That Affect Accuracy

Accuracy depends on three factors: measuring Δt, scaling acoustic path orientation (L and θ), and correcting for sound velocity (C). Theoretically, there is no limit to the degree to which errors in those factors can be reduced.

Errors in measuring Δt depend on the circuitry used in the digital processor and the number of Δt measurements made in computing the acoustic path velocity. High frequency digital circuits with 20-MHz capability, and numerous Δt measurements (up to 60/s), hold timing errors to less than ten nanoseconds (10^{-8} second). It can be assumed that future improvements in digital devices will reduce timing errors to about one nanosecond. The error in measured velocity produced by timing errors is directly proportional to the square of the speed of sound and inversely proportional to the path length. Because of the limiting effect on measurement accuracy that quantity is called the "minimum resolvable flow," and it is a primary factor in selecting path length or the path angle θ.

The distance L is easily measured and, as long as it remains constant, does not contribute significantly to measurement error. For example, if an error of 1/32 inch is made in measuring a three-foot acoustic path, the effect on accuracy is less than 0.1 percent. Changes in path length resulting from deflections of structures under load or from expansion and contraction during temperature changes are also encountered. However, normal measurement and design principles have held such changes in path length to the order of 0.1 percent.

The additional source of error introduced in measuring the acoustic path angle (θ) is held to within acceptable limits by using standard surveying methods to locate the transducer mounting holes.

Calvin R. Hastings is Manager, Leading Edge Flowmeter Program, Underseas Division, Westinghouse Electric Corporation, Annapolis, Maryland.

Sound velocity (C) is not as easily measured as is distance L and angle θ, and furthermore, it can vary significantly in many liquid velocity measurement applications. For example, the velocity of sound in water varies over the range from 4600 to 5100 ft/s, depending on salinity and temperature.

Since there is two-way transmission of sound with the LE Flowmeter, it is possible to calculate C independently of the liquid velocity and to provide direct compensation for speed-of-sound variations. That compensation allows the basic system equation (Equation 4) to be simplified to $V_{path} = K\Delta t$, where the parameter K adjusts automatically as the liquid medium changes. When desired, a separate system output for sound velocity is provided. The error in correcting for changes in sound velocity over the range of C from 4600 to 5200 ft/s produces an error in measured flow rate less than 0.1 percent in the LE Flowmeter.

After all sources of error are taken into account, the LE Flowmeter still provides liquid velocity measurements down to a guaranteed accuracy of 0.5 percent of the reading or equal to the minimum resolvable flow, whichever is greater.

Applications of the LE Flowmeter

The LE Flowmeter can measure the volume rate of flow in pipelines and penstocks, canals, and rivers. By using a short acoustic path, the LE Flowmeter can make essentially point velocity measurements. Bidirectional flow can be measured with only minor increase in system complexity. Moreover, it is possible for continuous data to be automatically displayed, recorded, and telemetered in digital or analog form.

Flow in Pipelines—Measurements of volume rates of flow in pipelines divides into two cases: fully developed flow (uniform) and distorted flow. Where fully developed flow exists (normally 20 to 50 diameters downstream from a bend, junction, or other disturbance), the LE Flowmeter can be applied in its simplest form. A single acoustic path is directed across the pipe at an angle to the pipe centerline ranging from 20 to 60 degrees, depending on the specific situation.

For fully developed flow, velocity profiles within the pipe are symmetrical about the axis, and in circular pipes they are identical in all planes including the axis; they are also stationary in time. Thus, for a given profile, the average velocity throughout the cross section area is related to the average velocity across a diameter by a constant. That is, $V_{area} = KV_{dia}$. When flow profile data are not available, K may be calculated from the expression

$$K = V_{area}/V_{dia} = 2/(2+f^{1/2}), \qquad (5)$$

where f is the friction factor.

To measure volume rate of flow, Q, it is merely necessary to employ a single acoustic path and implement the relationship $Q = KAV_{dia}$ in the digital processor. In that relationship, A is the cross section area of the pipe. This is depicted in Fig. 2a where typical velocity profiles are shown. Since both K and A are constants, volume rate of flow is computed from the average acoustic path velocity measurement by no more than a change in scale factor. An accuracy of ± 1 percent is achieved for flow rates greater than the minimum resolvable flow.

For distorted flow, textbook flow factors applied to a single-acoustic-path velocity measurement can be inadequate. Three cases of distorted flow are of interest. They are: (1) the flow profile is distorted, stationary in time, and has been measured; (2) the flow profile is distorted and changing in time; (3) and the flow profile is distorted and of unknown shape.

The first case is the simplest to evaluate. Graphical integration of the measured profile permits evaluation of the constant $K = V_{area}/V_{dia}$, thereby allowing calculation of the volume rate of flow with a single-acoustic-path velocity measurement. When the data is uncertain or when minor fluctuations occur over the range of operating conditions, accuracy can be improved by installing additional acoustic paths. In practice, however, that case rarely occurs and multiple diametral paths are seldom recommended.

The last two cases are the most commonly encountered, and have been almost impossible to evaluate outside of a laboratory in the past. However, they also submit to the ability of the LE Flowmeter to accurately measure volume rate of flow. Four acoustic paths are used, but instead of their lying in diametral planes of the pipe, they lie in chordal planes that are parallel to one another (Fig. 2b). Measurements along the paths are scaled as functions of the path lengths and special coefficients and then added to produce an accurate volume rate of flow measurement.

The special coefficients and the locations of the four paths are the same for all applications. They were developed from the method used by Gauss[1] for performing an integration having only four values of the function specified.

The chordal orientation of acoustic paths is so effective that a measurement accuracy of ± 1 percent of reading is guaranteed down to the limit of minimum resolvable flow.

Flow in Open Channels—Measurement of flow in open channels such as canals, aqueducts, and rivers is accomplished by applying the LE Flowmeter in fundamentally the same manner as in pipelines. The LE Flowmeter offers an attractive, and in many ways the only practical, method of doing the job.

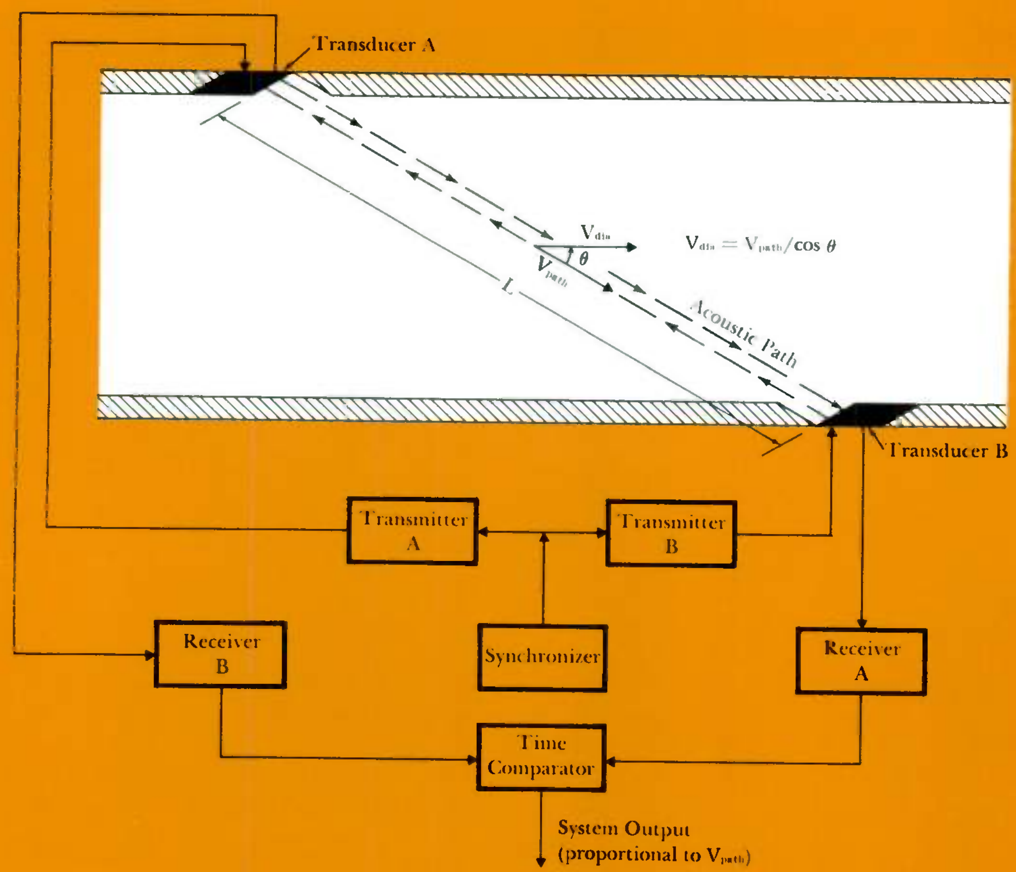
Conventional stream gauging requires taking many velocity measurements across the open channel. At present, the method

[1]Leon Lapidus, "Gaussian Quadrature with Unequally Spaced Data," Sect. 2.11, *Digital Computation for Chemical Engineers* (New York: McGraw-Hill Book Co., Inc., 1962).

1—Typical LE Flowmeter arrangement shows the operating principle used to measure acoustic-path velocity. Pulses moving in the direction of liquid flow travel between the transducers in less time than do pulses moving in the opposite direction. The difference in transit times is used to compute actual liquid velocity.

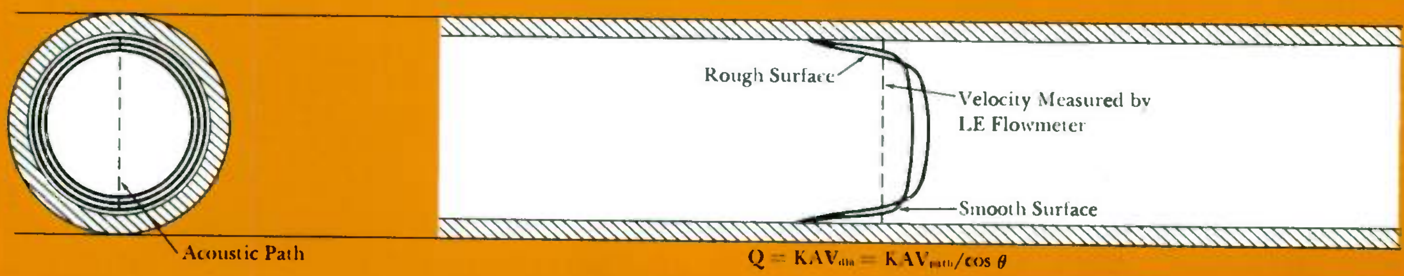
2—Velocity profiles for the metering sections of fully developed flow and distorted flow. For fully developed flow (*a*), the velocity profiles are symmetrical, identical in all planes, and constant so only one acoustic path is needed to measure flow velocity. For distorted flow (*b*), the velocity profiles are uncertain because of minor fluctuations; therefore, four acoustic paths, with chordal orientation, are needed to measure flow velocity accurately.

1



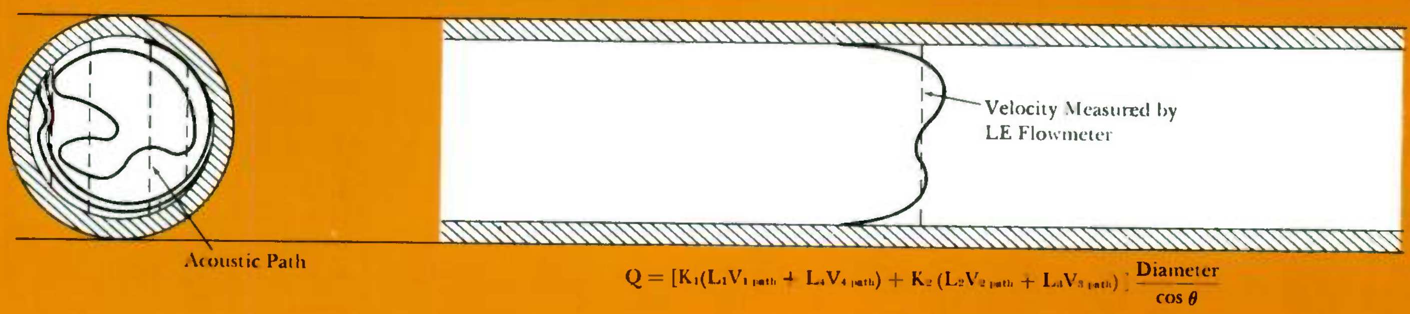
Transducer A
V_{dia}
θ
V_{path}
L
$V_{dia} = V_{path}/\cos\theta$
Acoustic Path
Transducer B
Transmitter A
Transmitter B
Receiver B
Synchronizer
Receiver A
Time Comparator
System Output (proportional to V_{path})

2a



Acoustic Path
Rough Surface
Velocity Measured by LE Flowmeter
Smooth Surface
$Q = KAV_{dia} = KAV_{path}/\cos\theta$

b



Acoustic Path
Velocity Measured by LE Flowmeter
$Q = [K_1(L_1V_{1\,path} + L_4V_{4\,path}) + K_2(L_2V_{2\,path} + L_3V_{3\,path})]\,\frac{\text{Diameter}}{\cos\theta}$

most commonly used in the United States is to divide the cross sectional area of the channel into 20 increments of equal width. Two velocity measurements are taken in each area, one at 0.2 depth and the other at 0.8 depth. Volume rate of flow is calculated by multiplying the average of the two velocities of each increment by the area of the increment and then adding all of these products. That method is time-consuming and cumbersome since it requires manual placement of the velocimeters during a traverse of the channel, a formidable task in a raging river.

When an LE Flowmeter is used, an acoustic path is directed at an angle across the channel (as in pipelines). The transducers are placed in the wall of the channel or near the shore, thereby allowing traffic to continue unimpeded, a highly desirable feature at many locations. Another advantage is the presentation of flow rate data on a continuous basis, even during periods of ice formation. Elimination of manual gauging through the use of the LE Flowmeter results in economy over a period of years.

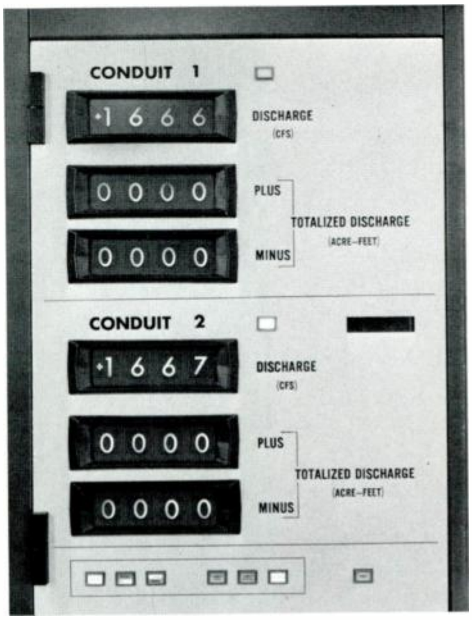
The simplest application of the LE Flowmeter for open channel flow measurement is that for which the flow profile has been measured and the water level is constant. A number of acoustic paths may be used, depending on the accuracy required. Experience thus far suggests that the position of the single path that produces the most accurate measure of volume rate of flow is at 0.6 depth. Single-path measurement is particularly suited to those cases where only an average velocity rather than volume rate of flow is desired or when detection of changes in flow rate rather than exact magnitude of change is needed. By empirically scaling the measurements of the one or more acoustic paths, an output proportional to the flow rate is provided.

If the water level in the channel is variable, the outputs from one or more acoustic paths are combined as before except that the scaling is made a function of water level (which must be measured and fed into the system).

Other Applications—Specialized applications for LE Flowmeter principles include flow measurement of liquid metals, metal slurries, petroleum products, and cryogenic fluids. Measurement of ship's speed and ocean currents are other promising areas.

The LE Flowmeter is an attractive device for measuring ship's speed because of its accuracy and inherent calibration. The equipment is basically the same as for other applications except that the transducers must be mounted in probes extending into the water through the ship's hull. Three probes, providing two acoustic paths, are used when the measurement of speed must not be affected by sideslip of the ship. Two probes with one acoustic path are used for general applications.

When using the LE Flowmeter as a current meter, three co-planar acoustic paths forming an equilateral triangle are used to provide measurement of both magnitude and direction of the current in their plane. Path lengths are only two or three feet, thereby providing a localized measurement.



Electronic control and display panel of a typical LE Flowmeter. Digital displays show volume rate of flow (discharge) and total discharge. The control and display panel can be tailored to suit particular applications.

Economic Advantages

Choice of the LE Flowmeter over other flow measuring devices for a given application is influenced by the costs involved as well as the technical advantages offered. Costs include not only that of equipment but also the costs of installation, maintenance, and calibration. The following economic examples are for measuring volume rate of flow in pipelines, where the cost factors are most important.

The initial cost of an LE Flowmeter is independent of pipe size, whereas the cost of a venturi system varies approximately in proportion to the pipe diameter. The point of equal cost depends mainly on the venturi mechanical requirements, that is, material used and required structural properties. Typically, a venturi used to measure the flow velocity of a liquid in a 10-foot conduit would cost about twice as much as an LE Flowmeter used for the same purpose.

System cost also varies as a function of the number of metering locations. LE Flowmeter cost is nearly constant, increasing slightly with the addition of cables and transducers. Venturi cost increases in proportion to the number of meters installed.

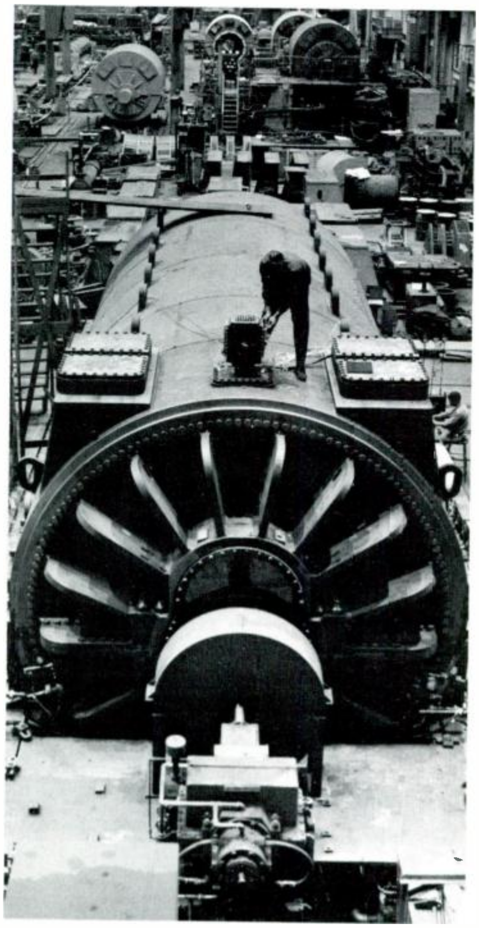
When more than one LE Flowmeter is required, unit cost is reduced. The reduction is similar to that for other electronic equipment and results from price discounts that normally result when materials are purchased in large quantities and from decreasing unit-labor cost as production volume increases.

Other cost factors, more difficult to treat in general terms, almost always favor the LE Flowmeter. For example, the LE Flowmeter produces no head loss in pipelines and thereby provides an indirect cost saving; in some water distribution systems, a reduction in head loss by one foot reduces construction costs by $1,000,000. Where volume rate of flow varies more than ten to one, venturi systems may require parallel piping and multiple venturis; the unlimited dynamic range of the LE Flowmeter permits elimination of parallel piping, further reducing construction costs.

Largest Generator Shipped

The most powerful electric generator ever built was shipped recently for installation at the Indian Point II nuclear power plant of Consolidated Edison Company, Buchanan, New York. The generator is rated at 1,013,040 kW—enough to meet the residential electric needs of 3,000,000 people when it goes into operation next year. Its rotor alone is 67 inches in diameter, weighs 365,000 pounds, and will spin at 1800 r/min. The entire generator is 47 feet long and weighs 1,560,000 pounds.

The generator was shipped disassembled by railroad from the Westinghouse East Pittsburgh plant to Jersey City, New Jersey. There the components were loaded onto barges for the trip up the Hudson River to an unloading point about a mile from the plant site, from which special trucks carried the components to the site.



Electric generator rated at a record 1,013,040 kW undergoes tests on the manufacturing floor before being shipped to Indian Point II nuclear power plant.

Optimized Integrated Process Control Saves Space and Installation Costs

A new integrated process control concept centralizes mill control equipment into an optimized system, saving space and installation costs. The concept is applicable to almost any rolling mill and to the larger process lines.

Mill control functions (such as automatic gauge control, drive-position regulation, automatic crop-shear control, and strip-in-stand detection control) previously required as many as 18 separate cabinets and large quantities of interconnection wiring. The new concept groups the functions in a single controller that combines digital computer logic controls, data links, and interconnection wiring into compact, factory-constructed units using space-saving components such as integrated circuits. The compact controller packages fit into the rear of the operator's control pulpit, which also houses all input/output wiring and the main control console. The concept was worked out and is being applied by engineers at the Westinghouse Industrial Systems Division

In addition to providing factory-wired highly reliable equipment in compact packages, the optimized integrated process control concept greatly reduces conduit runs and connections and also eliminates multiple trays of control cable. Other benefits include faster installation and checkout, easier maintenance and troubleshooting, and better regulation of control environment. The concept is flexible and facilitates field changes.

A recent analysis for a large hot-rolling mill installation showed that the optimized integrated process control concept combined with centralized equipment designs could achieve approximately 30 percent fewer control cables, 70 percent reduction in control cable length, 32 percent fewer control connections, 50 percent reduction in control conduit runs, and 80 percent fewer control cable trays. Those benefits could save the customer an estimated $1,500,000.

Transistors Produced on Flexible Inexpensive Substrates

Thin-film transistors traditionally have been fabricated on highly polished brittle insulator substrates such as glass, sapphire, alumina, and quartz. Substitution of flexible and comparatively rough-surfaced substrates has several potential advantages, so experimental transistors are fabricated on a wide variety of unconventional bases at the Westinghouse Research Laboratories. The bases used include Mylar tapes, cellulose acetate film, polyimides, anodized metal foils, and even rough-textured paper. (See photograph on back cover.)

The transistors have stable operating characteristics, and some have operated at frequencies up to 60 MHz. Essentially, they can be used for any application not calling for high power, very high frequency, or high temperature.

The potential advantages include substantial reduction of transistor cost. The devices could then be used for many applications where cost is now prohibitive, such as toys, novelties, hobby kits, teaching aids, and other expendable items. Use of flexible substrates should reduce costs because the substrates themselves are inexpensive and because of the possibility of mass production of transistors in continuous strips; a roll of substrate material could be put into a vacuum chamber and wound through the "printer" one frame at a time, and the vacuum would have to be repumped only after changing rolls. At present, more than 600 of the new devices can be deposited per frame on an area of about one square inch.

Moreover, since thin-film passive components such as capacitors, resistors, and interconnections are readily prepared by the same techniques, the development may permit fabrication of circuit arrays (on a continuous substrate tape) that could then be tested and encapsulated. The entire process could be automated; it would be fast and have high potential yield since manual operations would be completely eliminated, atmospheric contaminations avoided, and the number of successive process steps made quite small (8 to 12 depositions).

To print the transistors, their component materials are simply evaporated one after another through metal masks in a vacuum chamber and deposited in layers on the insulator substrate. The layers are only as thick as necessary to function, typically a few millionths of an inch, so the transistors can be flexed repeatedly without damage.

The new transistors are possible because the "roughness" of the substrates, although disturbingly visible under a light microscope, does not really matter on the atomic scale; the very thin films see the roughness as gentle undulations rather than sharp and disruptive peaks. (However, for some configurations it is helpful to deposit first an evaporated dielectric layer, which tends to smooth out the small-scale imperfections that are the most troublesome.)

Short-Circuit Studies for Industrial Power Systems

Technological advances in industry in the past few years have resulted in installation of ever-larger motors: motors rated at five to ten percent of total supply-system capability have become common. The current contributed to three-phase or line-to-line faults by such large motors cannot be assumed to be negligible, as it often is with smaller motors.

The current contribution becomes especially critical when very large motors are added as new equipment to an existing system, because then short-circuit requirements on existing breakers may be increased considerably. Moreover, although industrial distribution systems often provide alternate schemes for delivering power to loads, the protective devices are often difficult to apply and set without knowledge of the fault currents and voltages to be expected under many different conditions.

Short-circuit studies, then, are not only desirable but necessary in operating and planning industrial electric power systems. To provide a fast, accurate, and economical study method, the Westinghouse Electric Utility Headquarters Department has devised a digital short-circuit computer program. The program calculates symmetrical values of line current and bus voltage for three-phase and single-line-to-ground faults. It employs mesh analysis techniques, the fastest developed to date.

Provision is made for calculating faults following the removal of lines due to breaker operation or scheduled line outages. Printed output from the short-circuit program includes positive-sequence symmetrical values of fault current and voltage for three-phase faults, and zero-sequence symmetrical values of fault current and voltage for single-line-to-ground faults. Several output options are available, but, in general, the current in any or all system lines and the voltage at any or all system buses can be printed for all faults considered.

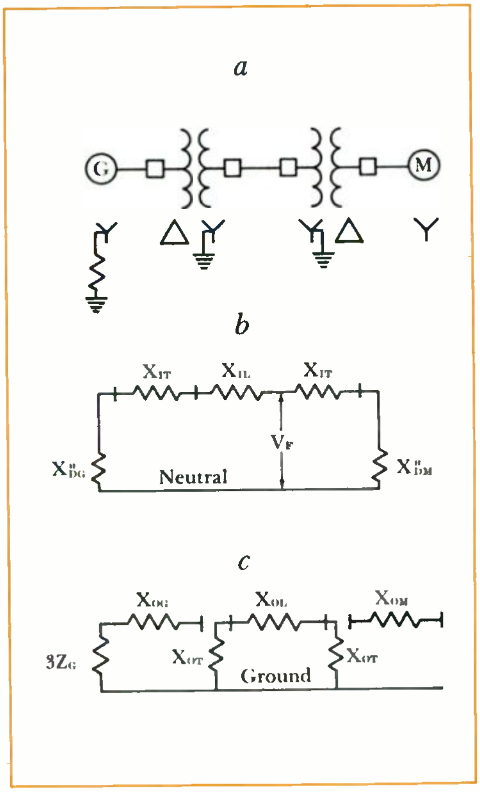


Diagram of a simple electrical system (*a*) illustrates the kind of data needed for a digital short-circuit study. The positive-sequence network (*b*) is used for a three-phase fault study; zero-sequence network (*c*) is used for studying single-line-to-ground faults.

Where the intent is to determine the maximum fault duty on a circuit breaker, an auxiliary program (the breaker duty program) is available to edit data from the short-circuit study. That program calculates the maximum fault current through an imaginary breaker in each line connected to each faulted bus. The printed output is in a form convenient for comparison with published breaker ratings.

The kind of data necessary for a short-circuit study is indicated in the diagram. For a three-phase fault study, only the positive-sequence network is considered. The change in current due to a fault can be determined (through application of the compensation theorem) by applying a voltage (V_f) between the fault point and neutral, with all other applied voltages equated to zero. V_f is the voltage at the point of fault before the fault occurs. As the diagram shows, the network is completely described by the positive-sequence impedances of the machines, transformers, lines, and the connections between them. Those quantities are handled by the computer in per unit or percent on some common base.

For computing momentary duty currents, synchronous motors and generators are represented by their subtransient reactances, and induction motors are represented by an impedance representing their backfeeds to the system under faulted conditions. For computing interrupting duty currents, generators are represented by their subtransient reactances, synchronous motors are represented by their transient reactances, and induction motors are neglected.

For systems grounded in such a way that the flow of ground or zero-sequence fault current is significant, a single-line-to-ground fault study may be desirable. Like the positive-sequence network, the zero-sequence network is described by its impedances and connections, although isolated impedances (such as the motor's zero-sequence impedance in this case) are not represented. The positive- and zero-sequence networks are connected in such a way that the resulting network can be solved (by applying the theory of symmetrical components) for the zero-sequence currents and voltages resulting from a single-line-to-ground fault at a particular location. The driving point impedance as well as the X/R ratio at the fault is also computed, and those values along with similar values from the three-phase fault study are used to anticipate transient overvoltage problems during ground faults.

600-MW Generators To Be Built for Grand Coulee Dam

The three waterwheel generators recently ordered for the U.S. Bureau of Reclamation's third power plant at Grand Coulee Dam on the Columbia River in Washington will be rated at 600 MW each. That rating makes them the world's largest, exceeding by 100 MW each the capacity of the present largest waterwheel generators—those at Krasnoyarsk Dam in the Soviet Union. The contract went to Westinghouse on the firm's offer to manufacture, install, and test three generators with an efficiency rating of 98.37 percent.

Besides being largest in generating capacity, the units will dwarf other waterwheel generators in physical dimensions as well. The biggest generators the United States now has are those at the existing Grand Coulee power plants. Their rotors are about 31 feet in diameter and weigh 566 tons each, but the rotors for the third power plant generators will be 68 feet in diameter and will weigh 2000 tons. They will operate at 72 r/min.

The initial three generating units are to be followed later by three additional units of the same size, which will give the third power plant a generating capacity of 3600 MW. And the forebay is being constructed large enough to supply water for an additional six units (though further Congressional authorization will be required for them.) The eventual 12-unit third power plant then will have a generating capability of 7200 MW. That capability added to the present 2000-MW capacity will bring Grand Coulee's total capacity to 9200 MW, exceeding the capacity of any other power plant in the world.

The initial 600-MW generators are to be completed and operable on the following schedule: first, September 15, 1973; second, March 15, 1974; and third, September 15, 1974.

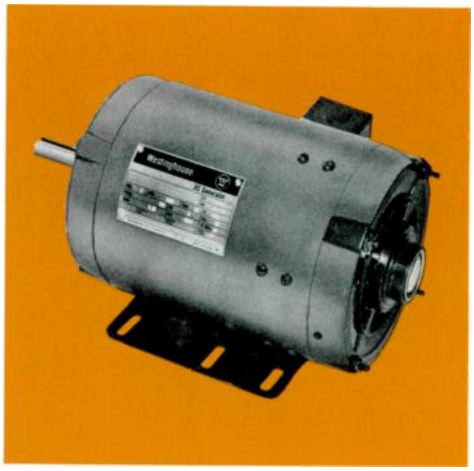
Products for Industry

Ceramalux lamp is a discharge-type lamp similar in principle to the mercury vapor lamp but having sodium sealed in a small ceramic inner arc tube. The sodium greatly increases efficiency: the lamp produces 105 lumens per watt, compared with 52 lumens per watt for an ordinary mercury vapor lamp and 17 for an incandescent household lamp. *Westinghouse Lamp Division, 1 Westinghouse Plaza, Bloomfield, New Jersey 07003.*

Thyristor dc crane hoist drive has power conversion and adjustable-voltage control equipment in one compact unit, reducing size, weight, and installation wiring compared with the m-g set drives in general use. The 600 Line drive is designed for all NEMA, EOCI, and AISE crane service classifications. Other advantages compared with m-g sets include less maintenance, greater reliability, and improved performance because of faster response. A dual converter provides full regenerative four-quadrant control of hoist motor. The drive operates on 230- or 460-volt three-phase ac power. Standard ratings range through 200 hp, but it can also be supplied in larger ratings. *Westinghouse Industrial Systems Division, 4454 Genesee Street, P.O. Box 225, Buffalo, New York 14240.*

Brushless ac generator is mounted in NEMA 56 frame; its small size and essentially maintenance-free construction suit it for remote and mobile applications where conventional ac power is not available. Permanent magnets provide field excitation, eliminating need for a battery. The 220-volt, three-phase, 3600-r/min unit is rated 2 kVA at 60 Hz, and it weighs 40 pounds. Lower ratings can also be supplied. *Westinghouse Small Motor Division, P.O. Box 566, Lima, Ohio 45801.*

Model 617 Cargo Tug is a compact electric vehicle measuring 76 by 32 by 50 inches and producing 750 pounds of drawbar pull. Features include reversing switch, trailer hitch with foot release, two brakes (hand and foot operated), and dual accelerator levers. Series-wound motor, rated 3½ hp at 24 volts and 4½ hp at 36 volts, operates on eight 6-volt 217-ampere-hour heavy-duty batteries. *Westinghouse Electric Vehicles Division, P.O. Box 868, Pittsburgh, Pennsylvania 15230.*



Brushless AC Generator

Model 617 Cargo Tug

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Author Index

(Author biographies appear on the inside back cover of each issue.)

About the Authors

Bruce H. Rule of the California Institute of Technology designed the new 130-foot radio telescope described in this issue, and **Geo. F. Gayer** supervised Westinghouse engineering work on the project.

Rule received his B.S. in Engineering from Caltech in 1932 and his Teaching Credential from U.C.L.A. in 1933. He worked as an electrical engineer in the Light & Power Departments of both Los Angeles and the City of Vernon before joining the staff of Caltech in 1937 as Project Engineer for the Mt. Palomar 200-inch Hale telescope.

During World War II, Rule's work at Caltech included the development of an aerial survey camera for the U.S. Army Air Forces and antisubmarine and rocket work for the National Defense Research Committee.

Rule was the Chief Engineer for the Synchrotron Laboratory at Caltech for a number of years and has been a consultant for most of the large optical telescopes in existence today, including the 120-inch at Lick Observatory, the 84-inch at Kitt Peak, and the two 150-inch telescopes now under construction for A.U.R.A. at Kitt Peak and Cerro Tololo in Chile. He is presently consulting on the proposed 150-inch Canadian and Anglo-Australian telescopes. He has been a member of the N.A.S. Advisory Panel on Astronomical Facilities.

Bruce Rule's interest in radio astronomy began about 1955 with the design and construction of the two 90-foot dishes at Caltech's Owens Valley Radio Observatory. His most recent design is the 130-foot antenna, also located at Caltech's O.V.R.O. site. He has also been a consultant on numerous other large radio telescopes.

Rule has been active in the design of many instruments for use with optical telescopes. He is both a Registered Professional Mechanical Engineer and Electrical Engineer in the state of California. He has been Director of Caltech's Central Engineering Services since 1943 and is the Chief Engineer of the Mount Wilson and Palomar Observatories and the Owens Valley Radio Observatory.

Geo. F. Gayer came with Westinghouse on the graduate student course in 1929 after graduating from Oregon State College (BSME). He also obtained his MS from the same school in 1949. Gayer's first Westinghouse assignment was at the Steam Division in the experimental laboratory. He shortly moved to the Marine Division as a design engineer and later became a section engineer.

Gayer left Westinghouse in 1940 to serve as Chief Test Engineer for a shipbuilding firm in the Seattle-Tacoma area. He rejoined Westinghouse in 1947 as Engineering Manager of the Westinghouse Manufacturing and Repair plant at Sunnyvale.

Gayer was Plant Manager of the M & R plant when it was enlarged to the Sunnyvale Divisions, and he was then made Divisions Engineering Manager. Although Gayer "retired" in early 1968, he continues to serve as a Consulting Engineer for the Missile Launching and Handling Department of the Westinghouse Underseas Division.

W. A. Elmore received his electrical engineering degree from the University of Tennessee in 1949. He is a member of Eta Kappa Nu, Tau Beta Pi, and Phi Kappa Phi honorary societies.

Following two years of substation design work with a utility company, Elmore joined Westinghouse and served 13 years as a District Engineer. He is now a Fellow Engineer in the systems engineering section of the Westinghouse Relay-Instrument Division.

Elmore is a registered professional engineer in the state of New Jersey and a member of the IEEE Power System Relaying Committee.

Frank Carr graduated from the University of Pennsylvania in 1951 with a BS degree in electrical engineering. He joined Westinghouse on the graduate student program and has served since then in the fields of manufacturing, marketing, and computer systems in division and headquarters organizations. He served on the faculty of the Sloan School of Management at Massachusetts Institute of Technology in 1964 as visiting lecturer on operations management and management information systems. The following year, he attended the Advanced Management Program at Harvard Business School.

Carr assumed his present responsibilities as Director, Westinghouse Information Systems Laboratory, in 1967. Before that, he was Director of Systems and Organization Planning.

Robert M. Hruda has been responsible for or has contributed to the development of more than 100 electronic tube devices, including thermoelectric converters; microwave devices; electron guns; X-ray tubes; gas discharge devices; external-anode transmitting tubes; and tubes for industrial r-f generators, dielectric heating and communications, high-power pulse modulation, and high-power communications. He is presently a senior design engineer working with high-power, r-f, and pulse tubes at the Electronic Tube Division.

Hruda graduated from Ohio State University in 1949 with a BSEE degree, and he has since done graduate work at Cornell University and the University of Buffalo. He joined International Telephone and Telegraph Corporation in 1950 and came to the Westinghouse Electronic Tube Division in 1952.

Calvin R. Hastings came to Westinghouse after graduating from the University of Maryland in 1958 with a BSME degree. After several assignments on the graduate student program, followed by a semester of graduate study in the Westinghouse Advanced Design School and a short tour of duty with the U.S. Air Force, Hastings joined the Westinghouse Air Arm Division. There he helped design sonar transducers and electromechanical devices and performed aerodynamic studies on rockets.

In 1961, Hastings transferred to the Ordnance Division (now the Underseas Division, Westinghouse Defense and Space Center), where he has held supervisory positions in development programs in hydrodynamic design, propulsion, and control of submarines, towed vehicles, and deep-submergence search vehicles. He also received an MSME degree from the University of Maryland during this time.

Early this year, he was made program manager at the Ocean Research and Engineering Center of the Underseas Division with complete product line responsibility (from design through final installation) for the Leading Edge Flowmeter, the subject of his article in this issue. Hastings is now attending the Center for Advanced Engineering Study at the Massachusetts Institute of Technology as the first Westinghouse employe to be sponsored for the Practicing Engineer Advanced Study Program.

The strip being unrolled contains batches of transistors deposited in successive frames as the strip was reeled through the magazine. Such transistors have been deposited on a variety of flexible substrates, including plastic tapes, metal foils, and paper. The experimental technique raises the possibility of reducing transistor cost to the extent that they could be used in applications where cost is now prohibitive. For more information, see page 187.