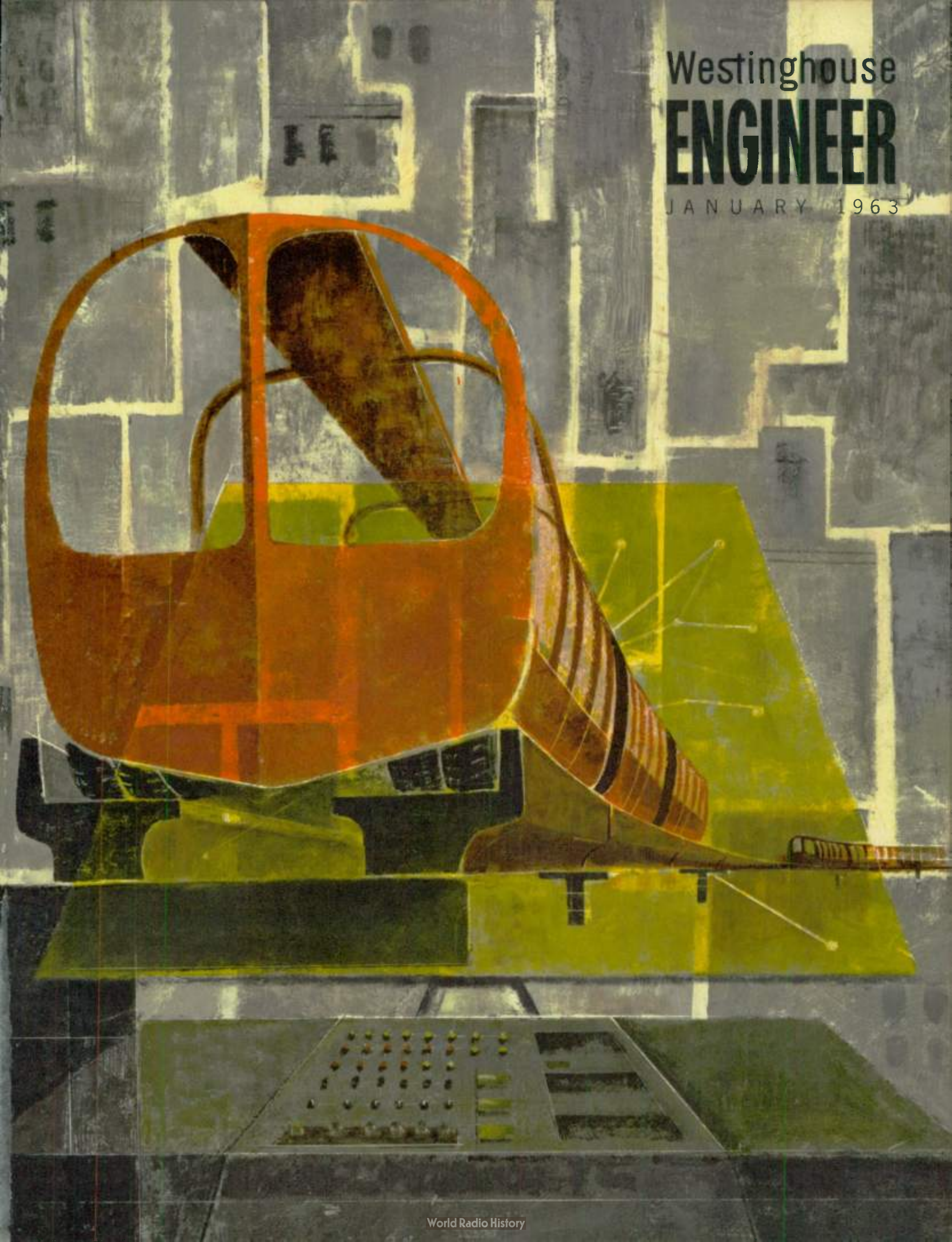
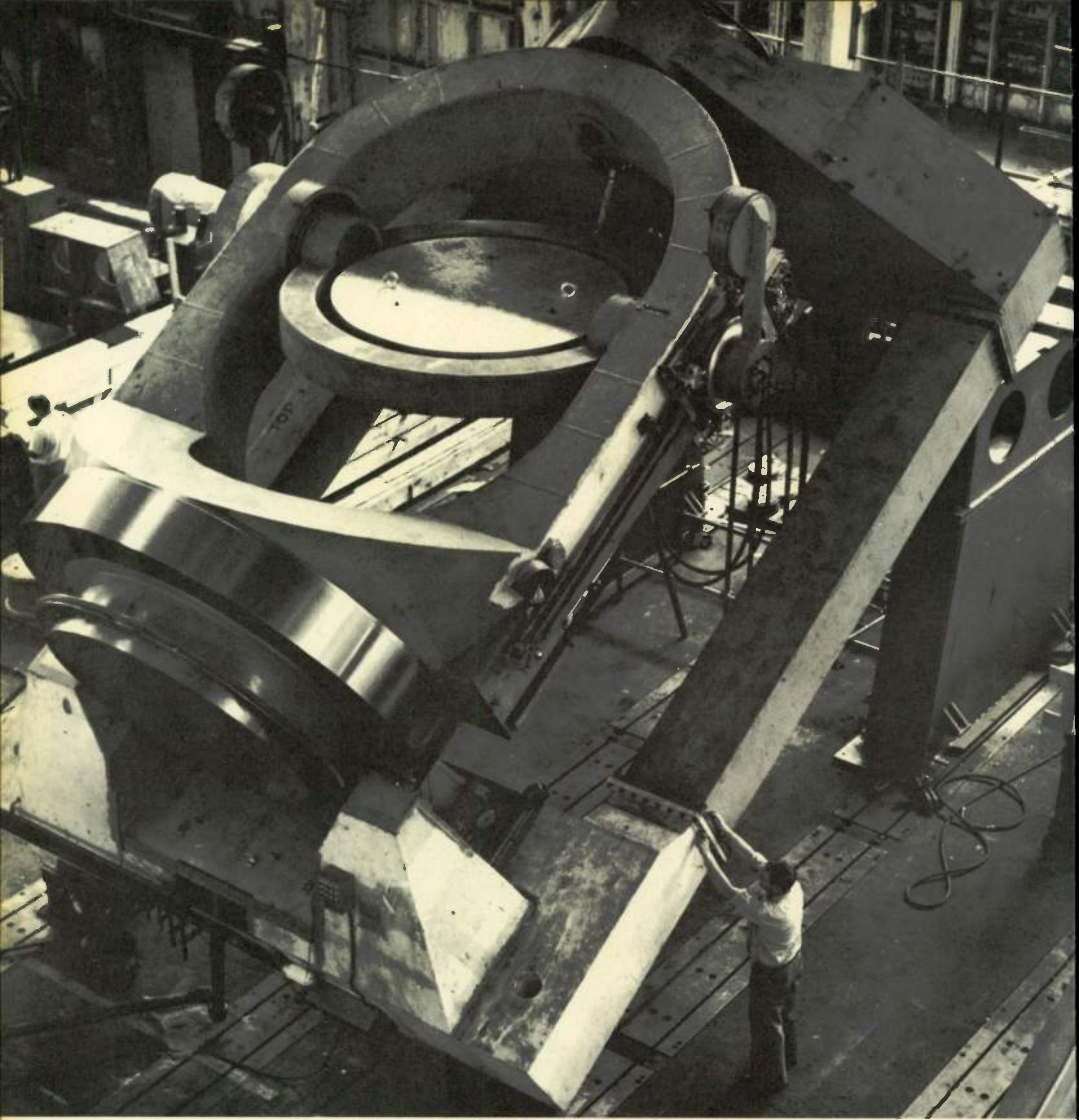
Westinghouse
ENGINEER
JANUARY 1963

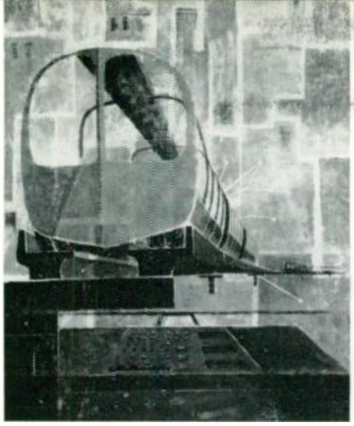




Mount for the Largest Solar Telescope

This 50-ton instrument, called a heliostat, is for the world's largest solar telescope at Kitt Peak National Observatory in Arizona. In this photograph a concrete disc simulates the 80-inch diameter reflecting mirror. The completed telescope will be capable of photographing 500-mile areas on the sun 93 million miles away.

Westinghouse
ENGINEER
JANUARY 1963



VOLUME 23 • NUMBER 1

Cover Design: A new concept in rapid transit is the subject of this month's cover. The basic 20-passenger carrier operated in multiple-unit trains, a trespass-free overhead roadway, and computer-supervised system operation are the key ingredients used by cover designer Gene Gogerty of Ad-Art Studios, Pittsburgh.

The following terms, which appear in this issue, are trademarks of the Westinghouse Electric Corporation and its subsidiaries:

Fosterite, Pulsetter, Pulstac, Trinistor, Westing-Arc

Published bimonthly by the Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.

Subscriptions: United States and Possessions, $2.50 per year; all other countries, $3.00 per year; single copies, 50¢ each.

Mailing address: Westinghouse ENGINEER, P. O. Box 2278, 3 Gateway Center, Pittsburgh 30, Pennsylvania.

Microfilm: Reproductions of the magazine by years are available on positive microfilm from University Microfilms, 313 N. First Street, Ann Arbor, Michigan.

Printed in the United States by The Lakeside Press, Chicago, Illinois.

The Transit Expressway

A rapid transit system that provides 24-hour service at two-minute intervals requires some new concepts in system design.

Charles Kerr, Jr.
Industrial Systems
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

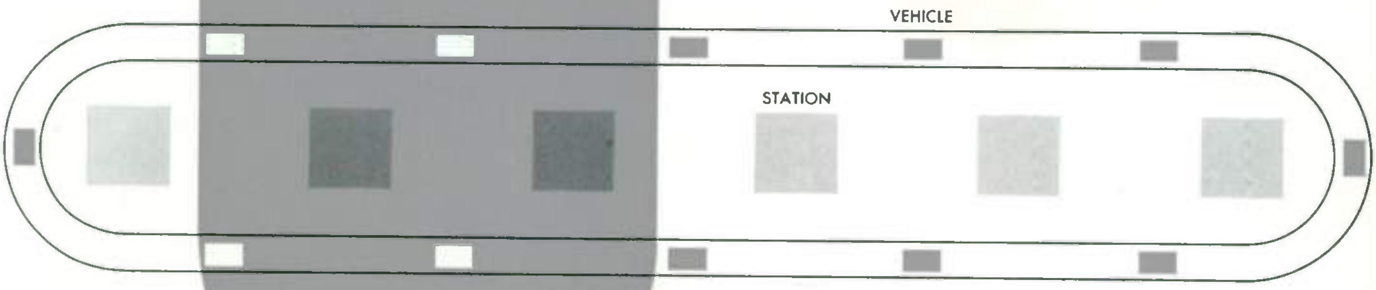


Fig. 1 Individual passenger carriers moving at close intervals become a reasonable approximation of the ideal endless belt.

A new kind of rapid transit system is needed in many metropolitan areas in the United States of medium population density, where use of the private automobile is high. The fundamental problem in these cities is not that of handling the masses with which New York City and Chicago are faced, but rather of attracting riders so that the transit system can successfully relieve traffic congestion, and can be made financially self-supporting. The problem is one of the most difficult that city planners have faced. To solve these problems, the operating philosophy of other utilities—electric, gas, or communication—can be studied to good advantage for they also have the problem of large investment cost and high peak-hour demands.

A Systems Approach

In developing the *Transit Expressway* system, Westinghouse transportation engineers therefore have applied the "systems approach" in the same way that other basic utilities have done in fulfilling their service to a community. The Transit Expressway concept recognizes that rapid transit service is a complex made up of many factors. For example, the primary objective of low initial investment and low operating cost must be balanced against considerations of safety and appearance. Therefore, such a systems approach to rapid transit must weigh and integrate at least three principal factors:

1) Compelling appeal to commuters
2) Low initial investment
3) Low operating cost

What Kind of Service is Required?

Before selecting any particular arrangement of vehicles and structures, it is first necessary to determine what kind of service is required from a transit system to guarantee rider patronage; the other two principal factors, low initial investment and low operating costs, must be obtained by optimizing the vehicle-structure interrelationship.

The public utilities with excellent service records have established two mandatory service standards: Service is *instantly available* at all times; and service is of *uniform quality* at all times. These standards could be easily attained in the public transportation field if high-speed endless belts for carrying people could be built and operated; such a system is theoretically capable of providing instant transport (no waiting), uniformly good service, and adequate capacity with low operating expense. Unfortunately, no way is known to load and unload people from high-speed belts. The next best approach to the endless belt is the system shown in Fig. 1, where individual passenger carriers move at high speeds along a route with a *minimum time interval* between successive vehicles. Stations are strategically located for boarding or leaving the carriers, which stop at each station. If the carriers move reasonably fast and have adequate capacity to handle the maximum passenger load that the system will generate, the system becomes a reasonable approximation of the endless belt.

Stations in a rapid transit system are usually spaced at intervals of one mile or less; on such a system, operating speeds in excess of 50 miles per hour by vehicles that must stop and start frequently would serve no useful purpose. Rapid acceleration and braking are far more important. At these speeds, passenger carriers can follow each other at a minimum time interval of 90 to 120 seconds, a limitation imposed by fundamental safety considerations. However, even with this interval, the average wait for a car is only 45 to 60 seconds. Therefore, to satisfy the funda-

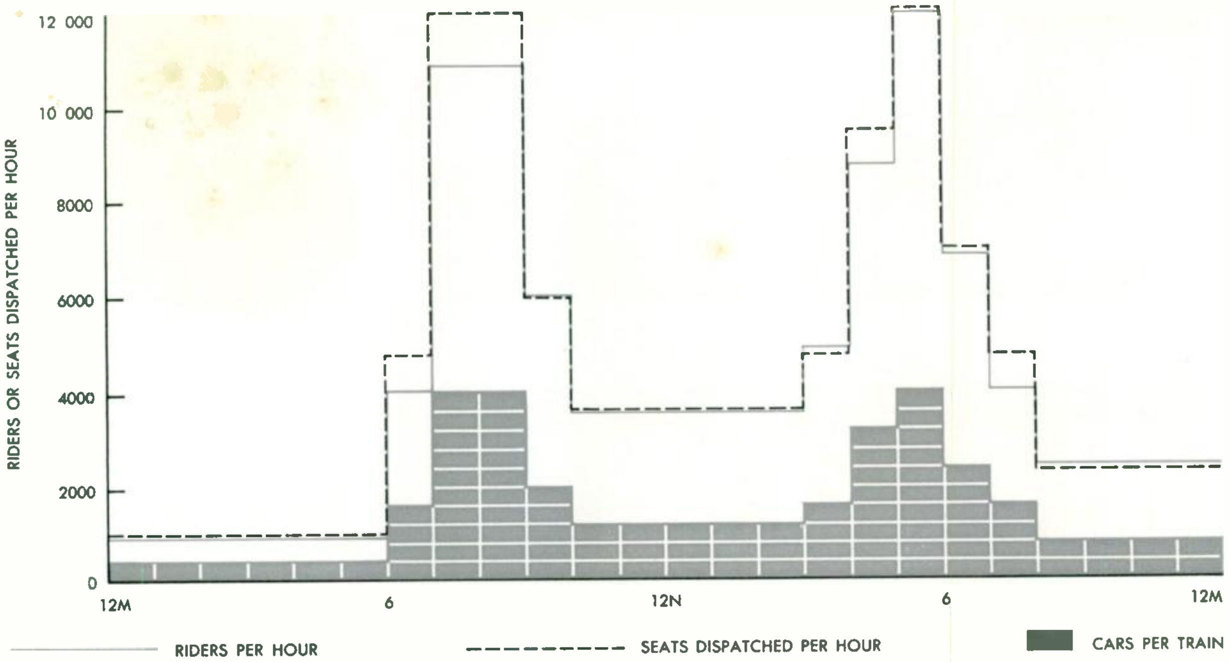


Fig. 2 A typical passenger-loading chart for a medium-sized metropolitan area indicates the expansion and contraction in train capacity required to accommodate commuter demand.

mental requirement of instant availability, designers of the Transit Expressway established this basic operating principle: The average waiting time should not exceed one minute, *at any time of day or night.* This 24-hour "instant service" requires a new look at system design and construction to make it economically feasible.

The selection of the basic passenger vehicle in the rapid transit system is a critical decision because the vehicle influences practically every other component of the system. In the past, rapid transit systems have been composed of large passenger vehicles selected to best accommodate peak-hour traffic. Service was curtailed during minimum traffic periods. However, if uniform service standards are to be maintained *at all times,* the key to economic operation lies in selecting a basic passenger vehicle capacity suited to *minimum* traffic requirements. This basic passenger carrier unit is then operated in multiple units to obtain adequate capacity for higher loadings.

Traffic studies from a number of metropolitan areas provided information on expected weekday distribution of transit riders. One typical chart of passenger loading is shown in Fig. 2, and points out two fundamental facts:

1) The capacity of carrier trains must expand and contract over a considerable range—in this case, 10- to 12-to-1—to economically accommodate commuter demand.

2) Over 50 percent of the system's potential revenue will be derived from patronage during off-peak hours; therefore, off-peak operation must be made profitable if the system is to be financially self-supporting.

The Transit Expressway System

Based on traffic in medium-density cities, designers of the Transit Expressway system selected a 20-passenger carrier as the ideal compromise for accommodating both minimum and maximum traffic requirements. Trains of one to ten or more units are formed as traffic conditions demand. By accurate matching of capacity to demand, every car dispatched is economically loaded, and at the same time, good uniform service is provided. Operating on a two-minute fixed headway, this 20-passenger multiple-carrier system can accommodate traffic ranging from 5000 to 14 000 riders per hour in either direction.

The Transit-Expressway Car—The basic 20-passenger carrier is presently designed as a rubber-tired vehicle powered by its own propulsion system and capable of operation in trains of one to ten or more units. The car is guided by horizontal guide wheels that ride against curbs provided on a special concrete roadway. A 12-foot wheel base permits the use of rigid axles without excessive tire wear for all curves anticipated in a system of this kind.

Dual tires will be used on each wheel to provide protection against "flats," allow lower tire pressures and thereby improve the ride, and permit the use of high production, low cost tires.

The vehicle is approximately 23 feet long, 8 feet wide, and 9 feet high, and weighs about 8600 pounds. Designed to utilize high-production, low-cost components, these cars will provide a smooth, quiet, fast ride. With this small car size and normally all passengers seated, entrance and exit at stations should be relatively jostle free.

Structures—Since structures represent the largest part of the initial cost of a rapid transit system, a major economic advantage of the Transit Expressway system is the reduced roadway structure costs made possible by the small, lightweight carrier.

Since costs are minimized when the structures are above

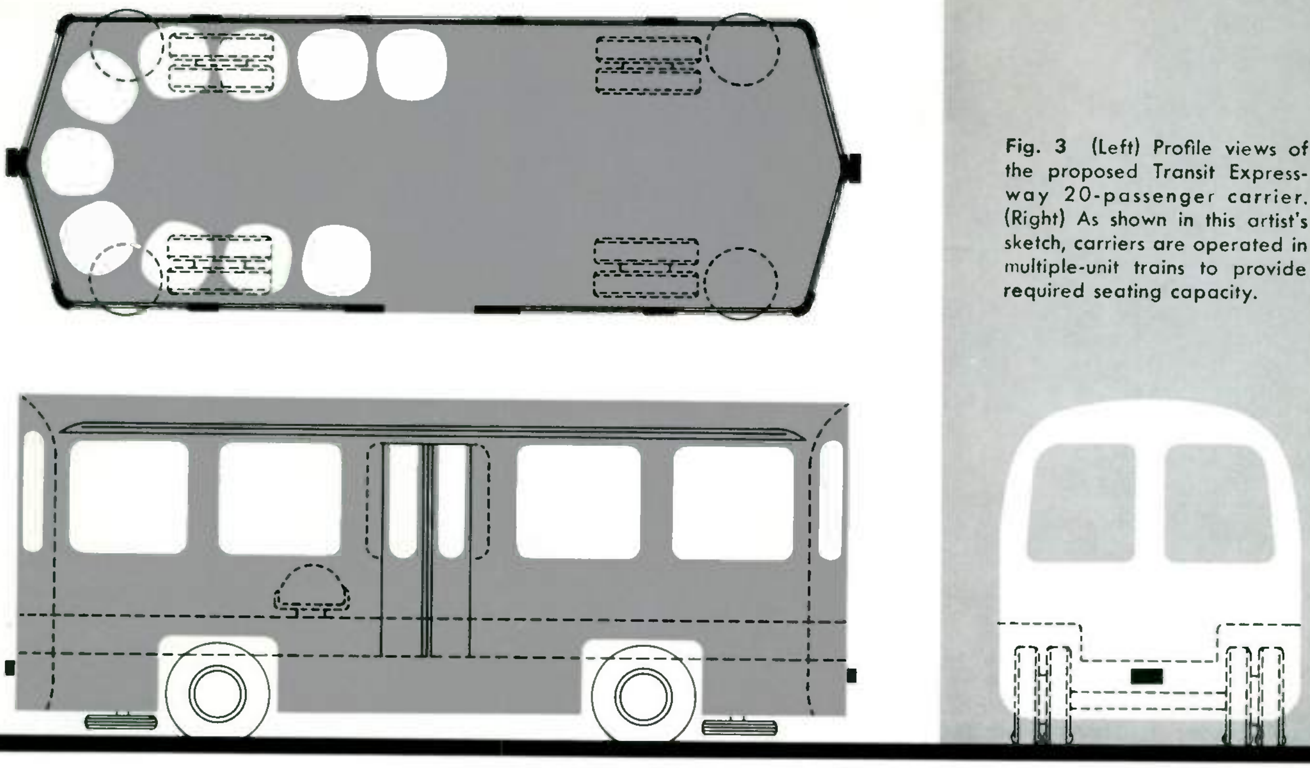


Fig. 3 (Left) Profile views of the proposed Transit Expressway 20-passenger carrier. (Right) As shown in this artist's sketch, carriers are operated in multiple-unit trains to provide required seating capacity.

ground and the small vehicle permits a lightweight structure that lends itself readily to artistic treatment, a trespass-free overhead roadway is the logical optimum of economics and appearance.

The suggested roadway structures are a building-block assembly of prefabricated, precast concrete parts designed to minimize field erection expense. The roadway for each lane consists of two precast, prestressed concrete beams, supported by concrete piers at 44-foot intervals. The roadway beams have a special cross-section profile that provides a smooth running surface for the cars, and a curb that guides the vehicle. This curb structure also acts as an added safety precaution, shields tire noise from the street, and improves structure appearance by hiding the trolley system and underside of vehicle.

The piers are built up from precast concrete sections held together by tension rods on footings. All parts can be prefabricated and put into place with a minimum of field labor. Pier height can be adjusted to accommodate terrain requirements by varying the number of sections.

This type of roadway construction is suitable for two lanes on single piers, or one lane per pier. Hence, the roadway can go down the center of streets, over sidewalks, on abandoned rail right-of-way, or on private right-of-way. The roadway can be altered to suit almost any local condition. If local conditions demand, the roadway can be carried underground.

Stations—With two-minute intervals between trains, elaborate waiting stations would serve no useful purpose. All that is needed is a 200-foot platform with some form of protective roof structure. This type of station is attractively designed, requires a minimum of space, and simplifies policing and maintenance. Adequate parking facilities will be provided at outlying stations.

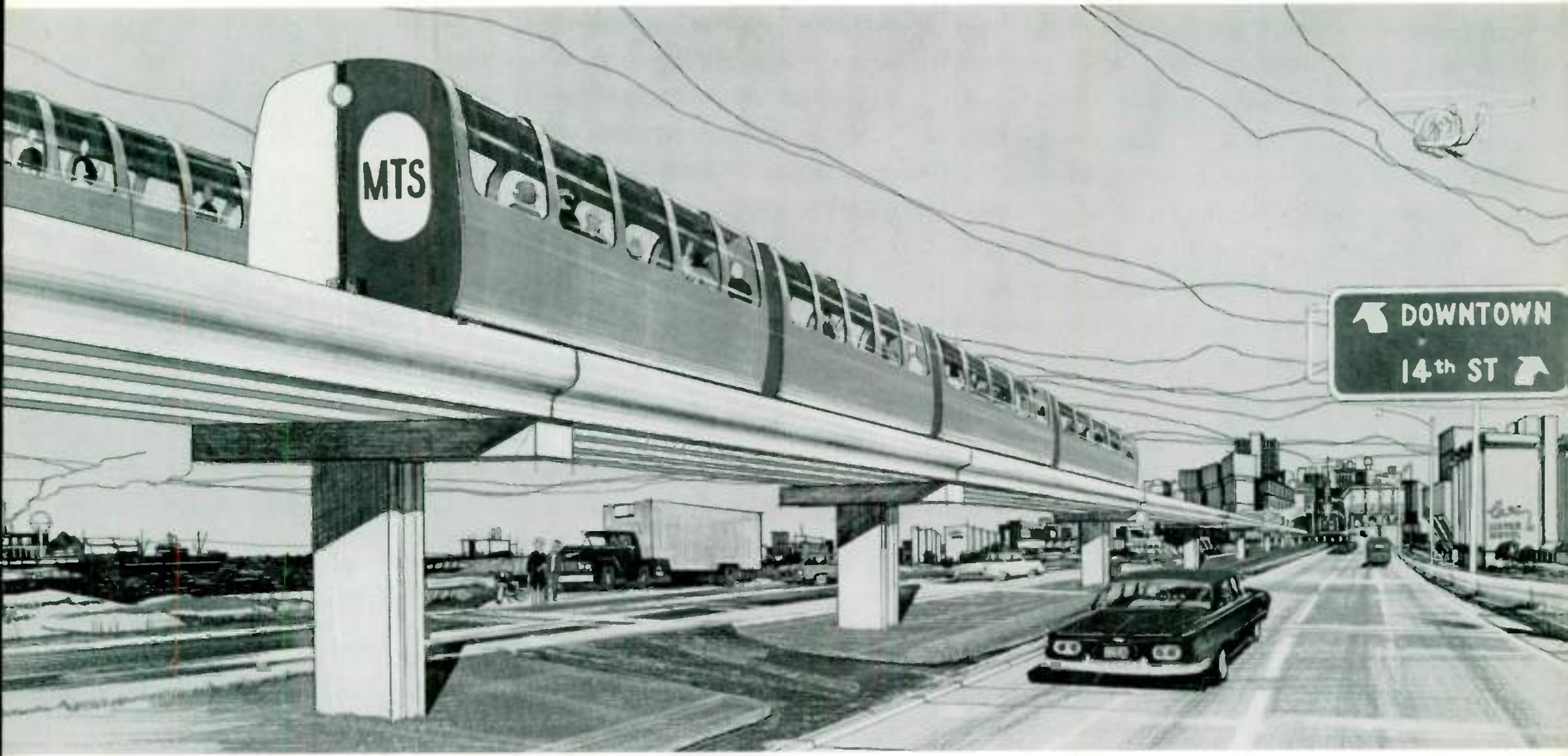
Power System

The propulsion system for each car can either be a dc drive or an ac induction motor operating through a torque converter. If an ac propulsion system is chosen for the Transit Expressway system, commercial 60-cycle, 3-phase power could be used without conversion equipment. Most of the problems previously encountered with three-phase trolley systems for railroad application came from the difficulty of switching. Since the Transit Expressway system uses continuous loops with no turnouts, the problem is eliminated.

A 550-volt, 3-phase, 60-cycle trolley system is carried between the roadway strips. A three-phase current collector located under the car floor brings power to the car. With a 550-volt system, standard industrial electric drive equipment could be used. A transformer mounted on each coach provides 110 volts for heating, lighting, and air conditioning. A battery is also carried in each car for emergency lights and control circuits.

The trolley system is fed from transformer substations located at suitable intervals along the roadway. The spacing and capacity of these stations will depend upon the traffic demands of the system, such as frequency of trains, size of trains, grades, etc. In most cases, the stations would probably be spaced one-half to one mile apart and range in capacity from 500 to 750 kva.

With an ac propulsion system, the motor can run continuously when the car is in service. The motor drives a torque converter, which is especially designed for this



type of operation. The input shaft of the torque converter is connected or disconnected from the motor by a clutch.

To start a train, all motors are clutched to the converters (under control of the lead vehicle). The torque converter accelerates the train to full speed with extreme smoothness. To stop, the motors are declutched and the brakes applied. For braking, air-operated mechanical brakes could be used in combination with a hydraulic retarder.

The equivalent of an intermediate running speed is provided for operation where severe curves or other conditions impose reduced-speed operation, by reducing clutch pressure, permitting a predetermined degree of slip.

Since rubber tires running on a concrete surface have excellent traction, only one axle of each coach is driven. The differential in the powered axle provides the necessary gear reduction to provide a 50-mph maximum speed.

System Operation

A Transit Expressway system would consist of a number of routes serving the major traffic arteries in a metropolitan area. Each route would be operated as an independent loop with passenger transfer at intersecting points. With each loop operating on a maximum headway of two minutes, the average waiting time at transfer points is only one minute, a wait comparable to changing from a local to an express elevator in an office building.

Passenger stops normally will be located from one-half mile to two miles apart. The schedule speeds that can be maintained with trains operating at 50 mph maximum speed, and 15-second station stops are shown in Table I.

With a fixed time interval between trains, system capacity is altered by changing the number of carriers per train. Trains must be made up quickly so that system capacity can be rapidly adjusted.

In a loop system, all turnouts are eliminated. A mechanized yard consisting of a series of power-operated transfer tables is proposed. Coach handling and storage techniques would be similar to those used in automatic garages.

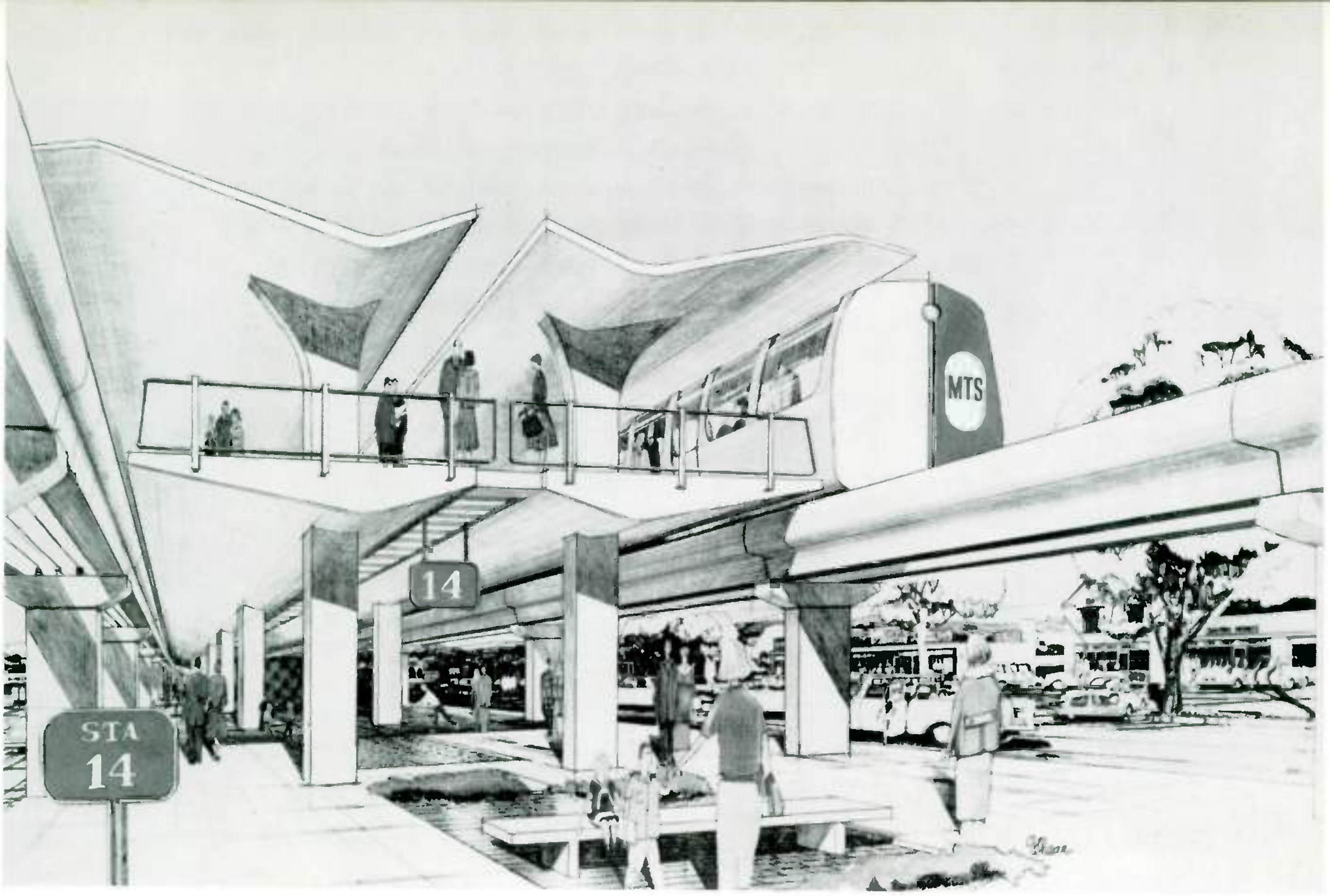
The ground area required for each car is approximately 200 square feet, or 20 000 square feet for the storage of 100 cars. Allowing for runout space on the transfer tables, about 40 000 square feet, or approximately an acre of ground, is needed to handle and store 100 cars. Since transit systems operate in areas where real estate is expensive, the ground area saved by a mechanized yard may more than offset the extra cost of mechanizing the yard. Yards may be located at any point on the system.

Table I

Distance Between Stops	Schedule Speed	Running Time
Miles 0.50	MPH 23.5	Seconds 77
0.75	29.7	91
1.00	32.2	112
1.25	34.5	130
1.50	36.2	149
2.00	39.0	185

Operating Techniques

With today's developments in automatic and programming controls, the Transit Expressway system, operating on a trespass-free roadway, could be automated to almost any degree desired. The main purpose of automation is not to replace people, but to permit improvements in operation by giving operators more complete control of the sys-



Above A passenger station for the Transit Expressway system is basically a 200-foot platform with a protective roof structure.

Fig. 4 (Right) Cross-section profile of a proposed Transit Expressway overhead roadway structure.

tem and more information about its status than ever before possible. Automation will not eliminate the need for attendants to police the system, help people in distress, and prevent vandalism and passenger annoyances. Hence, automation will be used to the greatest practical extent to reduce operating expense and provide better service.

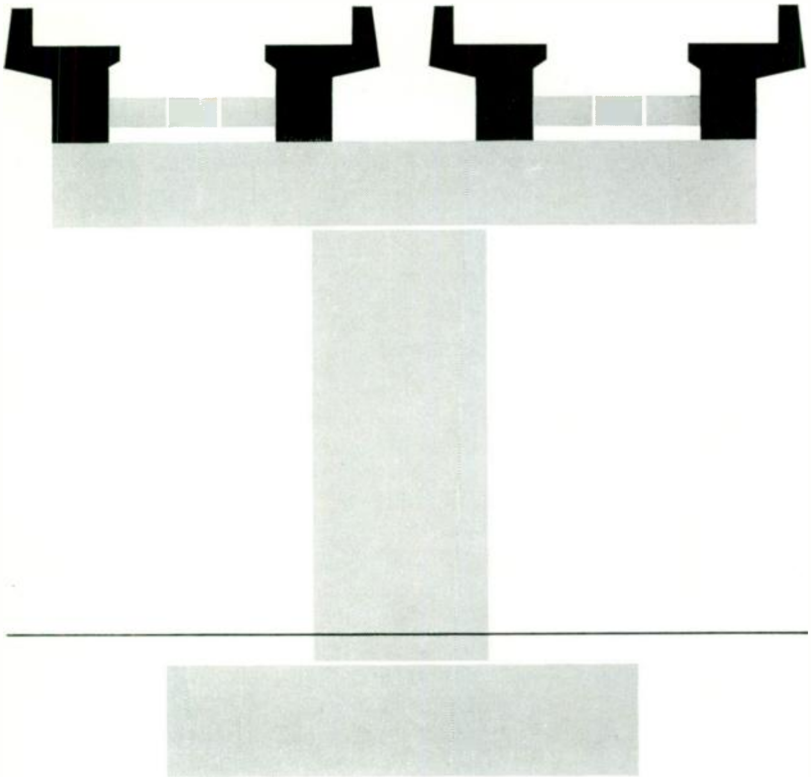
Automatic Train Operation—The Expressway carriers, whether operating as single units or in trains, can be run operatorless with ample protection against rear-end collisions or other mishaps. Dispatching trains on a fixed two-minute headway simplifies operating procedures and thereby reduces the functions required of an automatic control system. Basically, trains are started at a station, proceed down the route, and stop at the next station on a fixed-time interval.

Local controllers at each station, under the supervision of a central control computer, can regulate train speeds, starting and stopping of trains, door operation, and also monitor individual train performance. A communications wire secured to the inside vertical surface of each roadway beam provides a transmission path between the local controller and the train. The local controller obtains continuous and exact information from the train on speed and location. Information on location of speed limits, station platforms, and other reference points needed in train operation is permanently stored in the controller. Through a continuous comparison process, the wayside controller selects the appropriate commands for optimum train performance under the prevailing system conditions and particular train location.

Commands are transmitted from the wayside controller via the communication wire to a receiving antenna on the car. Typical commands transmitted are: *Accelerate maximum rate*, *accelerate minimum rate*, *apply brakes*, *release brakes*, or *open doors*. Checked coding assures integrity of the transmission channel and prevents action on an incorrect command.

Automatic control of train speed provides smooth acceleration and deceleration for maximum passenger ride comfort, and greater speed accuracy to permit operating trains at their maximum capability, at maximum speeds permitted by curves and other structure-imposed limitations, and with safe speed-distance relationship between trains. Precision station stops can be made in minimum time and car doors controlled to load passengers quickly and safely.

Fare Collection—Fares that are proportional to distance traveled would be attractive to short-distance passengers, and would assure reasonable revenue from long-haul passengers. Automatic fare collection permits the use of a zone or station-to-station fare system, which would be awkward and costly to administer with manual procedures. An automated system also opens new opportunities for production of origin-destination time-of-day statistics. This information provides the basis for new scheduling techniques, and can be used to introduce rates that will en-



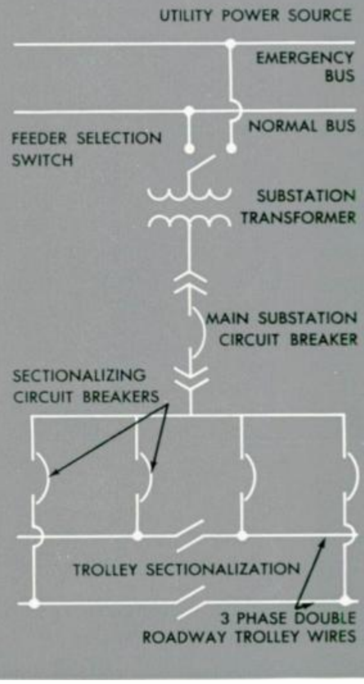


Fig. 5 Typical section of ac power distribution system for Transit Expressway.

courage patronage, such as fares favoring the regular passenger over the occasional passenger, and the off-peak passenger over the rush-hour passenger.

Fare collection and passenger control includes equipment for coin and bill verification, change making, ticket coding and issuing, ticket verification, fare computation, automatic charge account billing, and remote supervision.

Train Scheduling—A comprehensive train movement programming and supervision system will insure regular on-schedule operation under normal conditions. Early detection of delays or irregularities and continuous information on system changes provide an opportunity for sophisticated operation and immediate adjustment to system requirements. In case of serious disturbances, emergency crews can be more effectively dispatched to minimize passenger inconvenience.

Overall control of train operations can be provided by a central control computer, which supervises the wayside station controllers. Schedules for each unique day—weekday, weekday with evening shopping, holidays, etc.—are stored in the control computer memory for system programming. These schedules are subject to both short and long-term modification by the origin-destination statistics reported by the fare-collection system.

Arrival and departure of each train at each station is reported by the local controller to the central control computer for system monitoring and supervision. If corrective measures are required, the control computer can cause trains to leave earlier or later, coast for longer or shorter times, vary the door-open period, and add or subtract to the number of trains operating on the system.

Train make-up requirements are transmitted to terminal stations so that cars can be added to or subtracted from the system as traffic conditions dictate. Terminal departures are expected to be on a regular interval basis over long periods except for minor adjustments to allow for changes in loading times, fluctuations of system operating speed, peak hours, etc.

Maintenance—To reduce on-road car equipment failures to the lowest practical level, and maintain safety at the highest level, car equipment can be monitored and tested automatically. Routine car maintenance will be expedited by continuous recording of car mileage and operating time and regular indication of which cars are scheduled for maintenance and for what purpose.

Summary

For low-density areas, the Transit Expressway system is an optimum design. Any rapid transit system must be integrated with other forms of existing transportation serving the area to provide the maximum benefit from a coordinated transport network. The flexibility of the Transit Expressway system makes it easily adaptable to a variety of local traffic patterns. The concept of essentially instantaneous service coupled with a fast, comfortable ride will give the rapid transit system new public appeal. Economies in initial investment and operating expenses will allow many more communities to afford the luxury of rapid transit. And finally, the proposed Transit Expressway structures are artistically compatible with the progressive building programs of cities throughout the country.

The T-100 Regulating System

Digital speed sensing improves accuracy of process line drives

R. P. Derrick Pulp and Paper Mill Systems Engineering, Industrial Systems, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania
W. H. Watson Systems Control Division, Westinghouse Electric Corporation, Buffalo, New York

Successful operation of a paper mill depends to a large extent on successful operation of the adjustable-speed paper machine. Consequently, the industry relies heavily on regulated dc adjustable-voltage systems for precision regulation of the paper machine (as well as of coating lines and converting machinery). The growing popularity of these systems stems from recent improvements in regulator accuracy and reliability.

The T-100 regulating system combines the advantages of accurate digital speed sensing and reliable solid-state circuitry. It is intended primarily for use with new paper machines and off-machine coaters, but it also serves as a replacement regulator for existing drives. In addition, it has applications in the textile, synthetic-fiber, steel and nonferrous-metals industries. This article compares the operation and performance of the T-100 analog-to-digital regulating system with those of the conventional analog system and an all-digital system.

Paper-machine drives are of two general types—mechanical lineshaft and electric sectional. The former consists of an adjustable-speed steam turbine or electric motor driving a lineshaft that powers the machine sections. The electric sectional drive consists of a separate regulated dc motor driving each machine section. This type of drive, using the various dc adjustable-voltage regulation systems, is now the principal electric system used. The motors are usually energized by individual dc generators.

Modern versions of the basic adjustable-voltage drive differ in the regulator and control equipment applied. In the conventional analog system (Fig. 1a), a dc reference voltage is compared with the voltage feedback from a dc tachometer to obtain an accurate input signal for the high-gain solid-state amplifier that controls the dc generator field and thus the section motor speed.[1]

Another, typified by the Pulsetter system, is a completely digital system for applications where unusual accuracy is required (Fig. 1b). A digital reference pulse train from a crystal oscillator is compared to the pulse feedback from a digital tachometer to obtain a highly accurate input signal for the amplifier.[2]

The T-100 digital-to-analog regulating system has an accurate dc reference and high-gain solid-state amplifier like the conventional analog system (Fig. 1c). However, it has the advantage of a digital tachometer to gate a crystal-controlled oscillator as a decoder to provide an analog feedback signal. This eliminates the maintenance problems and inherent drift of the dc analog tachometer.

Paper-Machine Electric Drive Requirements

A paper machine is fundamentally a constant-tonnage device whose operating speed depends on the drying capacity available and the product caliper (thickness) desired. Most paper machines produce several grades of varying caliper, so the drive must provide adjustable-speed operation over a range up to 10 to 1. (See *The Paper Machine*, p. 9.)

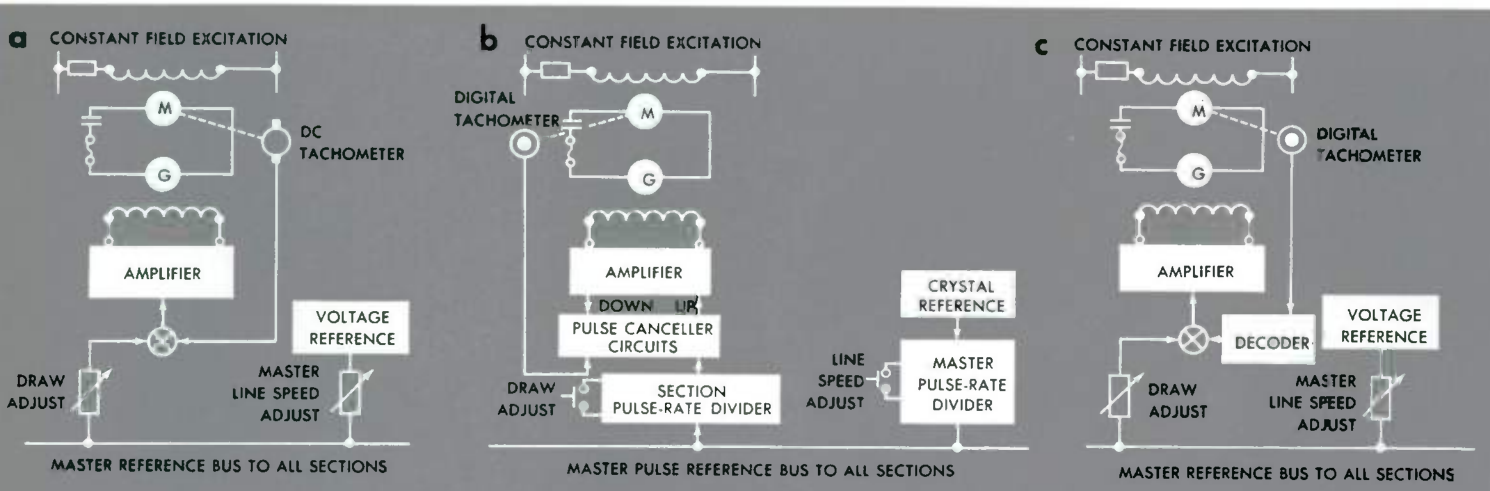


Fig. 1 These three modern versions of the basic adjustable-voltage dc drive for sectional machines differ in the regulator and control equipment applied. They are: (a) conventional analog system, (b) completely digital system (Pulsetter), and (c) digital-to-analog system (T-100).

Regulation of *overall machine* speed (speed of the entire line) must be accurate through the speed range to allow uniform operation of the machine and thus produce an acceptable quality sheet. Most drives are now designed for a nominal regulation of ±0.1 percent of rated maximum speed. (See *Typical Drive System Accuracy Characteristics*, p. 12.) *Machine section* speed regulation also must be accurate within ±0.1 percent over the required speed range. Section speed variations of even a few tenths of a percent can cause stress changes in the sheet that may break the sheet or alter its properties.

The operator must have control of overall machine speed and the draw of each section. Machine speed changes must be made slowly (about three to five minutes for the entire 10:1 range) to avoid disturbing the production sheet. Section start, stop, jog, and load indication are also required for safe operation, maintenance, and washup.

Equipment must be of high quality for dependable operation over a long lifetime. The typical new machine may have a downtime (lost production) charge of up to a dollar a second ($3600 an hour), a 330-day operating year, and a useful lifetime of 20 years or longer. Total installed cost of a new machine, drive, and building may exceed $20 000 000.

The T-100 Regulator

Each section of any multiple-generator drive system consists of a dc generator with regulated field excitation powering a dc motor with constant field excitation. A regulator acts on the generator field to control the armature voltage, and thus the speed, of the motor. The regulator has five principal circuits: A reference device to supply a constant quantity of satisfactory accuracy; a speed setting device, such as a potentiometer, to properly modify this reference to obtain a signal indicative of the desired operating speed; a tachometer to provide an accurate speed feedback signal; a comparison device to compare the tachometer signal of actual speed with the speed-setting signal of desired speed; and a high-gain, stable, drift-free amplifier to excite the generator field. These circuits are shown in Fig. 1.

Reference and Speed Setting—A Zener diode serves as the static reference element in a regulated power supply for the T-100 system. Its output (voltage drop) is amplified by regulating transistors to provide a drift-free signal of suitable magnitude. This type of reference can be designed for better than ±0.1 percent system regulation over a 24-hour period under the variations in temperature, frequency, and voltage commonly found in industrial plants.

The reference output is maintained at a fixed value regardless of operating speed. This value is attenuated by an adjustable-resistance network to provide an output voltage proportional to the desired speed of the entire machine. The proper rate of change of the reference signal for smooth speed changes can be provided by a small geared motor-operated rheostat or by static ramp function generator circuitry based on transistor-controlled constant-current charging of a capacitor. Multiturn potentiometers further modify the reference for draw adjustment at each section.

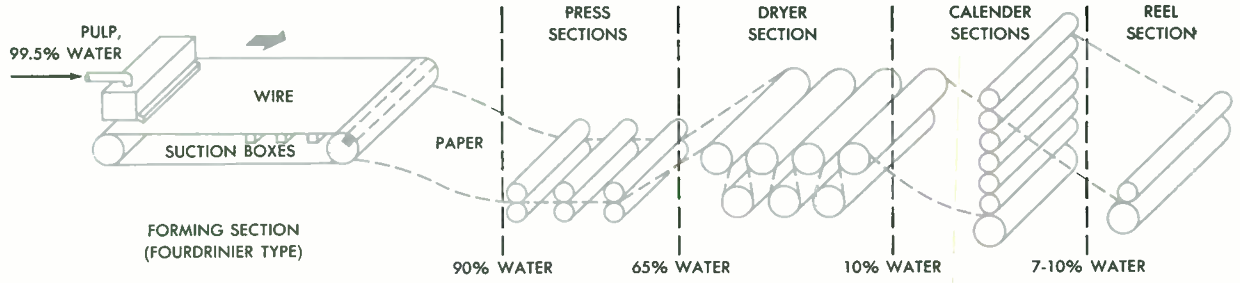
Speed Sensing—Pure analog systems commonly use the conventional dc tachometer, driven by the regulated section drive motor. The tachometer produces an output voltage, proportional to speed, that is fed directly into the comparison circuitry. Although this is one of the oldest speed-sensing devices in general use, drift and maintenance problems persist because of temperature and alignment sensitivity and the need for commutation.

The T-100 system has a more modern speed-sensing device, the pulse-generating tachometer (Pulstac). This device is driven by the regulated section drive motor and provides an output pulse rate proportional to motor speed. It has none of the problems of conventional tachometers.

The tachometer's rotating element is a wheel whose surface has many magnetic poles along its circumference. These poles generate an electric signal as they pass under a pickup head. The unit has no commutators, slip rings, or

THE PAPER MACHINE

Paper is manufactured in a process line consisting of independent sections of a paper machine, which may be more than 500 feet long. The paper is produced as a strip up to 300 inches wide and at design speeds up to 3000 feet per minute. The primary function of the paper machine is to remove most of the water from the pulp stock in such a way as to form a uniform continuous sheet of paper. Water is removed by free and vacuum drainage, by pressing between rolls, and by drying with steam-heated dryer rolls. Paper stretches ("draws") during manufacture, and this draw must be taken into consideration in drive design since it must be accurately controlled and easily adjusted by the operator. Thus, any speed reference used for the overall paper machine must be modified for the draw of each section.



conventional field excitation. It is designed for operation in ambients above 65 degrees C (150 degrees F), and it has no drift with time or temperature since the quantity of interest is pulse rate rather than signal magnitude.

Digital-to-Analog Decoding—The decoder converts the pulse signal from the digital tachometer to an analog voltage for comparison with the reference setpoint (Fig. 2). It is a single module on the regulator panel.

The pulse rate from the digital tachometer depends directly on tachometer speed. Although the pulse amplitudes may vary, all pulses are of sufficient magnitude to operate the input flip-flop switching circuit. The crystal oscillator frequency is constant and selected as at least ten times the maximum pulse rate from the digital tachometer. The gate circuit allows pulses to pass only when turned *on* by the input flip-flop as triggered by the tachometer.

Assume that the gate is in the *off* mode and a pulse is received from the tachometer at the input flip-flop. The gate then passes pulses to the three-stage divider circuit. The eighth ($2^3=8$) pulse from the oscillator through the gate occurs before the next pulse from the tachometer, since the tachometer maximum pulse rate is much less than that of the oscillator. This eighth pulse resets the input flip-flop and the oscillator gate to the *off* mode. The next pulse from the tachometer causes the process to repeat so that the output pulse occurrence rate is identical with that of the digital tachometer. The divider circuit provides a NOR inversion, so the output appears as a pulse whose width is determined by four times ($\frac{1}{2}$ of $2^3=4$) the period of the oscillator.

The output filter includes a Zener clipper circuit for pulse height uniformity and a capacitor filter element to provide a dc output proportional to input pulse rate. This output is an accurate drift-free analog of machine speed.

Signal Comparison and Amplification—A network of precision resistors accurately compares the reference voltage with the voltage fed back from the decoder and so provides an error signal to the amplifier.

Both signal voltage and power have to be amplified. Adequate forward amplifier gain is needed so that proper degenerative feedback will reduce the system error to tolerable limits and still provide sufficient output closed-loop amplification to the machine field. These requirements are met in the T-100 system by a two-stage signal voltage and power amplifier.

The input error signal is applied to a high-gain signal amplifier similar to operational amplifiers used in the differential analyzer type of analog computer. All operational amplifier is characterized by high gain (10^6 open loop), polarity reversal (180-degree phase shift), and wide frequency range (dc to 30 kc). Phase reversal and high internal gain are essential, since a negative feedback is usually applied to achieve desired performance characteristics. The transfer function for an operational amplifier with such a feedback may be reduced to the ratio of the feedback impedance to the external input impedance. Proper selection of the values and combinations of resistors and capacitors in the amplifier input and feedback circuits makes the operational amplifier capable of integration, differentiation, time delay, and function generation.[3] For example, very accurate speed regulation is provided by a resistor and capacitor in the feedback to give combined speed and position regulation. The speed regulator portion gives good transient response, and the position portion provides an output signal to hold constant speed and thereby improve steady-state accuracy and long-term stability.

The industrial type operational amplifier is specially designed to meet industry's requirements of ruggedness, long life, and trouble-free operation in difficult environments. It has been applied widely in industrial control systems for multimotor and single-motor applications and for the normalizing circuits in on-line process control computers. The circuitry is functionally arranged on printed circuit board subassemblies and housed in a module. This arrangement saves space, provides a rigid unitized construction, and facilitates servicing.

The power stage of amplification, needed to excite the generator field, is a Trinistor controlled-rectifier power amplifier (Fig. 3). It is housed in two modules, as shown in Fig. 4. The amplifier is capable of large power outputs at high gain and combines the better features of magnetic amplifiers and silicon controlled rectifiers.

The magnetic amplifier output controls a gating transformer to provide a pulse output for "firing" the controlled rectifiers. Firing depends only on the occurrence of a pulse, not on the magnitude of a firing signal. (Conventional phase-shifting circuits, frequently applied to thyratron tubes, do not give a definite firing point and may be subject to interaction under some conditions.) Each input signal is isolated by the magnetic-amplifier control windings. This feature eliminates the need for connecting high- and low-energy control circuits and simplifies circuit checking. It is especially valuable when applying the T-100 regulating system to existing drive systems that may have unknown extraneous circuits ("sneak-circuits").

Digital Speed Indicating Equipment

An added advantage of the T-100 system is its compatibility with digital speed-indicating and data-logging equipment.[4] A special dual-frequency digital tachometer provides the proper output frequency for this instrumentation (shown in Fig. 5). Experience with more than 70 paper machines and off-machine coaters shows that the instrumentation reduces costs through exact duplication of machine draws and speeds, shorter threading time, increased equipment life, and improved system maintenance. Unscheduled downtime is often reduced by 25 percent.

Regulator and Control Power Supply

The T-100 regulating system includes a single 60-cycle alternator to provide regulated ac power to the section regulators. The alternator also supplies dc power to the constant-potential exciter bus for the motor fields and

---

REFERENCES

[1] "Modern Regulated Drive Techniques for the Paper Industry," by R. P. Derrick, AIEE District Paper #62-550, April 1962.

[2] "Digital Speed Controls for Sectional Drives," by H. H. Bell and J. M. Bentley, *Pulp & Paper*, June 11, 1962, p. 46.

[3] *Reference Data for Radio Engineers*, Fourth Edition, Chapter 14, International Telephone and Telegraph Corporation, New York, N.Y., 1956.

[4] "Digital Instruments for Accurate Strip-Process Measurements," by S. Salowe and W. C. Carter, *Westinghouse ENGINEER*, July 1961.

[5] "Electrical Downtime on Sectional Drives—Project 435," Technical Association of the Pulp and Paper Industry, New York, N.Y., Vol. 38, No. 10, October 1955.

2

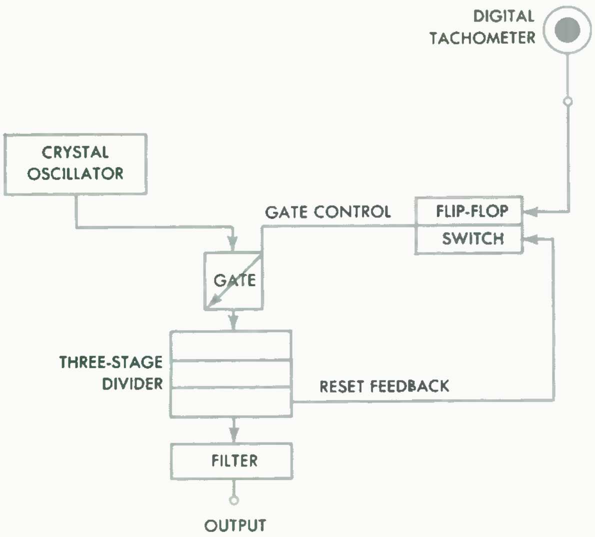


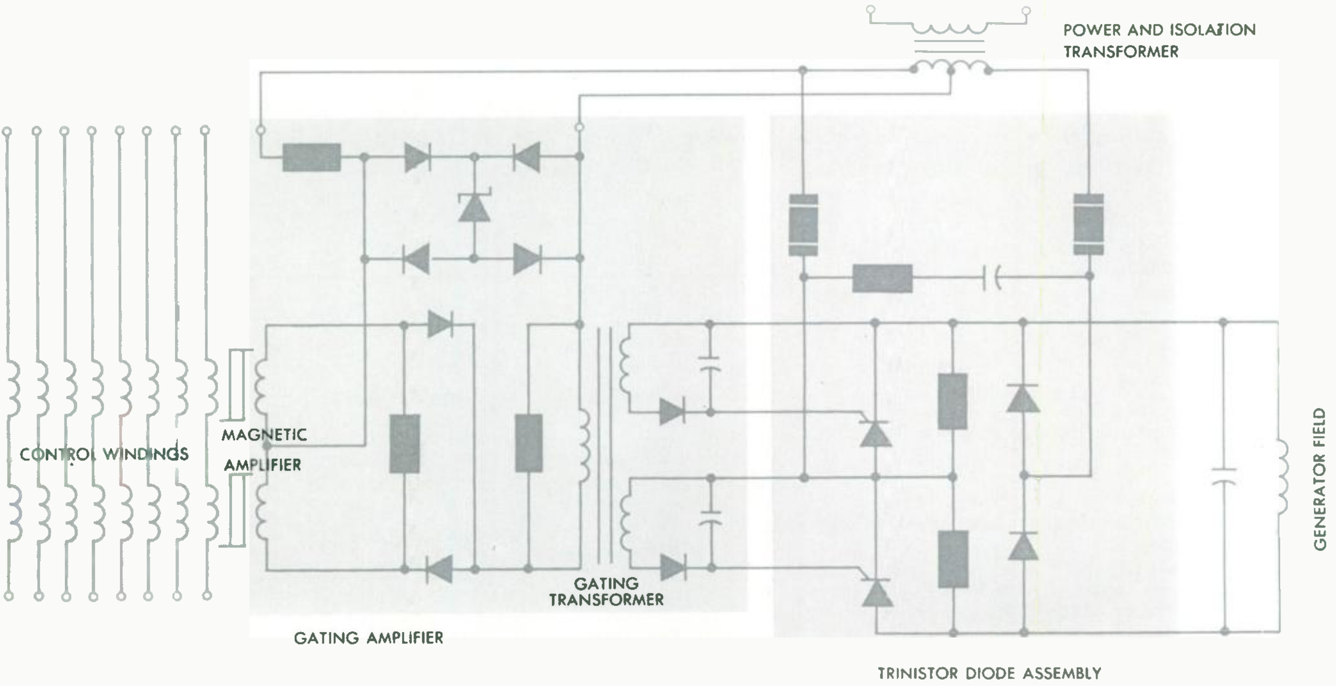
Fig. 2 Principal circuits of the T-100 regulating system's digital-to-analog decoder. A gated crystal oscillator converts the accurate digital signal from the pulse tachometer to a dc signal for comparison with the reference signal.

Fig. 3 The power amplifier for exciting the generator field for each machine section consists of a gating amplifier and a Trinistor controlled-rectifier diode assembly. A magnetic amplifier controls a gating transformer to provide a pulse output that causes the controlled rectifiers to conduct power. By controlling the firing angle, or duration of conduction during each half cycle of ac power, the gating amplifier controls the amount of power transmitted.

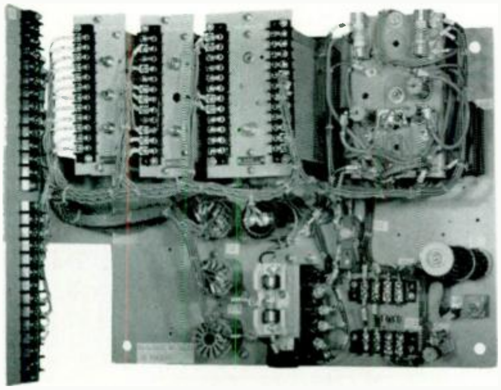
Fig. 4 A typical section regulator panel for the T-100 regulating system. From left to right at the top of the panel are the decoder, signal amplifier, gating amplifier, and Trinistor controlled-rectifier diode assembly. These components are packaged as self-contained modules.

Fig. 5 This is the master console for controlling an off-machine coater's T-100 sectional drive. Digital speed instrumentation, in the cabinet at the right, displays section speeds numerically.

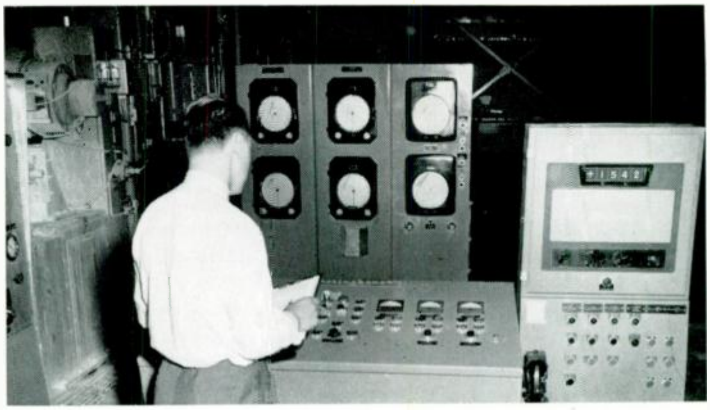
3



4



5



control circuits through a three-phase silicon rectifier.

The alternator is located with the section generators on the main motor-generator set. This arrangement isolates the control system from the mill power system so transient disturbances on the power system will not affect the process line drive. The alternator is voltage regulated by a Trinistor controlled-rectifier regulator similar to the power amplifiers in the section speed regulators.

Control Equipment Construction

The T-100 regulating system is available in either open-panel construction for erection in a control room or in NEMA I enclosed control cubicles. Open construction is generally less expensive than enclosed but can be used only in control rooms that are protected from dirt, water, pulp, other harmful materials, and unauthorized personnel.

Regardless of construction, each section control unit consists of two functional panels—magnetic control and section regulator. The magnetic control panel contains the main line contactor, overload relay, and the necessary sequencing relays. The regulator panel contains the digital-to-analog decoder, signal amplifier, Trinistor power amplifier, calibration and damping devices, and regulator test equipment. (See Fig. 4.) The entire process line is controlled by a single master control unit that includes the alternator regulator, drive reference, line speed-setting control, and master control sequencing devices.

A replacement line of T-100 regulating equipment is used for improving existing sectional drives or when adding new sections to existing lineshaft or sectional drives. Carbon-pile, rotary-contactor, electronic, or early magnetic-amplifier regulated drives can be so upgraded. These replacement regulators may use the existing drive's magnetic control and system reference, or a new reference can be applied for drift-free performance. Replacement equipment is available in NEMA I cabinets or open panel construction. The new regulators usually improve paper-machine availability by appreciably reducing the downtime charged to the older regulating systems.

Conclusion

Published information on downtime of electric sectional drives indicates that total drive availability is about 99.68 percent of scheduled operating time.[5] More than half of the 0.32 percent unscheduled downtime is attributed to the regulator system. The ease of maintenance and excellent performance of the T-100 regulating system, achieved through use of modern solid-state amplifier components and digital speed sensing, increase regulator reliability over that of dc analog systems using analog tachometers. This improved reliability can mean a 12-hour production saving a year, which is equivalent to a product value of more than $45 000 with a modern 600-ton-per-day paper machine.

Westinghouse
ENGINEER
Jan. 1963

TYPICAL DRIVE-SYSTEM ACCURACY CHARACTERISTICS

Characteristic	DC Analog (*Fig. 1a*)	Digital (*Fig. 1b*)	Digital-Analog (*Fig. 1c*)
Allowable Ac Power Supply Variation			
Voltage	±10% of rated	±10% of rated	±10% of rated
Frequency	±0.5% of rated	±1 cps from rated	±1 cps from rated
Allowable 24-Hour Temperature Variation (10°F/hr)			
Control room	20°—40°C	0°—50°C	20°—40°C
Tachometer (max)	65°C ambient	>65°C ambient	>65°C ambient
Steady-State Regulation			
Constant load	±0.1% nominal	Better than ±0.025%	±0.1%
100 percent load change	±0.1% nominal	±0.025%	±0.1%
Drift Regulation	±0.1% nominal (8 hrs)	±0.01% (24 hrs)	±0.1% (24 hrs)

Specified accuracies must always be defined in terms of operational and environmental conditions. For the purpose of this article, the following definitions are applied. (These definitions are generally compatible with "NEMA Definitions—Industrial Automatic Systems," Pub. No. AS 1-1961.)

$$\textit{System accuracy} = \frac{\text{actual value} \times 100\%}{\text{correct value}}$$

(e.g., 99.99% accurate). *System regulation* =

$$\frac{\text{maximum deviation} \times 100\%}{\text{correct value}}$$

(e.g., ±0.01% regulation). Unless otherwise stated, the expression *percent speed regulation* refers to rated machine maximum speed.

Drift is the maximum change in control characteristics (e.g., shift in set point) due to unassignable causes over a 24-hour period (unless otherwise specified). System variations caused by changes, within the specified limits, of ambient temperature and power-supply voltage or frequency variations are included. Explainable transients of short-time duration (e.g., due to load or system reference point changes) are excluded.

Steady-state regulation is the error that remains after a transient condition has passed. This accuracy applies to normal operating load conditions, specified load changes, or constant load situations. A stable regulated system's response to a transient disturbance depends on the mechanical time constant (inertia) of the driven machine and the amount of forcing action available from the regulated drive. The systems described in this article provide adequate forcing action when properly applied in the usual paper mill.

Cast-Resin Power Transformers

J. H. McWhirter
Power Transformer Division
Westinghouse Electric Corporation
Sharon, Pennsylvania

N. C. Foster, Daniel Berg, and C. F. Hofmann
Research Laboratories
Westinghouse Electric Corporation
Pittsburgh, Pennsylvania

Transformer coils are cast in solid resin in this new concept for power transformers. While still in the development stage, the concept holds unusual promise for the future.

The high-voltage insulation for a conventional power transformer is a composite structure of solid insulating materials, such as pressboard, and oil or gas. Moreover, each of these materials has a dual function in the transformer; the solid insulation materials provide structural support for the coils, and the insulating oil or gas must also serve as a cooling medium.

A new approach takes advantage of the high electric strength of thermosetting resins. High- and low-voltage coils are cast in solid resin, which provides the necessary high insulation strength. Cooling is a separate function, and is performed by vapor cooling the windings.

The cast-resin power transformer is now in development stages, and many problems must be solved before it comes into widespread use. However, the concept has many potential advantages over conventional construction; smaller size and lighter weight are two notable examples.

Why Cast-Resin Insulation?

The one outstanding or primary function of power transformer insulation is to insulate against high voltage. Other properties of insulation besides electric strength have to be considered and proved satisfactory, but nevertheless they are secondary. The three possible forms for insulating materials—gases (air), liquids, and solids—have, roughly, relative intrinsic electric strengths of 1, 10, and 100. Solids are therefore the most desirable insulating materials.

Solid insulating materials, such as liquid-impregnated pressboard and others, have been used for some time to advantage; however, this insulation structure has some liquid voids and creepage paths through the liquid. This limits its effectiveness. This fact led to the consideration of thermosetting resins, which can be poured into place as a liquid; when hardened, ideally the solid completely fills the insulation space, excluding all gases and liquids from regions of voltage stress.

In designing a transformer to use the high electric strength of the resin, proper cooling of the transformer is a key consideration. Although cast resin is a good conductor of heat compared to most insulating materials, conduction through the resin has definite limitations as a means of removing heat from the transformer coils. This becomes more of a problem as ratings increase, and therefore a cooling method independent of the insulation system is needed.

Considerable experience has already been gained with vaporization cooling in transformers, and its characteristics are well known; this method was selected for the prototype cast-resin transformers.

In vaporization cooling, an inert liquid is maintained in contact with the surface of the heat source. The heat losses at this surface cause the liquid to vaporize, absorbing the latent heat of vaporization with no increase in temperature. The vapor then travels to the cooling surface where it condenses, giving up its latent heat of vaporization with no change in temperature. The advantage of vaporization cooling is that cooling can take place at very high surface heat flux densities with a small temperature drop from the coil to the external heat exchanger. This minimizes the space required in the coil for heat transfer, and the size of the external heat exchanger. It permits the effective use of fans to obtain overload ratings. The inert, nonflammable liquid eliminates fire hazard.

Other methods of cooling cast-resin transformers may prove to be more suitable for certain installations—for economic reasons, for simplicity, or because of special requirements of the application. However, this can be done with minimum difficulty because of the separation of the insulation and cooling functions.

A schematic sectional view through a cast-resin coil with vaporization cooling is shown in Fig. 1. The high- and low-voltage coils are insulated from ground and from each other by cast-solid-resin insulation. The coils are thoroughly impregnated with a solid resin to provide the electric strength within the coils. The first units will have a light metal case around the core and coils for appearance and safety; the case will have louvers to permit air flow.

Design of the Transformer

Prototype units have been designed with losses and impedances identical to those of liquid-immersed units. However, considerable latitude is possible.

The operating temperatures are Class A, or 105 degrees C hot-spot. This is conservative because the insulating materials are excellent Class B materials by the usual standards. However, with the efficient heat transfer provided by vaporization cooling, there is no great incentive for going above Class A temperatures. As experience is gained, the units can easily be redesigned for a higher temperature.

Prototype units have the same impulse strength as conventional oil-immersed units and are subjected to the same low-frequency tests. This is made possible through the high intrinsic electric strength of the solid resin.

The coils are securely imbedded in an integrated resin structure. This gives them some unusual mechanical properties. The magnetic interactions that produce high forces on short circuit are easily withstood by these coils. The resin covering also gives the coil protection from environmental influences, such as dirt, dust, and moisture.

The Resins Used—A number of properties are of importance in formulating a resin for power transformers:

The resin must have basic physical properties that enable it to withstand processing and operating stresses without cracking. The significant combination of these properties might be described as toughness, or a combination of mechanical strength, low shrinkage, and the ability of the resin to deform under stress without fracturing. Methods have been devised to evaluate the combination of these properties that is significant in making cast coils.

The dielectric loss characteristics of the resin must be low over a range of temperatures.

The electric strength of the resin must be high. However, this is usually more closely connected with the elimination of voids in the resin than to a basic property.

The problems of resin casting are affected by the presence of a winding, which may not expand and contract with temperature in the same manner as the resin. One approach to this problem is to use flexible resins, which yield with this expansion and contraction. Another approach is to attempt to match the coefficient of thermal expansion of the copper or aluminum winding.

In general, the coefficient of thermal expansion of unfilled resins is much higher than that of the common metals, but the addition of fillers reduces the coefficient (see Table I). Low viscosity is also a highly desirable property. Large amounts of filler can be added to low-viscosity resins; this reduces the total amount of shrinkage and helps obtain a low coefficient of thermal expansion.

These properties must be maintained over the life of the transformers when they are subjected to heat, thermal shock, and voltage stress.

After thousands of tests, an epoxy-type resin was chosen to insulate these transformers. Although some excellent flexible resins were made and successfully cast around coils, a rigid resin with a relatively high heat distortion point is now being used. Tests indicate that the more rigid systems have the advantage of greater thermal stability, physical strength, better electrical properties, and more resistance to water and chemicals. To permit the resin to withstand thermal cycling, it is heavily loaded with a low coefficient of expansion filler. The material has a coefficient of expansion closely matching that of copper.

The Coolant—The coolant is F-75 fluorocarbon liquid. This is a fully-fluorinated product composed of a mixture of compounds containing eight carbon atoms. It is thermally stable and compatible with the materials with which it is in contact at temperatures far in excess of those present in these transformers. Low viscosity, low surface tension, and a high heat of vaporization contribute to its excellent heat transfer properties. It is nonflammable.

Electrical Testing

Since the primary purpose of this development is to take advantage of the high electric strength of the resins, many tests have been made to verify the high electric strength and its maintenance over a satisfactory lifetime:

1. Impulse and 60-cycle tests have been made on resins under idealized electrode conditions, to verify the intrinsic high electric strength.

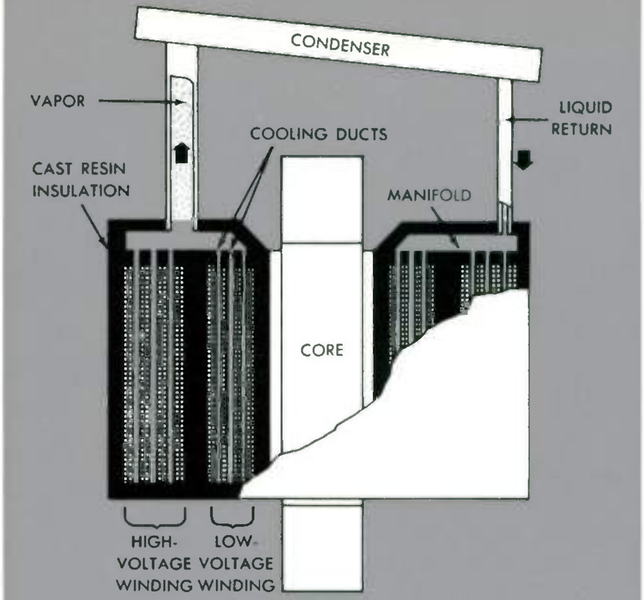


Fig. 1 The vaporization cooling takes place in a closed system. The system is filled with the liquid coolant to a level several inches above the top of the ducts. The liquid vaporizes and the vapor bubbles up through the ducts into the manifold where it is collected. It then goes into a vapor-filled pipe and into the condenser. Here the vapor gives up its heat of vaporization and again becomes a liquid. It returns by gravity to the duct to complete the cycle.

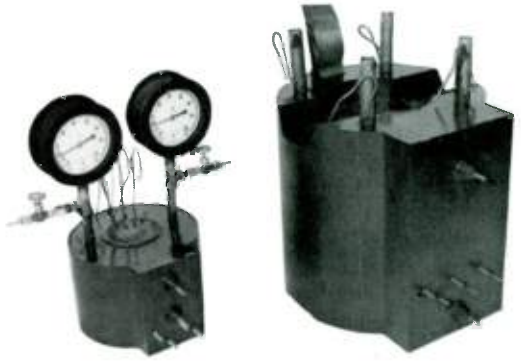


Fig. 2 (Above) At left is a model coil, and at right a prototype coil for a 500-kva 15-kv transformer. (Below) Another view of the prototype coil.

2. Impulse and 60-cycle tests have been made on the completed coils, to verify that sufficient initial insulation strength is present. During the life tests on model coils, these tests are repeated at intervals.

3. The long-time effects of the normal voltage stress have been of primary concern, not because this is necessarily a problem, but because there was no assurance that it was not a problem, and tests necessary to verify this are difficult and time-consuming to make.

In spite of the use of high vacuum in manufacturing these transformers, there is evidence that minute voids are still present. When a very high stress is applied, these voids will ionize. The small amount of ionization may not be harmful, but until this is proved, cast-resin transformers are being designed to operate at stresses below the ionization level.

This is now the limitation on the efficient use of cast-resin insulation. For this reason, research is proceeding to increase the voltage stresses at which this ionization occurs, and also to determine its effect on the insulation life. As an example of some of the results obtained so far, coils have been continuously under stress for over a year at voltages four times the voltage at which ionization is initiated. This has not produced a detectable change in the insulation.

This void ionization is not a radio-influence problem because the radio influence produced is so low that it generally cannot be detected on test equipment.

Voltage endurance tests are also being made at voltage stresses below the ionization level, to insure that there are no long-time harmful effects present. Some of these tests are being made at elevated temperatures.

Models and Prototype Units—Two types of units, shown in Fig. 2, have been built thus far. The first type is called a *model* coil and was designed: (1) to simulate the problems that were anticipated in building a large unit, but to accomplish this in a reduced size for ease and economy in manufacturing a large number of experimental units; (2) to verify the adequacy of the construction by full level impulse, 60-cycle, and ionization tests, and thermal cycling; and (3) to permit long-time functional life tests.

Several hundred model coils or parts of model coils have been manufactured in developing designs, processing techniques, and materials.

The second type, called a *prototype* coil, is one coil phase of a 500-kva, 15-kv transformer; this is used for verification of results obtained on the smaller models.

Tests made on model coils include: temperature cycling; impulse tests on the high-voltage winding; 60-cycle overvoltage tests, including ionization measurements on the major insulation and between low-voltage coils; and functional life tests.

Table I COEFFICIENT OF THERMAL EXPANSION OF VARIOUS MATERIALS

($R \times 10^{-6}$ in./in./degrees C)

Unfilled Resins	60
Filled Resins	25–30
Aluminum	22
Copper	15
Steel	12

During the functional life tests, a current is passed through the outer low-voltage coil to heat the coil to a hot-spot temperature of 135 degrees C. This provides accelerated aging of the resin insulation. A voltage stress equal to 175 percent of the design stress is applied between low-voltage coils, and 250 percent of the design stress is applied to the insulation between the high-voltage winding and the low-voltage winding and ground. Any long-time harmful effect is accelerated by the over-voltage. In addition, there is the acceleration of the voltage deterioration effect due to temperature. The ionization deterioration rate is proportional to the frequency of the applied voltage and for this reason the voltages are at 400 cycles frequency. This provides an accelerating factor of 6.7 on any ionization present and some models do have small amounts of ionization at these high-voltage stresses. The fluorocarbon is evaporated and condensed at an accelerated rate.

The large prototype coils are built occasionally to verify the correlation between the results on the smaller model coils and the performance of the large coils.

Possible Applications

Applications are suggested by several characteristics: The cast-resin transformer is small and light; the hazards and inconvenience of oil are eliminated; the insulation has good resistance to unfavorable environment; and it has full impulse levels and good mechanical characteristics.

These characteristics would be particularly advantageous in several applications. One is for mine power centers, which have a severe height limitation. Another is power centers in all-electric apartment buildings, where considerable electric power is needed and space is very valuable. A third is shipboard and other applications where oil-immersed units are undesirable and space is valuable.

These transformers will initially be competitive with the present ventilated and sealed dry types, and askarel-immersed units. Higher voltages than are now practical with dry-type transformers will be obtainable. Eventually these units will be competitive with oil-immersed transformers. No inherent barrier has been encountered yet that would limit the size and voltage of cast-resin transformers.

Status of Development and the Future

Considerable experience has been gained from building model and prototype coils, and from basic investigations. The development has proceeded to the point where a limited number of commercial units are under consideration. At the same time, development work is continuing to improve on the materials, design, and manufacturing techniques. Life test data is being accumulated. A great deal of development work remains to be done before cast-resin transformers become economically feasible for wide-scale application. Also, new concepts should be explored, such as making the cast transformer without a case, thus eliminating the need for bushings.

A systematic development program has been undertaken to solve these problems and to insure a reliable product. The objectives of using the best form of insulation and the most efficient type of cooling are so basically sound that it will be only a matter of time until this type of transformer occupies an important place in the transformer market.

RESEARCH AND DEVELOPMENT

WORKING FLUIDS FOR POWER GENERATION CYCLES

Since 1920, electric power generation capacity has approximately doubled in each ten-year period, while steam plant overall efficiency has continuously improved along lines that were theoretically predictable. Although installed capacity promises to continue to grow at its present rate or faster, the limitations of steam as a thermodynamic fluid indicate that the practice of increasing steam pressure and temperature to improve cycle efficiency is coming to an economic end.

Steam as a high-temperature working fluid has two fundamental shortcomings: (1) Its vapor pressure is too high, and (2) it absorbs too little heat at the maximum cycle temperature. High operating pressure makes necessary thick-walled vessels with difficult thermal stress problems, and small inefficient high-pressure turbine blades. The small amount of heat absorbed at maximum cycle temperature limits overall cycle efficiency. The relatively small gains possible in efficiency and the extremely high steam pressures required with present and higher steam temperatures probably will effectively limit further economic improvements in the steam cycle as we know it today.

This raises some serious questions for the industry to ponder: What is the next step for the steam cycle? Should we continue to develop the steam cycle for operation at higher steam pressures and temperatures? Or are there other more promising methods of large-scale power generation that should be developed?

Future Power Generation

Several methods are under investigation for providing more efficient electric power generation, ranging from extensions of existing steam plant cycles to completely "new" power sources. However, in each case, a considerable portion of the power must be developed in the temperature range of 1000 to 1400 degrees F. The shortcomings of steam in this temperature range means that to obtain maximum efficiency from any of these new methods, a better working fluid is required.

Combined Steam/Gas-Turbine Cycle—There is considerable interest in combining the gas turbine with a steam plant. Such a power plant could be developed with little additional effort if gas or fuel oil is used as the fuel.

The efficiency improvement expected over the straight steam cycle is primarily due to the higher inlet temperature possible with the gas turbine. However, the steam cycle provides a major portion of the useful power output, so that long-range cycle improvement would depend on future developments in the steam cycle.

Nuclear Power Generation—The nuclear energy heat source is expected to play an increasing role in large-scale power generation. However, the heat source probably will not have a controlling influence in determining the working fluid used. Therefore, as reactors are developed to operate at higher temperatures, the thermal properties of steam would limit cycle efficiencies, just as with fossil fuel.

Magnetohydrodynamics

The large amount of research and development being carried on by industry and government indicates that many changes and advances will occur in power generation methods. For example, scientists and engineers are devoting an increasing amount of attention to "new" power sources. The four that presently show the most promise are thermoelectric generators, thermionic generators, fuel cells, and magnetohydrodynamic (MHD) generators. Of these, only the fourth, MHD, presently offers hope of becoming an economic large-scale power generation source. And even here, much background research, material studies, and engineering development remain to be done. In the MHD cycle, as presently conceived, either steam or gas turbines will be needed for driving the gas compressors and for developing approximately 50 percent of the plant power output. The theoretical overall efficiency of this plant from fuel to bus bar is 60 percent (as contrasted with present best steam plant efficiencies of about 42 percent). This efficiency could be increased to 65 percent if a better thermodynamic working fluid could be used.

Working Fluids

If the power plant designer could have a working fluid made to order, what would he specify? The ideal fluid would have the following characteristics:

1) High critical temperature, so that evaporation can take place at a high temperature. This provides high Carnot cycle efficiency.

2) Vapor pressure at high temperatures should not be excessive.

3) The condensing vapor pressure, at ambient temperature, should not be too low. This would avoid large, expensive low-pressure turbine blades and a multiplicity of exhaust ends.

4) Specific heat of the liquid should be low and latent heat high. This would re-

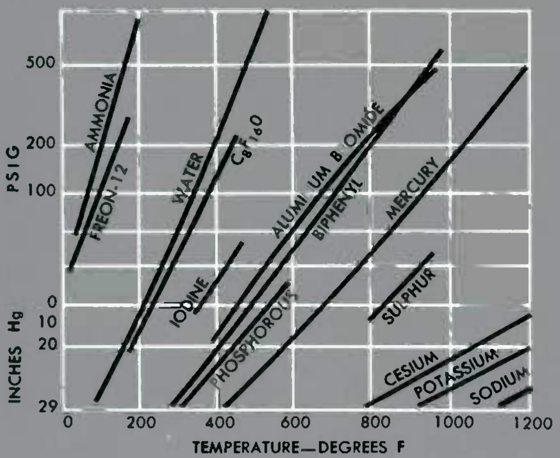


Fig. 1 Some possible working fluids are shown in this pressure-temperature chart.

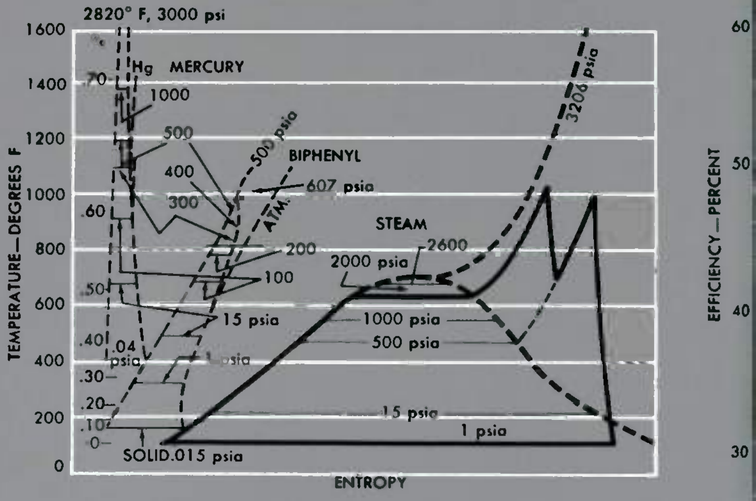


Fig. 2 Temperature-entropy chart for mercury, biphenyl, and steam.

duce the relative amount of heat required for liquid heating, dispense with the complications of regenerative feed heating, and permit most of the heat to be absorbed at maximum temperature.

5) The fluid should not be toxic or corrosive.

6) The fluid should be chemically stable in the required temperature range. It should not dissociate or polymerize.

7) The fluid should be inexpensive and plentiful.

8) It should be liquid at ambient temperature.

9) The saturated vapor line should be nearly vertical on the temperature-entropy diagram. This avoids excessive moisture with its turbine losses, or excessive superheat which would require a regenerator to recover the heat from the turbine exhaust.

10) The fluid should be nonflammable.

11) It should have good heat transfer properties.

12) If used in the primary part of a nuclear system (i.e., the part which includes the reactor core), the material should have a low thermal neutron cross section. This restriction does not apply if the working fluid is used only in the secondary (non-nuclear) system.

Unfortunately, no single fluid has been found that fits all of the above specifications. Steam falls short by having too low a critical temperature, too high vapor pressure at high temperature, too low condensing vapor pressure, and a too large liquid specific heat. Some of these deficiencies have been offset by ingenuity in cycle arrangement.

Many other working fluids have been considered; some are shown in Fig. 1. But each has drawbacks. Mercury, sulphur, sodium, cesium, and potassium have desirable critical temperatures above 1200 degrees F; but sulphur is extremely reactive, and sodium, cesium, and potassium have too low vapor pressures at ambient heat rejection temperatures. Mercury is perhaps the nearest approach to the ideal fluid, but it too has limitations. It is extremely toxic, has low condensing pressure, is expensive, and has limitations as to specification 12 for direct-cycle nuclear use. A comparison of the mercury temperature-entropy diagram with steam is shown in Fig. 2.

Unfortunately, ideal condensing pressures are found only in fluids that have low critical temperatures. Ammonia and the fluorocarbons have condensing pressures in the 50 to 100 degree F ambient temperature range, which are 100 times those of steam.

Binary and Ternary Cycles

Since no single fluid has all the desirable characteristics, a combination of two fluids in a series-binary cycle presently appears to be the best approach. The mercury-steam cycle is already well known. Work on the mercury cycle was started by Dr. W. Emmet in 1913[1,2]. The first mercury-steam binary cycle was installed in 1922. Since then, some seven units ranging in capacity up to 20 000 kilowatts have been installed, the latest in 1949. Two units are still in operation. Difficulty with the development of a reliable mercury boiler has been the most serious drawback to the application of this cycle; however, modern methods of controlling mercury can overcome the boiler problems encountered. The obvious economic drawback is that mercury is very expensive.

The efficiency of the mercury-steam cycle as compared to the steam cycle is shown in Fig. 3b. The efficiency improvement is principally due to the higher critical temperature of mercury, which permits the mercury-steam cycle to use more heat at maximum cycle temperature.

For maximum efficiency, minimum cycle temperature must be as low as possible. Available cooling water temperature normally establishes the practical exhaust temperature somewhere in the vicinity of 100 degrees F. Water at 100 degrees F has a saturation pressure of approximately 1.0 psia, which means very large exhaust volumes are necessary. Ammonia, with a vapor pressure of 200 psia at 100 degrees (Fig. 1), would allow a large decrease in the required exhaust volume. Therefore, as larger ratings for steam turbines are considered, some thought should be given to a binary cycle in which some fluid, such as ammonia, is used as the low-temperature (subposed) working fluid. Such a cycle would not offer efficiency improvement, but it would make economic gains possible by eliminating large rotating apparatus. In place of rotating apparatus, additional static heat transfer apparatus such as a steam-condenser/ammonia-boiler would be required. Such a cycle is illustrated in Fig. 4.

In looking for more economic power generation cycles in the range of 1100 to 1400 degrees F or higher, either a binary mercury-steam cycle or a ternary mercury-steam-ammonia (or fluorocarbon) cycle presently comes closest to approaching a practical ideal working fluid arrangement.

Evaluation and prediction of working fluids for future economic power generation cycles is difficult and far from dependable. Certainly, the trends of past progress can no longer be merely extrapolated. This would ignore new methods, possible major breakthroughs in important areas, and known limitations of present systems.

Westinghouse
ENGINEER
Jan. 1963

---

[1] "The Mercury-Vapor Process," by A. R. Smith and E. S. Thompson, *Transactions of the ASME*, Vol. 64, 1942, pp 625–46.

[2] "Mercury for the Generation of Light, Heat, and Power," by H. N. Hackett, Ibid., pp 647–56.

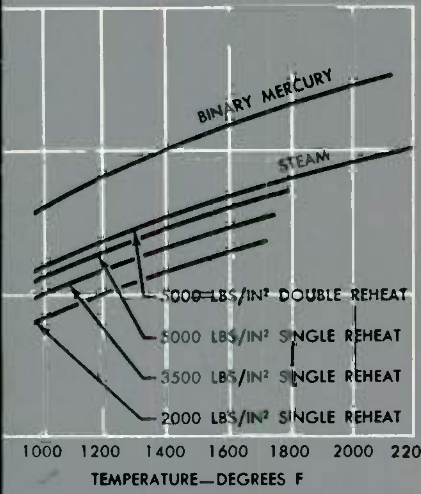


Fig. 3 Efficiency of binary-mercury cycle and steam cycle.

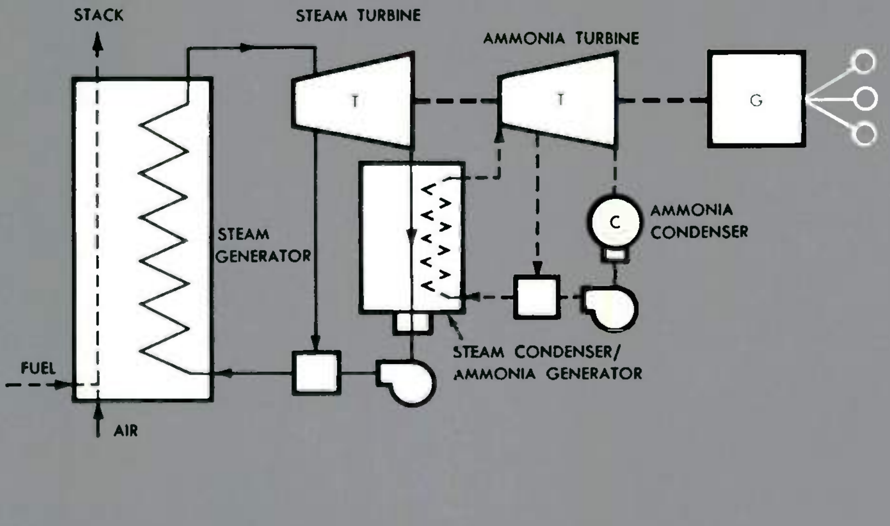


Fig 4. Diagram of combined steam-ammonia cycle.

Turbine Supervisory Instruments for Modern Station Operation

Solid-state devices and circuitry, and a new power drawer design, provide improved reliability for Turbo-Graf supervisory instrumentation.

J. H. Bednarek
Assembled Switchgear and Devices Division
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Turbine supervisory instruments serve as reliable sentinels to help assure safe operation of modern steam turbines. The primary function of these instruments is to accurately record the mechanical status of a machine, which they do by monitoring seven basic turbine characteristics: speed, governor valve position, rotor eccentricity, casing expansion, rotor position, differential expansion, and rotor vibration. The supervisory equipment must correctly and rapidly advise of any abnormal situation that might cause serious damage to the turbine. Therefore, the electrical detectors within the turbine and the power units that interpret the detector information at the control board must be rugged, trustworthy devices. The need for reliability is even further emphasized now that supervisory instruments serve as primary information sources to digital control computers and data loggers being installed in some of the newer stations. And finally, since central station turbine generators often run continuously for several years between shutdowns, their supervisory instrumentation must operate reliably over these same periods.

For all of these reasons, reliability was the prime requirement in the recent design of a new line of Turbo-Graf supervisory instruments. Furthermore, the new design improves the coordination of supervisory instrumentation with station computers or data loggers. For example, the vibration and eccentricity measuring devices will have a built-in "live zero function," which will continuously check the equipment to be sure there has been no equipment failure. (The value of eccentricity and vibration could truly be zero during normal turbine operation whereas the other instrument readings cannot.)

Solid-State Circuitry

Reliability improvements made possible by advances in solid-state devices and circuitry provided the fundamental basis for developing the new supervisory instruments. Solid-state devices (no tubes) are used in all equipment that provides outputs for recorders, data loggers, or computers.

Solid-state circuitry has made practical a miniaturized power drawer design, which minimizes panel space requirements and simplifies calibration and maintenance procedures. Many circuits that were previously external to the

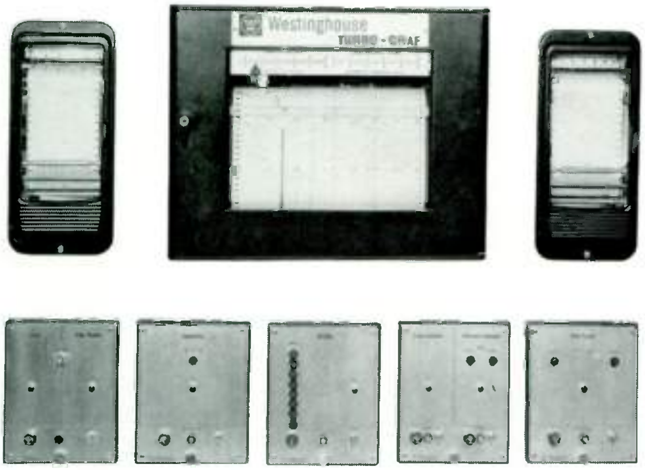


Fig. 1 The panel layout for a typical Turbo-Graf installation consists of five drawout power units—speed and valve position, eccentricity, vibration, casing and differential expansion, and rotor position—and suitable pen and printing recorders.

supervisory instrument equipment, such as alarm circuitry, have been built into the drawer, so that a minimum of additional installation wiring is required.

A panel layout for a typical Turbo-Graf installation is shown in Fig. 1. It consists of five drawout power units, two trend recorders, and one 16-channel printing recorder. Each drawer has a 7 by 8½ inch front, and is housed in an individual enclosure approximately 21 inches deep (Fig. 2). A spiral cable between the back panel of the enclosure and the drawer unit allows the drawer to be withdrawn without de-energizing input power, input and output signals, etc. (However, interlock switches disengage external alarm circuits when the drawer is withdrawn.) With this arrangement, drawer circuitry can be checked and recalibrated, or alarm setpoints can be changed.

A power switch, lamp, fuse, and test pushbutton are mounted on each drawer front. The test button provides a fast check of drawer operation by inserting a test signal, which should give a specific reading on the recorder. A test module in each drawer allows for a calibration check of the total circuitry.

The two trend recorders are five-milliampere D'Arsonval-movement devices, approximately 14 by 6 by 10 inches deep. One records axial rotor position, the other records both rotor speed and governor valve opening. Not shown, but furnished, is a speed indicator, approximately 4 by 4 by 5 inches.

The multipoint printing recorder, 20 by 15 by 14 inches deep, is a high-input impedance device (4 tubes). The chart is split so that eccentricity and vibration are recorded on the left side (12 channels) of the chart; casing expansion and differential expansion are recorded on the right side of the chart (4 channels). Values are printed sequentially at a rate of one channel every five seconds.

Speed-Governor Valve Position

During starting and emergency conditions, such as overspeed, a record of speed is important. When the unit is on the line, speed is known to be synchronous and a record of governor valve position, which varies directly with load, is often desired. Therefore, since valve position and speed information are not required simultaneously, a single recorder can share these two functions. The selection of either valve position or speed input to the recorder is controlled by the position of the main generator breaker (speed is recorded when the breaker is open, and valve position when the breaker is closed). An auxiliary "a" contact of the main breaker (Fig. 3) operates the recorder input transfer relay.

Governor valve position is sensed by measuring a signal from a potentiometer that is coupled to the valve mechanism. The rotation of the potentiometer arm varies directly with valve opening. This potentiometer, energized by a constant voltage, furnishes a signal to the recorder proportional to its wiper-arm position.

The speed signal is provided by a permanent-magnet tachometer generator mounted on the end of the main generator rotor. The tachometer generator rotor is supported by the main generator shaft. The stator is an eight-pole armature supported by the generator frame, which surrounds the tachometer generator rotor. No bearings are required with this arrangement.

The ac output of the tachometer generator is fed into a saturating-core transformer, as shown in Fig. 3. The transformer secondary output consists of two equal size pulses of short duration for each cycle of the tachometer generator. These secondary pulses are rectified, providing a signal to a recorder responsive linearly to frequency rather than voltage of the tachometer generator.

Eccentricity

When a unit has been shut down after operation, the turbine rotor tends to bow because of uneven cooling between the upper and lower half of the rotor. Usually, the rotor is placed on turning gear operation and rotated at speeds as low as 1.5 rpm to minimize rotor bending.

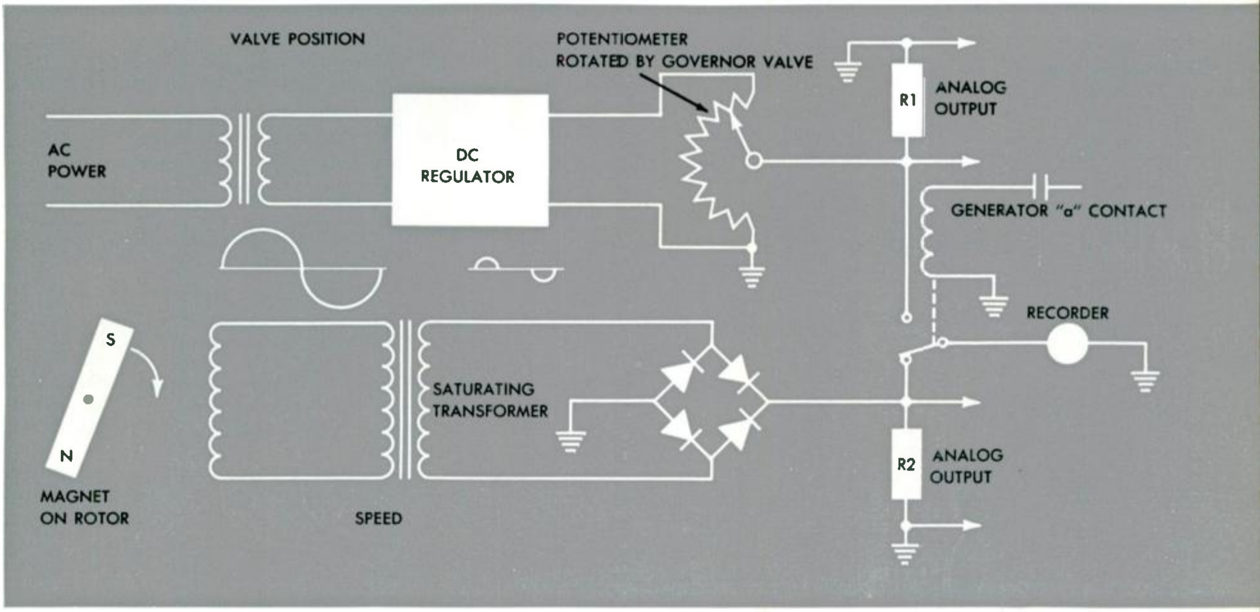


Fig. 2 (Left) Turbo-Graf power drawer construction simplifies installation, calibration, and maintenance.

Fig. 3 (Right) The selection of speed or governor valve position, monitored with a single recorder, is determined by the position of the main generator breaker.

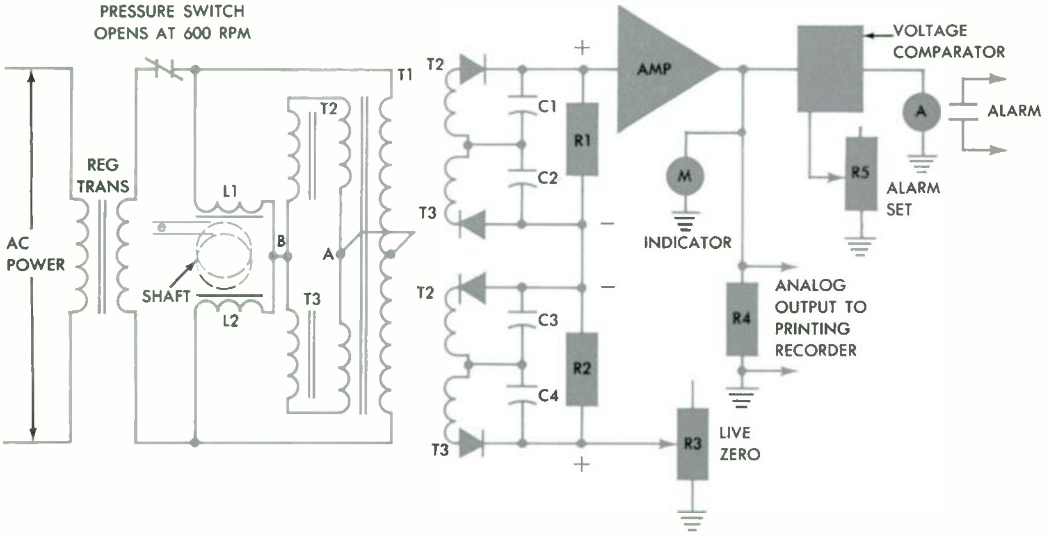


Fig. 4 Any eccentricity in the shaft is sensed by pickup coils connected in series across a regulated line. Two equal secondaries of transformer T1 energize two identical transformers T2 and T3. One set of secondaries of T2 and T3 charge an RC circuit that has a long time constant; a second set of secondaries of T2 and T3 charge an RC circuit with a short time constant. These RC circuits are charged with opposite polarity, so that the drop across them is the difference of their voltages.

When shaft eccentricity is zero, the voltage at *B* is the same as at *A*. Hence, the charge on the two RC circuits will be equal and opposite giving a sum voltage of zero. When shaft eccentricity is not zero, the voltage at *B* will change because of the impedance change in the pickup coils. This causes the charge on the long time constant RC circuit to be higher than the short time constant circuit. Their difference voltage is proportional to shaft eccentricity.

A rotor at rest will tend to bend because the upper half of the casing enclosing the rotor is at a higher temperature than the lower half of the casing. By rotating the rotor slowly on turning gear, uniform heating of the rotor results, allowing the rotor to "run true." Rotor eccentricity is checked continuously as the unit is taken off turning gear and brought up to higher speeds. When the unit attains the speed of 600 rpm, an oil-pressure switch cuts out the eccentricity instrument and energizes the vibration instrument, since any bowing of the rotor at this speed will appear as vibration.

The mechanical method for reading eccentricity is to place the foot of a dial indicator on the rotor and subtract the minimum reading from the maximum reading. However, the ideal eccentricity instrument should display its reading as a smooth curve from turning gear speeds to 600 rpm, so that the operator can read the value of eccentricity directly. The electrical method for accomplishing this is shown in Fig. 4.

Detector coils are placed 180 mechanical degrees apart, so that rotor shaft eccentricity will increase the air gap between one coil and the rotor (causing this coil impedance to decrease), and decrease air gap between the other coil and the rotor. Memory circuits take the signals from the detector coils, remember the maximum excursion, remember the minimum excursion, and electrically subtract these values to obtain a difference voltage proportional to eccentricity; the memory circuits gradually forget this value so that changed values can be received.

The difference voltage, amplified by a solid-state amplifier, is the input to the printing recorder. This voltage output is also used to drive a transistorized voltage-comparator type alarm circuit. A current output is also provided for an eccentricity indicator, if desired.

Casing Expansion

As a unit is taken from its cold condition to its hot and loaded state, the thermal change in the casing will cause

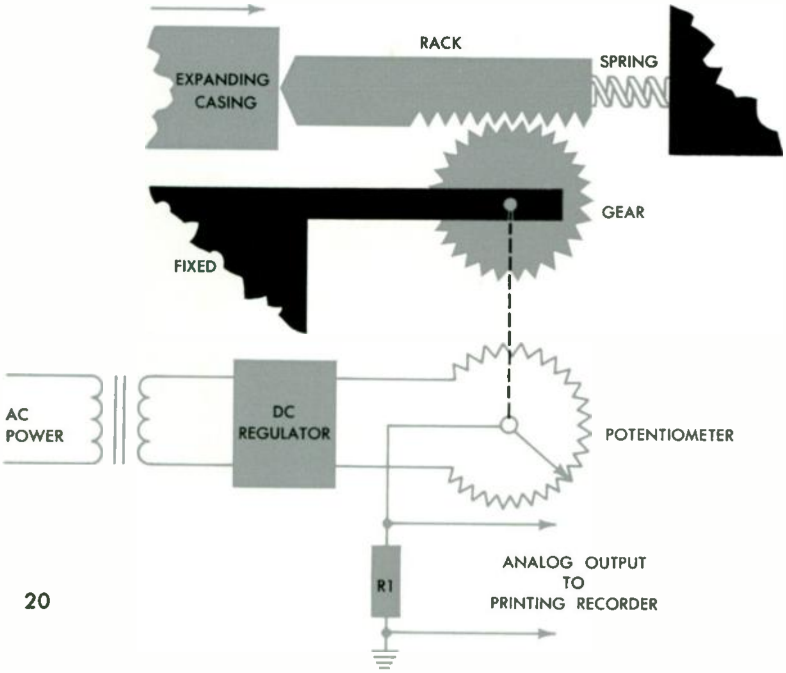


Fig. 5 (Left) Casing expansion is sensed by a rack-and-pinion arrangement, which drives a potentiometer arm to provide a signal to the printing recorder.

Fig. 6 (Right) Rotor position movement in the governor-end or generator-end direction causes a change in reluctance of the sensing coils, L1 and L2, resulting in an unbalance current in the bridge circuit.

Fig. 7 (Far Right) Differential expansion is measured by an unbalanced-bridge technique. Since relative movement can be as much as one inch, air gap variation is reduced by machining a 14-degree protuberance on the shaft, thus permitting the coils to operate within their linear gap range.

it to expand. Inasmuch as one end of the unit is secured to the foundation, the casing will expand axially away from this anchored point. The opposite end of the unit is designed to move freely along lubricated longitudinal keys. If for some reason the nonsecured end of the unit is hampered from sliding smoothly along the guide keys as the casing expands, damaging stresses can develop causing serious damage to the units.

Detection of casing expansion is made using a potentiometer-type transmitter located at the end of the unit (Fig. 5). This transmitter consists of a spring-loaded rod to which a toothed rack is fastened. The rod is butted against the casing housing so that the expanding casing will move the rod. A gear on the detector potentiometer shaft is coupled to the rod rack to cause the potentiometer to rotate proportional to casing expansion. Thus, an operator can observe if the potentiometer signal indicates normal casing expansion.

Rotor Position

Axial movement of the turbine rotor can be caused by wear of the thrust shoes or by a heavy thrust load on the rotor. Present turbine designs are such that axial movement can be in the generator-end or governor-end direction.

Axial motion is measured with an electrical bridge circuit (Fig. 6) consisting of a pair of pickup coils at the turbine, and resistors mounted in the power drawer unit. The pickup coils are mounted on each side of a disc on the rotor shaft. This disc is located close to the thrust collar to prevent thermal expansions and contractions between the disc and collar from appearing as rotor position errors.

When the turbine is in a normal position, equal air gaps exist between the coil and the disc. However, when axial movement occurs, the air gap between one coil and the disc increases while the gap between the other coil and disc decreases, causing a change in reluctance value of the two coils. This reluctance change unbalances the bridge circuit, and the unbalance signal is rectified for display on a recorder as rotor position.

Silicon controlled rectifiers are used as the alarm switching devices. These are set by potentiometers at predetermined values of rotor motion toward the governor end and the generator end of the unit.

Differential Expansion

When steam is admitted to a turbine, thermal expansion will affect both the rotating parts and the casing. If the rotating parts expanded at the same rate as the casing, there would be no problem. But since the rotor is of smaller mass than the casing, it will heat faster and therefore expand faster than the casing. Axial clearances between the rotating and stationary parts are provided to allow for this differential expansion in the turbine. However, rubs between the rotating parts and stationary parts will occur if allowable differential expansion limits are exceeded. Therefore purpose of the differential expansion instrument is to chart the relative motion of the rotating parts and stationary parts.

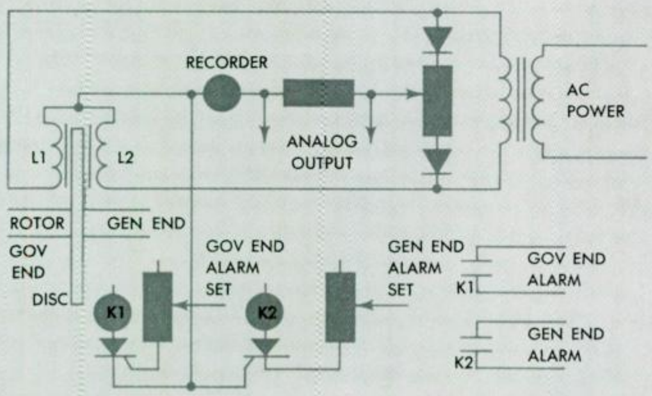
An electrical bridge circuit, a duplicate of that used for measuring rotor position, measures differential expansion. However, because differential expansion can be as much as one inch, much beyond the linearity gap range of the pickup coils, a machining technique on the turbine rotor is required to correct for this characteristic. Therefore, a protuberance on the rotor is machined to a 14-degree angle with respect to the rotor centerline (Fig. 7). Pickup coils are mounted with their pole faces parallel to the machined surface, so that axial movement of one inch of the rotor produces only 0.240 inch change in the coil gap (cosecant of 14 degrees = 4.13). This allows the pickup coils to be operated within their linear gap range.

As with rotor position, alarms can be set for off-normal differential expansion in both the governor-end direction and the generator-end direction.

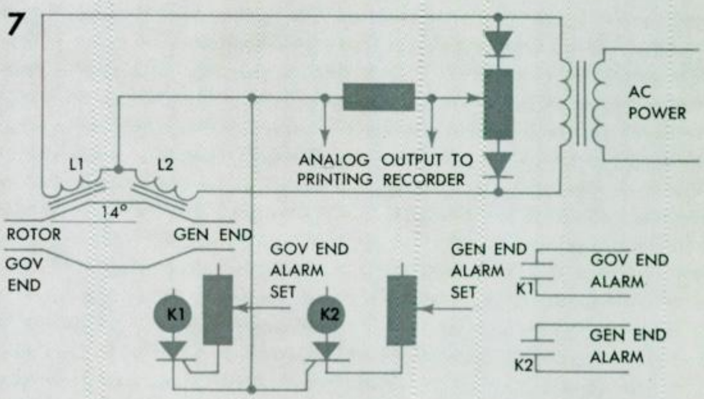
Vibration

Since the rotor is the source of turbine vibration, rotor vibration is the logical quantity to monitor. Measurement must be made directly at the rotor because vibration of other more accessible points, such as the rotor bearing structure, varies erratically in both amplitude and phase angle from rotor vibration. For this reason, the vibration detector is a probe, which has a babbitted shoe riding directly on the rotor (Fig. 8). To this shoe is fastened a push rod. At the opposite end of the rod is a coil, surrounded by a strong seismically mounted permanent magnet. As the rotor vibrates, coil movement in the magnetic

6



7



field generates an alternating voltage proportional to both magnitude of rotor vibration and to rotor speed.

Since vibration is measured from rotor speeds of 600 rpm to 3600 rpm, the vibration detector voltage will be six times greater at synchronous speed than at 600 rpm for the same amplitude of vibration. Because vibration amplitude is the only value desired, a corrective scheme must be used to eliminate the error due to rotor speed. This is accomplished by applying the detector voltage to an integrating circuit, consisting of a resistor and capacitor, which has a time constant longer than the frequency of the slowest vibration wave. The voltage drop of the integrating capacitor is amplified and converted to a dc voltage. This voltage is applied to a channel of a printing recorder and to a transistorized voltage-comparator alarm circuit. When the input signal to the alarm circuit exceeds a preselected value, a common relay closes and a particular alarm lamp on the front of the drawer unit lights, indicating the off-normal bearing.

Because vibration is one of the most important functions monitored, each bearing detector signal is taken to its individual plug-in amplifier and alarm circuitry, which is mounted on a printed-circuit card (Fig. 8). This arrangement assures continuous alarm monitoring for all pickups and makes the alarm circuitry completely independent of the recorder circuitry. This contrasts with earlier vibration schemes that had only one common amplifier for all bearing pickups and used a scanning device for sequentially taking all bearing signals to a common amplifier. The new scheme, therefore, eliminates the need for input scanning and the problems characteristic of such an arrangement.

Conclusion

Turbo-Graf supervisory equipment has been redesigned to obtain higher accuracy and better reliability. Drawer-type units have been used to simplify installation, calibration, and maintenance procedures.

Solid-state circuitry is used in drawer units to give long reliable service. Multiple use of similar components and similar circuits should prove helpful in maintaining the equipment. For example, total circuitry for rotor position and differential expansion is the same; total circuitry for casing expansion and valve position is the same; and alarm circuitry for vibration and eccentricity is the same.

In addition to recording turbine rotor axial position, rotor eccentricity and vibration, casing and differential expansion, and speed and governor valve position, the new line of turbine supervisory instruments is designed to provide analog outputs of above functions for computer operation.

Westinghouse
ENGINEER
Jan. 1963

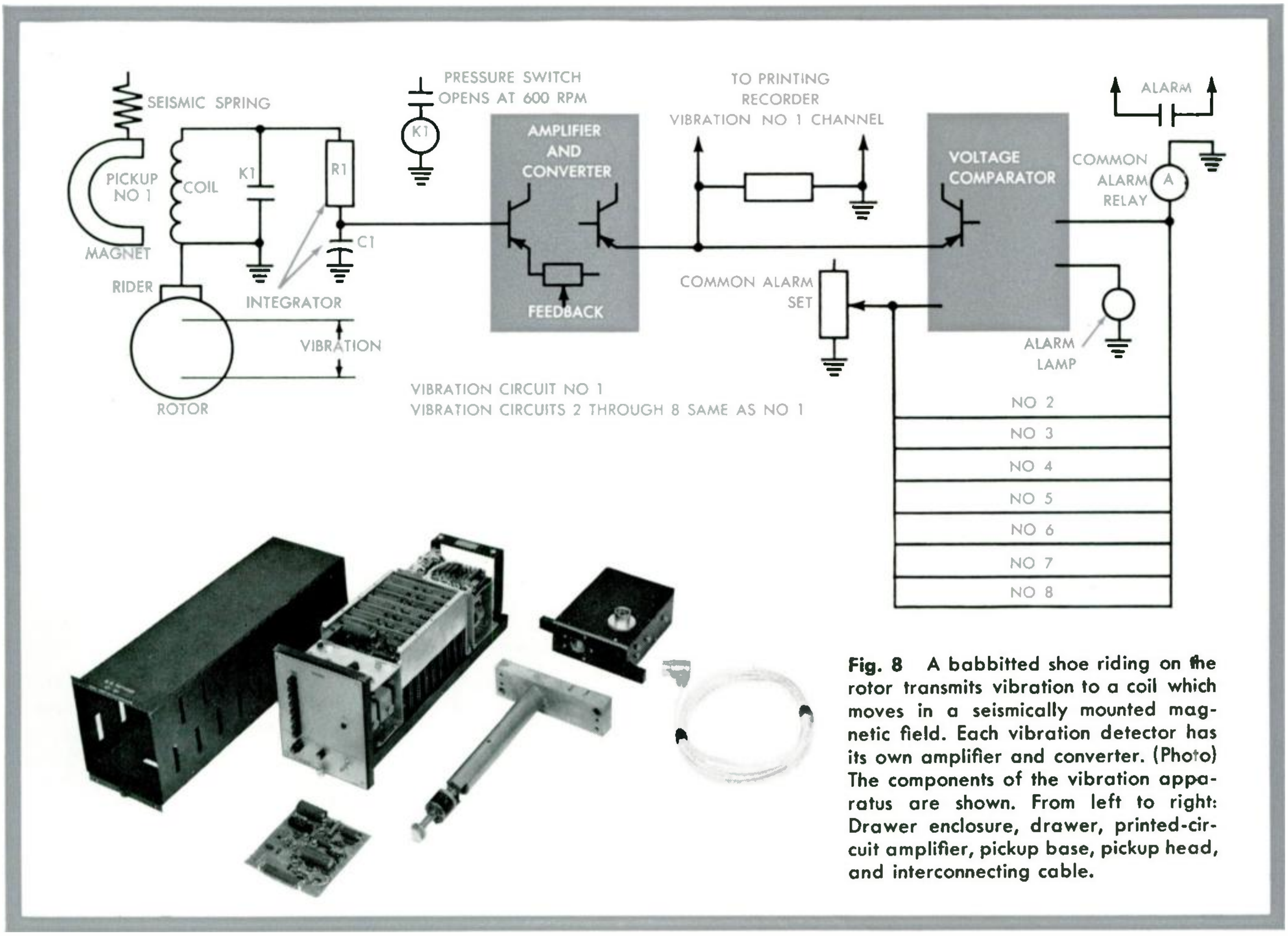


Fig. 8 A babbitted shoe riding on the rotor transmits vibration to a coil which moves in a seismically mounted magnetic field. Each vibration detector has its own amplifier and converter. (Photo) The components of the vibration apparatus are shown. From left to right: Drawer enclosure, drawer, printed-circuit amplifier, pickup base, pickup head, and interconnecting cable.

The Doppler effect, the apparent change in frequency of a wave train because of relative motion between source and observer, plays a key role in this new navigation system

Ship Navigation with Satellites

E. S. Keats
Manager, Transit Project
Electronics Division
Westinghouse Electric Corporation
Baltimore, Maryland

Satellites in space can provide highly accurate position information to ships with radio receivers than can measure and interpret the Doppler frequency shift of the satellite signal, and decode the orbital and time information contained in the transmission. A satellite navigation system can be exceptionally accurate because it depends on the measurement of time and frequency, which can be remarkably precise. Satellite navigation is suitable for surface craft and submarines all over the world.

History

A satellite navigation system for Navy submarines was conceived by the Applied Physics Laboratory of Johns Hopkins University; technical direction of the system development has been carried out by the Applied Physics Laboratory for the Navy.

Westinghouse participation in the satellite navigation program began with a contract in January 1961 to study and design a receiver set. Additional contracts for building prototypes and production equipments have followed. The first equipment, delivered in December 1961, has exceeded most of the performance requirements.

In addition to the design and construction of the receiver set, Westinghouse is responsible for the integration of the antenna, data processor, and computer with the receiver to form the *Navigational Shipboard Receiver* (AN/BRN-3). Associated with Westinghouse in the development of the AN/BRN-3 are: the Applied Physics Laboratory of the Johns Hopkins University, the technical director for the Navy; Chu Associates, builders of the antenna; and Thompson Ramo-Wooldridge, Inc., builders of the data processor and computer.

Seven experimental navigational satellites have been built by the Applied Physics Laboratory for the Navy, of which five have been launched into orbit by the Air Force to prove the practicability of the navigation concept.

The Navigation Satellite System

When the Navy's satellite navigation system becomes operational, present plans call for four polar-orbiting satellites (600-mile altitude) plus a ground network. The ground stations track the satellites and transmit Doppler-versus-time information to a computer center. The computer calculates and predicts the orbit of each satellite for at least twelve hours in advance. This orbital information, in the form of Keplerian orbital elements and correct time, is transmitted to each satellite once every twelve hours as it passes over a ground transmitter station. The satellite stores these orbital elements in its memory, and transmits them, together with timing information, every two minutes as it orbits the earth. The satellite carrier signal, provided by a precision frequency source in the satellite, is phase modulated with this orbital data and timing information in digital code.

How Satellite Navigation Works

As the navigational satellite orbits the earth, the relative motion between the satellite and a receiving station on earth is a combination of satellite orbital motion, earth rotation beneath the orbital path, and motion of the receiving station with respect to earth. Satellite orbital velocity is about 25 000 feet per second; rotation of the earth's surface varies with the latitude of the receiving station, from zero at the poles to a maximum of 1600 feet per second at the equator; and ship velocity is usually 20 to 40 feet per second. The change in position of a ship during the time that signals from the satellite are being received requires that all calculations be related to a common position.

The relative motion between the satellite and the receiving station produces an apparent frequency shift (Doppler effect) in the signal received from the ultra-stable radio transmitter in the satellite. The amount of the frequency shift depends upon wave length of the transmitted signal and relative velocity of the satellite according to the relationship:

$$\Delta f=\frac{V_r}{\lambda}$$

where Δf is the apparent of Doppler frequency shift, λ is

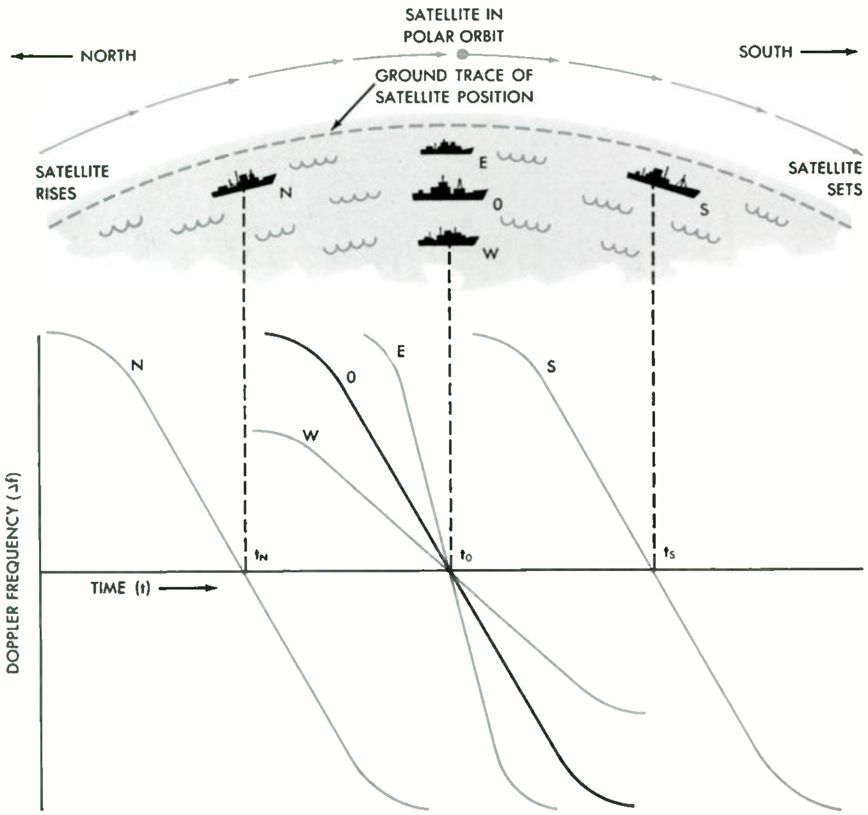


Fig. 1 Extremely accurate measurements of Doppler frequency and time provide the information necessary to determine receiver latitude and longitude.

The navigational satellite transmits its orbital position continuously. From this information and the time that the Doppler frequency passes through zero, latitude can be determined.

Longitude is determined by the rate of change of Doppler frequency. For example, assume position 0 as the reference, located west of the satellite orbit: A receiver west (W) of position 0 would have a lower rate of change in Doppler frequency; a receiver east (E) of position 0 (closer to the satellite orbit) would have a greater rate of change. Hence, Doppler frequency rate of change and navigational satellite orbit position provide the necessary information for computing receiver longitude.

the wave length of the transmitted signal, and V_r is the relative velocity of the satellite with respect to the receiving station.

The relative velocity of the satellite with respect to the receiver is a maximum at the time of satellite rise, when the satellite is more nearly headed toward the receiver. The relative velocity decreases to zero when the satellite reaches the point of closest approach, and increases in a negative sense until it sets.

For example, maximum excursion of the Doppler frequency shift, at time of rise or set, for a satellite operating in the ultra-high-frequency band, with a wave length of say 2 feet, is:

$$\Delta f = \frac{25\,000}{2} = 12.5 \text{ kcs}$$

Typical Doppler frequency versus time plots that would be received at different locations relative to the satellite orbit are shown in Fig. 1. The receiver to the north observes that the satellite rises, passes its zenith, and sets earlier than the center location. The plot of Doppler frequency versus time has essentially the same* shape but is recorded earlier on the time base. The receiver to the south records a similar plot but later on the time base. The receiver to the east observes that the satellite passes the zenith at the same time as the center location and thus has the same time base. The eastern position is closer to the satellite, however, so that the rate of change of Doppler frequency is greater. The receiver to the west is farther from the satellite and, therefore, will record a lesser rate of change of Doppler frequency.

Thus, *latitude* is basically determined by the time that the Doppler frequency becomes zero, and *longitude* by the rate of change of Doppler frequency with time. The ellipticity of the satellite orbit and the nonspherical shape of the earth affect this to a slight degree. A number of measurements are made so that an averaging process overcomes fading and noise effects.

Since the satellite orbit is known precisely, very small differences in latitude and longitude can be determined by making the receiver sufficiently sensitive to record small variations in Doppler frequency as a function of time.

A number of methods exist for computing receiver position, once Doppler frequency versus time is measured and the orbital elements have been obtained. The AN/BRN-3 equipment employs an electronic computer with a preestablished program to perform the calculations, which are made after the satellite has completed its pass.

The transmission path of radio waves from a satellite to the earth is bent by the ionosphere. If the Doppler frequency were not corrected for this refraction, the rate of change of Doppler frequency would appear to be less, so

---

*There would be a slight difference because (1) the component of velocity due to rotation of the earth is less at a location nearer the pole and (2) meridians converge toward the pole so that the distance to the satellite's track is less for a given difference in longitude.

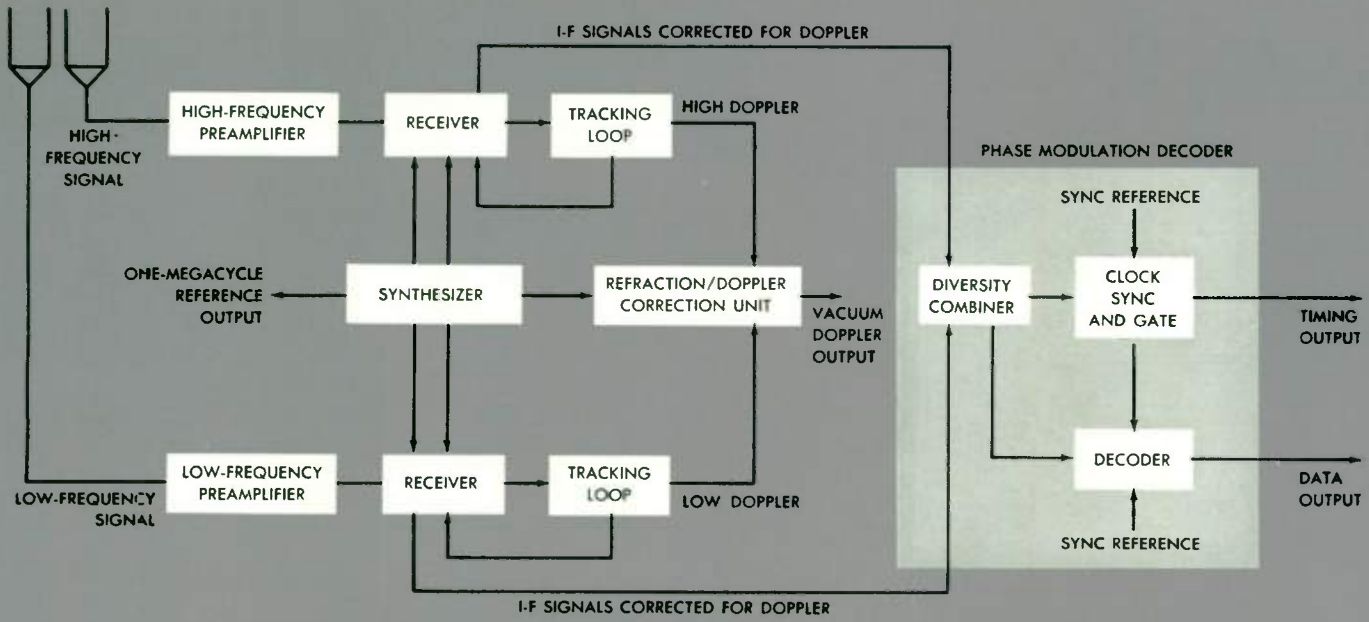
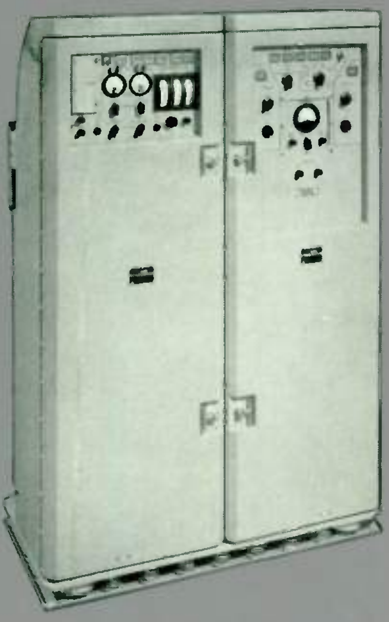


Fig. 2 The satellite signals, transmitted on two frequencies, are received on dipole antennas of essentially unity gain. Both low- and high-frequency signals are amplified and passed through frequency-selective circuits in low-noise *preamplifiers,* which are located near the antennas. Signals from the preamplifiers are passed to the *receivers* via coaxial transmission line. After conversion to intermediate frequencies, further amplification and selection is provided up to the *tracking loops.* The tracking loops consist of phase-locked oscillators and active filters, which follow (or track) the Doppler frequency. The tracking loop operates under computer control to automatically acquire the satellite signal, and to switch the active filter bandwidth to provide the optimum compromise between phase error due to the tracking loop dynamics and phase error due to receiver thermal noise. A manual mode of acquisition and bandwidth selection is also provided.

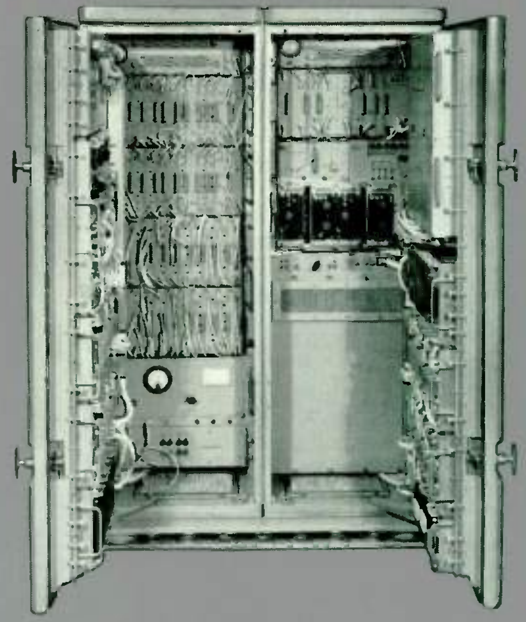
Doppler signals from the high- and low-frequency tracking loops are passed to the *refraction/Doppler correction unit.* Here, by a multiplication and subtraction process, two simultaneous equations are solved to provide vacuum Doppler output.

The tracking loop maintains i-f signals of constant frequency regardless of the Doppler frequency variations of the incoming signals. The signals from each receiver go to the *diversity combiner* in the *phase-modulation decoder.* The combiner delivers output signals with a signal-to-noise proportional to the combination of the signal-to-noise in the input signals. The same phase modulation is transmitted on each frequency. One output of the combiner goes to the *decoder,* where the phase-modulation signals are decoded. The other combiner output goes to the *detector and synchronizing circuits* that synchronize a local clock to the incoming bit rate. Timing pulses are generated and gating signals are generated for the decoder circuits previously described.

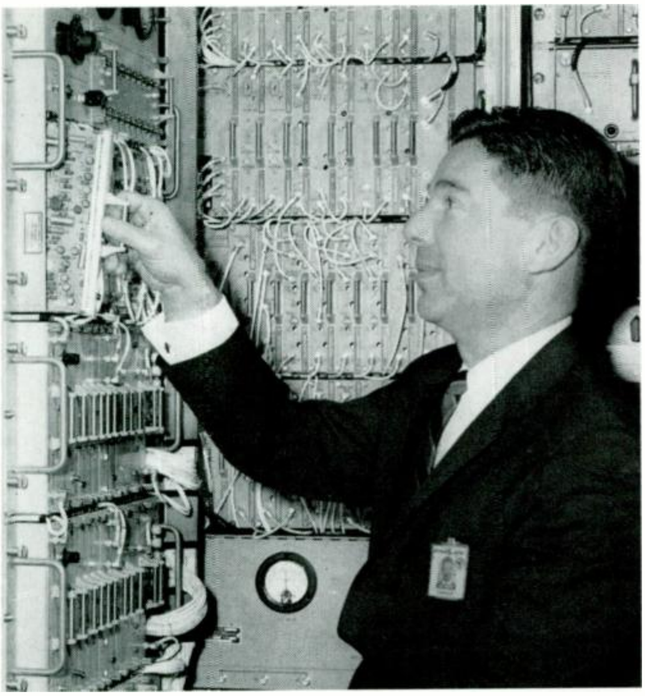
The *synthesizer* generates a one-megacycle reference signal, derived from a precision one-megacycle frequency standard. This unit provides ultra-stable frequencies throughout the equipment.



Left The receiver set is 60 inches high, 42 inches wide, and 15 inches deep. The receiver control panel is on the left, and the readiness control panel on the right.



Right Inside, the amplifier portion of the two receiver units is located above the frequency synthesizer on the left; on the right, the readiness test equipment is above the phase modulation decoder.



Module construction is used throughout the receiver. The module is being inserted in the control portion of the receiver units (inside left door); above the control portion is the diagnostic test equipment.

that the receiving station would seem farther from the satellite. Fortunately, refraction is inversely proportional to the frequency of the transmitted signal*. Therefore, the satellite transmits on two frequencies, which have an integral relation and are combined in the receiver in inverse proportion to frequency to give a single, true frequency called *vacuum Doppler frequency* (i.e., information that would be received in a vacuum, where there is no refraction).

The Receiver Set

The receiver set consists of preamplifiers, receivers, refraction correction unit, frequency synthesizer, phase modulation decoder, and operational test equipment (Fig. 2). Frequency conversion, amplification, automatic gain control, and filtering are carried out with extreme precision since any incremental change of phase as a function of time would constitute a frequency error in the output Doppler and become a position error for the navigator.

The receiver provides four basic outputs, which are needed for the navigation solution: vacuum Doppler frequency (corrected for refraction); data bits that furnish the navigator with satellite orbital information; timing pulses that provide accurate time information from the satellite; and a station reference frequency at one megacycle, which runs the station clock and, through the frequency synthesizer, provides all the conversions and reference frequencies that are needed in the system.

Westinghouse
ENGINEER
Jan. 1963

---

*To a first order approximation. When the refraction is great enough to require use of a second order term, the receiver indicates the deterioration of vacuum Doppler information on the operator's control panel, and indicates "no-go" to the computer.

PRODUCTS FOR INDUSTRY

ELECTRIC WALK transports passengers on a continuous treadway, either horizontally or up and down ramps. The walk is available in any length and is built with tread widths of 27 or 36 inches. Its drive mechanism is located within the treadway loop to save space, and a steel-reinforced rubber gearbelt drive provides smooth and quiet operation.
Westinghouse Elevator Division, Jersey City, N. J.

SEMIAUTOMATIC WELDING SYSTEM has a constant-voltage single-phase silicon rectifier power source. A voltage-sensing control automatically corrects for variations in the weldor's hand movements. The SA-150 system's hand gun has an amperage control device in its handle and a mechanized wire reel with adjustable feed rate.
Westinghouse Westing-Arc Division, Buffalo, N. Y.

MOTOR PROTECTION RELAY provides staggered starting of a number of motors energized from the same feeder line and also gives undervoltage protection for motor and contactor. Designed for 440-volt motors, the SVP relay has a 550-volt continuous rating. Contact rating is 10 amperes. Dropout is adjustable between 365 and 440 volts, with pickup at 112 percent of setting. Time delay is adjustable over a 2- to 30-minute range by turning a knob on the front of the unit. The relay mounts in a standard watt-hour meter socket for indoor or outdoor service.
Westinghouse Electric Corporation, P. O. Box 2099. Pittsburgh 30, Pa.

POLE-MOUNTED SINGLE-PHASE FEEDER VOLTAGE REGULATORS are rated from 2400 volts delta to 24 960 volts wye. Power ratings range from 19.1 to 250 kva. The units require less exciting current than previous models, and they have an improved coil structure. Bushings are keyed to the cover, the control panel is hinged to the side of the unit, and a switch on the control panel facilitates changing the current transformer ratio when using the load range selector.
Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh 30, Pa.

TECHNOLOGY IN PROGRESS

Low G_2 Picture Tubes

A new line of television picture tubes can be operated with a drive signal of only 35 volts—40 percent less picture signal than standard tubes, and 20 percent less than previous reduced-drive tubes. The improved performance was made possible by a new high-gain electron gun design. The first electron accelerator grid (G_2) requires only 30 volts of potential with respect to the modulator grid (G_1), instead of the usual 300 to 500 volts.

Instantaneous picture tube brightness is controlled by varying picture tube cathode voltage, which causes the first accelerator grid to vary beam current. Maximum current and brightness occur when the cathode is at zero voltage with respect to the modulator grid. This effect is controlled by the spacing of the gun elements.

When the cathode voltage is raised above the 30-volt potential of the first accelerator grid, both the modulator grid and the first accelerator grid become electron beam retarders and prevent the electron beam from being formed and delivered to the tube face. This retarding action makes possible the low drive-signal requirement of 35 volts, which gives complete modulation of the picture from black to maximum brightness.

Low G_2 tubes are now being manufactured in 19-inch and 23-inch sizes. A special order is being shipped for use in a battery-powered, transistorized TV receiver. ■ ■ ■

Low-Power Circuits Developed For Gemini Rendezvous Radar

Low-power flip-flop and stroke gate circuits for a combination 10-megacycle counter and one-megacycle shift register have been developed by computer systems engineers of the Westinghouse Air Arm Division. The combination forms the nucleus of the digital range and angle measuring unit in the Westinghouse rendezvous radar for the Gemini spacecraft being built by McDonnell Aircraft Corporation for the NASA Manned Spacecraft Center.

The range and angle unit measures the range and the antenna angles between the rendezvous vehicle and the target. Its operating temperatures are minus 55 degrees to plus 100 degrees C.

Use of the low-power flip-flops and stroke gates adds to the reliability of the combination counter and shift register by minimizing the amount of heat generated and by permitting very high derating factors for the components. The circuits also reduce the volume, weight, and power requirements of the range and angle measuring unit and thus help provide a system suitable for space use. ■ ■ ■

Induction Annealing For Thin Steel Strip

Steel strip is commonly annealed after rolling by passing it through a continuous furnace. This prepares it for subsequent processing and forming operations. The present furnace process, however, sometimes causes trouble when handling thin strip used in the new lightweight "tin" cans.

The difficulty is that furnace temperature cannot be varied quickly. In present practice, the furnace is operated at a temperature considerably above the desired strip temperature. The strip temperature desired is obtained by keeping the speed of the strip constant as it passes through the furnace. If the strip is stopped or slowed because of process conditions on either side of the furnace, it may be overheated to the point where it breaks under the applied tension.

Recent development studies and pilot tests conducted by Westinghouse Industrial Systems and the Industrial Electronics Division show that this difficulty can be overcome by supplying part or all of the heat by high-frequency induction heating. Induction heating permits very fast heating to recrystallization temperature. The amount of heating can be changed in fractions of a second by adjusting the amount of power supplied to the induction heating coil, so it can easily be made to respond to changes in strip speed, gauge, and other conditions. Consequently, induction heating permits control of final strip temperature at precise reproducible levels. This is in sharp contrast to the present furnaces, which respond slowly to temperature control changes.

When applied with furnace preheat, induction heating is economically feasible for high-speed high-tonnage annealing. Because induction heating heats at the same rate whether strip emissivity is high or low, it is not affected by the surface condition of the strip. Also, the precise temperature control obtainable improves control of the strip's metallurgical properties.

A typical plant equipment arrangement would be a 600-kilowatt 100-kilocycle radio frequency oscillator energizing a six-foot heating coil. Power control signals would cause a fast-response magnetic-amplifier regulator to vary the ac voltage to the oscillator plate voltage supply. ■ ■ ■

Hollow Cathode Tubes and Atomic Absorption Spectroscopy

Atomic absorption spectroscopy is a relatively new quantitative analytical technique, developed about six years ago in Australia. The technique is especially useful for rapid analyses of soils, body fluids, and trace elements in precious metals.

Basically, the method consists of passing the atomic emission spectrum of a selected element through a flame containing unexcited atoms of the same kind as the radiation source; the desired atomic emission line is selected with a monochromator and its intensity measured. (See diagram.) The radiant energy source is usually a hollow cathode tube with a cathode made of the element to be investigated.

For example, to analyze for zinc, a zinc-cathode tube is used, which emits radiation from the zinc atomic line at 2138 Angstroms. The radiation is passed through a flame, into which a solution containing zinc atoms is aspirated. A monochromator isolates the Zn 2138 A radiation that has passed through the flame, and a photoelectric detector registers its intensity. The greater the concentration of zinc atoms in the flame, the greater the absorption of the Zn 2138 A line. Therefore, to determine the zinc concentration in an unknown solution, a calibration curve is first developed by aspirating water (no zinc atoms) and then several solutions containing successively larger known amounts of zinc. (See graph.) The sample containing an unknown amount of zinc is then aspirated into the flame. From its intensity reading and the calibration curve, the zinc concentration can be determined.

Advantages of atomic absorption spectroscopy include speed, freedom from interferences, sensitivity, and ability to analyze for some elements, such as zinc and calcium, that are difficult to determine by other methods.

Westinghouse tube designers have perfected a hollow cathode tube for this application. It consists of a cathode and an anode sealed in an argon or neon atmosphere. (See photograph.) The tube operates in the glow discharge region where gas ionization is produced by electrons that have been liberated from the cathode by impinging positive ions. The excited cathode atoms in the negative glow region produce the desired atomic spectrum radiation. Because of the hollow cathode structure, maximum use is made of the positive ions, metastables, and photons in producing new electrons. This results in higher current density for a given cathode area and higher positive ion density, so that more of the sputtered cathode atoms are excited.

The operating characteristics of the hollow cathode tube are determined by the cathode material, the type of gas fill, and gas pressure. The atomic spectrum lines desired and the band pass of the instrumentation usually determine the gas fill, which is generally neon or argon.

The wavelength region to be investigated also determines the window material. The most versatile window is quartz, which provides good transmission down to about 2000 Angstroms but is difficult to seal. Another common material is Pyrex, which is good from about 10 000 Angstroms down to 3000 Angstroms.

Requests from research investigators in universities and industry have prompted Westinghouse research scientists and tube designers to investigate hollow cathode tubes with unusual cathode materials. The spectral and electrical characteristics of rare earth and alkali metal cathodes are presently under examination, and stability and life tests are being run. Examples are a europium (rare earth) tube and a lithium (alkali metal) tube. New materials will continue to extend the boundaries of atomic absorption spectroscopy. ■ ■ ■

Tin Reflow by Combination Conduction-Induction Heating

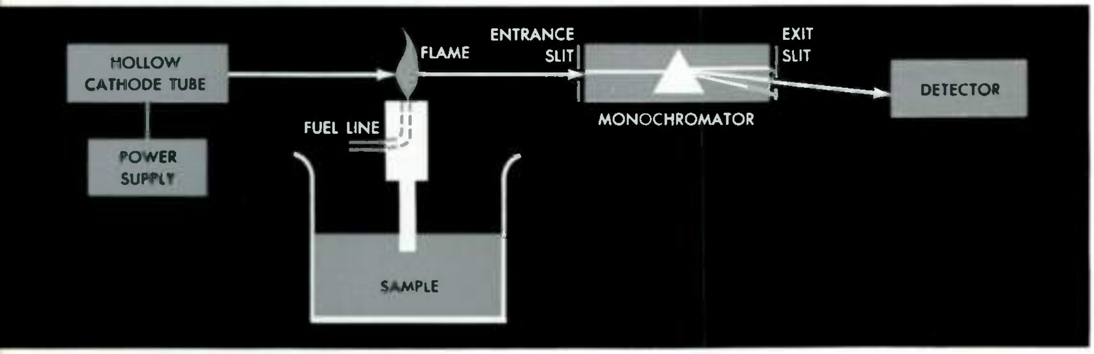
In the electrolytic tinning process, steel strip is plated continuously with tin and then heated to reflow and brighten the tin. Two basic methods have been used for reflowing tin electrically—conduction heating and induction heating.

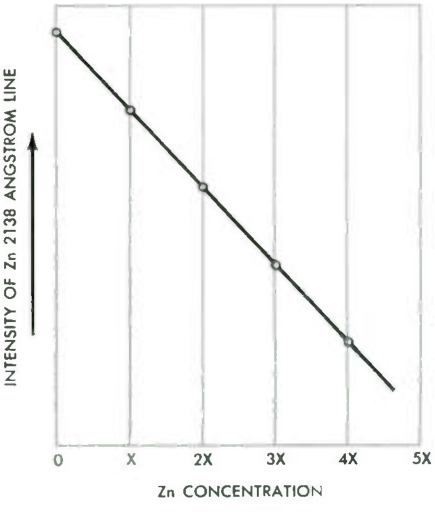
In the conduction method, electric power fed into a section of the strip through rolls heats the section. Low-voltage high-current 60-cycle power is used, with the current proportional to line speed. In the induction heating method, the strip is heated by passing it through a radio-frequency coil.

Now, the two methods have been combined. The strip is preheated by conduction, then passed through an induction coil that heats it rapidly and accurately to reflow temperature.

Conduction and induction heating sections have their own regulators. Each receives a basic line speed signal that varies the dc excitation to a saturable-core reactor, regulating the reactor's output. This controls the power output of a transformer in each section, thereby controlling power supplied to the conduction section and controlling the output of a rectifier and oscillator in the induction section.

Below This block diagram illustrates the principal components of an atomic absorption spectroscopy apparatus.
Right An ideal calibration curve for atomic absorption spectroscopy.
Photo Hollow cathode tubes developed for atomic absorption spectroscopy produce the desired atomic spectrum radiations.





Part of a shipment of the new AN TPS-22 tactical long-range search radar is shown here about to leave the Westinghouse Electronics Division plant for Seymour-Johnson Air Force Base, Goldsboro N.C. The complete radar—components, inflatable antenna, and radome—can be transported in about five trucks like this one. The AN/TPS-22 radar is part of the 412L weapons system. It can be set up and in operation within six hours after landing anywhere on the globe. The radomes on the hill house a prototype AN/TPS-22 radar (foreground) and other equipment undergoing test

The basic signal for the induction section is modulated by a flow-line position signal generated by a photoelectric scanner, providing vernier control for the section.

When line speed and strip size are changed, the control system automatically varies the amount of heating to maintain the flow line. This makes conduction-induction heating applicable to any line speed, strip width, strip gauge, and coating weight. Existing lines equipped for conduction heating can be converted by adding induction heating equipment and modifying the control.

The first full-scale application of the conduction-induction system was made at the U. S. Steel Corporation's Fairless Works. Conduction heating uses 3000 kva of electrical energy in this installation, and induction heating uses 600 kilowatts. ■ ■ ■

Propulsion Control for Electric Submarine

A new propulsion motor control system recently installed in the electrically powered experimental submarine USS *Albacore* handles much more power than has ever before been used in such a vessel. The control system was developed by Westinghouse to serve a new and larger propulsion motor. It fits into the space provided for the original system but controls about four times as much electric power.

The voltage applied to the propulsion motor field has to be adjusted for speed control and to accommodate large variations in battery voltage. This has been done in other battery-powered submarines by including a series rheostat in the motor field circuit to absorb excess power. However, the power requirements of the *Albacore's* new plant are so high that a rheostat would be too large and would dissipate too much heat.

In place of a rheostat, a two-unit "buck-boost" motor-generator set adds voltage to the battery bus circuit for the motor field when maximum field voltage is required. Reversing the motor-generator set's polarity causes it to buck the battery voltage and thus weaken the motor field for higher speed. In the latter mode of operation, it returns power to the system instead of dissipating it as heat. A low-energy circuit controls the field of the auxiliary exciter and thereby controls the field of the propulsion motor. This arrangement saves space, improves efficiency, and minimizes the load on the air conditioning system.

A new switch was developed for the motor armature circuits to carry the high currents required and to accommodate switching surges. The switch can carry 8000 amperes at high dc voltage in the steady state, and much higher transient currents. Its main contacts can be water cooled to increase its capacity, although only convection cooling is required for the 8000-ampere rating. ■ ■ ■

All-Static Drive Control for A Proportioning Feeder System

Reliability and low maintenance are basic requirements of drives in practically every industry. They are especially important in the cement industry because cement-making is a continuous process and one in which a dusty atmosphere has to be reckoned with. An all-static motor control system provided recently for a new proportioning feeder system in a cement plant constitutes a significant step in reliability improvement and maintenance reduction.

A proportioning feeder system assembles and blends materials in proportions preset by the plant chemist. The new one in this plant employs 33 dc motors grouped in four subsystems. The motors range in size from ¾ to 3 horsepower. They operate through a 48-to-1 speed range at constant torque, with speed control effected by armature voltage control.

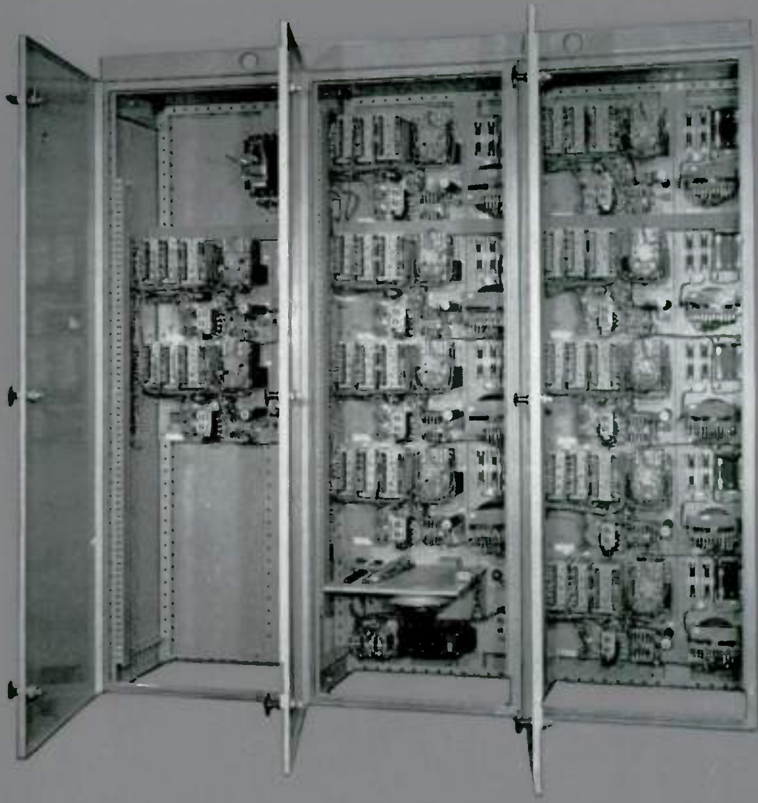
Each motor control includes a transistorized operational amplifier that magnifies the error between a speed reference signal and the signal from a motor-mounted tachometer. The error signal is applied to the con-

trol winding of a gating amplifier. This gating amplifier, essentially a small magnetic amplifier, then produces output pulses that are position modulated with respect to the ac supply voltage. The position-modulated pulses are applied to the control terminals of two Trinistor controlled rectifiers connected in a full-wave bridge, causing them to conduct power until the forward half cycle of supply voltage goes to zero. The conducted portion of the supply voltage wave provides the controlled power for the motor armature.

The speed reference signal for each motor control can be altered by a potentiometer to adjust the speed of each feeder drive, independently of the others, in a 12-to-1 range. In addition, a master reference potentiometer permits adjustment of all the drives together to change system speed over a 4-to-1 range while maintaining the speed proportionality previously set. Motor speed is regulated to 0.2 percent accuracy at the 2450-rpm design speed and to 1.5 percent accuracy at 1/12 design speed.

This installation is the first application in the cement industry of Trinistor controlled rectifiers for motor speed control through direct control of armature voltage.

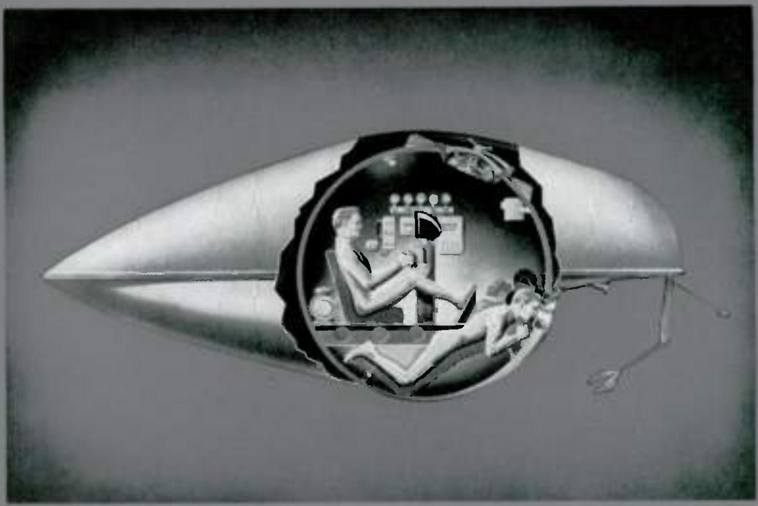
The control system's design, and its solid-state components, give it extremely fast response in correcting speed errors and adjusting to load changes. It is of modular construction, and the individual motor control panels are identical for interchangeability and to facilitate future expansion. Provision also was made for future computer control of the proportioning potentiometers to aid the plant chemist in his choice of types and quantities of materials. ■ ■ ■



The static motor controls for a group of 11 weigh-belt feeder drives in a cement plant are housed in this sealed cabinet. The drives, which are part of a proportioning feeder system, serve a large raw-material grinding mill. Space was provided in the cabinet at left for field installation of two more feeder drive control panels, which can be added without making any changes in the wiring or the panels already installed.

Unique Research Vehicle Will Explore Ocean Depths

A self-propelled deep sea vehicle soon will give its crew of three the maneuverability needed to explore earth's last frontier—the oceans—to a depth of more than two miles. The research vehicle, named *Deepstar*, will be built by the Westinghouse Ordnance Division in cooperation with its designer, Captain Jacques-Yves Cousteau. Captain Cousteau is head of the Office Francais de Recherches Sous-Marines and director of the Institut Oceanographique at Monaco.



This artist's concept of the *Deepstar* ocean research vehicle shows the fairing cut away to reveal the crew compartment. The compartment is a strong steel sphere that will withstand the crushing water pressure at depths down to 12 000 feet. The vehicle will be free of any surface ties and will give deep-sea explorers more mobility than they have previously had.

He is a noted undersea explorer and developer of the Aqua-Lung.

Westinghouse will build *Deepstar* as its own laboratory facility to test oceanographic instrumentation, develop new detection techniques, and generally study the marine environment. It will also lease the vehicle to other organizations and will build similar vehicles for sale or lease to organizations that may want them full time.

Deepstar will enable scientists to move about safely down to 12 000 feet— collecting bottom samples, planting and recovering oceanographic instruments, making geophysical measurements, making photographs, conducting environmental studies, testing sonar equipment, conducting salvage operations, making pipeline and cable surveys, and doing other useful work.

The crew compartment will be a six-foot sphere made of high-grade steel about 1¼ inches thick. Most of the equipment for propulsion, lighting, balancing, sample collection, and photography will be contained in or attached to a faired structure covering the sphere. Two portholes with windows four inches thick will permit viewing, and two remotely controlled mechanical arms will enable the crew to manipulate outside objects. The vehicle will weigh about seven tons.

The craft will descend and rise in a vertical attitude to make the most of its 24-hour submerged operating time. Its speed will be about three knots, and its range will be about 20 nautical miles. It will be handled by a "mother ship" that takes it to the point of departure for its dive and recovers it when it surfaces.

The vehicle will be propelled and maneuvered by two shaftless propellers whose outer rings are the rotors of reversible squirrel-cage motors. The stators form streamlined propeller tunnels. The motors will be energized by 120-volt batteries supplying power through two solid-state inverters with frequency controlled by the pilot.

Deepstar will be neutrally buoyant, with its attitude controlled by pumping mercury from one tank to another. If the pilot wants to surface quickly, he can release weights or equipment to produce positive buoyancy. Safety equipment will include smoke flares, light flares, sonar, and radio.

Westinghouse
ENGINEER
Jan. 1963

BOUND VOLUMES AND INDEXES for the Westinghouse ENGINEER

PERMANENT BINDING of your 1961–1962 issues of the Westinghouse ENGINEER can now be provided. Send your 11 copies to the address below for binding into a durable, attractive book with index. The cost: $3.75. Missing issues will be supplied at 35 cents each, additional. Or, a complete bound volume for 1961–1962 can be provided (we supply the magazines) for $6.00, postpaid.

INDEX for the 1961–1962 issues of the Westinghouse ENGINEER is available upon request, without charge.

Westinghouse ENGINEER
Westinghouse Electric Corporation
P. O. Box 2278
Pittsburgh 30, Pennsylvania

ELECTROMAGNETIC SPECTRUM CHART

What frequencies are used for UHF television? How is infrared energy absorbed in the atmosphere? How much energy is radiated by an object at −253 degrees C, at room temperature, or at the temperature of the sun? What are the principal atomic emission lines of carbon? What gamma rays are emitted from cobalt-60? What is the magnetic resonance frequency of hydrogen-1?

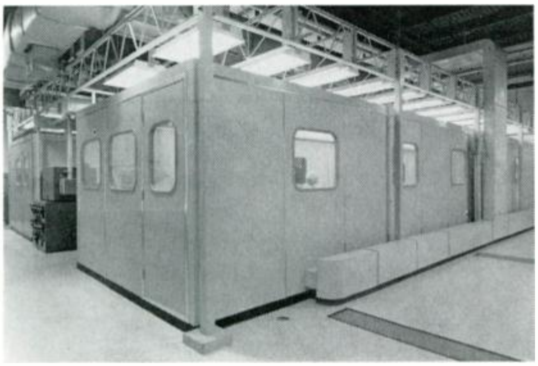
These questions and hundreds more are answered by a new wall chart that depicts the entire electromagnetic spectrum. The 29- by 41-inch color chart illustrates how power is generated, used, and absorbed over a frequency range of 22 decades, from 60-cycle power to billion-electron-volt gamma rays. The main divisions of the spectrum are graphically portrayed—power and telephone frequencies, radio waves, microwaves, infrared radiation, visible light, ultraviolet light, x-rays, and gamma rays.

A wealth of information of interest to the student, engineer, and scientist is placed in appropriate locations on the chart. In the radio spectrum, for example, the bands allocated by the FCC are illustrated. These include broadcast, TV, amateur, government, citizens, and navigation. The wavelength and amount of energy radiated by an object at any temperature between −263 degrees C and 1 000 000 degrees C are given. The many absorption bands in the earth's atmosphere are shown, as are the principal atomic emissions of most of the elements. The x-ray absorptions of lead, copper, aluminum, water, and air are plotted as functions of energy.

The chart is printed in color on tough, cloth-like paper with a metal strip top and bottom so that it can be hung without framing. The price of the chart is $3.50, and it can be ordered from Westinghouse Electric Corporation, Printing Division, Trafford, Pa.

Clean Rooms for Environmental Control

Interior view of typical clean room, used in making molecular electronics devices.



This exterior view of a typical clean room shows the arrangement of lights, which are suspended above a translucent ceiling. This method of lighting keeps the fixtures, which tend to collect dust, outside the facility.

Gauges indicating pressures, pressure differentials, temperatures and humidity are mounted on the control panel, along with operating controls for the air conditioning system, the communications system, and equipment to regulate the environment.

The term "clean room" once meant nothing more than the result sought by the careful housewife. But during the past few years, the term has taken on a technical meaning, and now specifies a room in which precise control can be exercised over environmental conditions. Such clean rooms are becoming more and more common as a manufacturing area for space and electronic components, where moisture, dirt, or temperature changes might drastically alter the performance or reliability of the component.

The need for clean rooms has increased rapidly during the past few years, and the man faced with the problem of getting one usually has designed and built it himself; in all too many cases the results were not completely satisfactory. Now, Westinghouse experience in this field has been consolidated and engineers are performing a coordinated service for anyone who needs a clean room. This includes studies of individual requirements, design of the room, recommendations for all equipment, and complete installation of the structure, and electrical, heating and cooling, air control and other services.

Depending on the requirements, these clean rooms consist of three or four separate sections—one for clothes changing, one for high velocity air cleaning of personnel, one for secondary parts cleaning, and one for final assembly or testing. The environmental requirements determine such factors as the size of the room, contents, cleaning equipment, lighting, controls, and other variables. One example of a clean room is shown at left.

As an example of the degree of control that can be achieved, one installation has dust contamination reduced to less than 10 000 particles per cubic foot, with particle size between 0.3 and 10 microns, as required for qualification as the best classification of a clean room.

ABOUT THE AUTHORS

Charles Kerr, Jr., last appeared on these pages in March 1961 to describe a new concept in transportation, the Roller Road, which dealt with extremely high speed (120 mph) intercity traffic. In this issue, he describes another new transportation concept, this one a rapid transit system. for medium sized cities.

Kerr, a graduate of the University of Virginia and M.I.T., has been associated with transportation in one form or another since he came with Westinghouse in 1922 and began working with railroad electrification. In 1945, Kerr was made consulting engineer of the Transportation Engineering Department so that his wide experience with locomotives could be used to best advantage. He served as automotive consultant in the Industry Engineering Department from 1954 until this year, when he was made Transportation Consultant for the Industrial Systems Department.

Our quartet of authors for the cast-resin transformer article includes three representatives from the Research Laboratories and one from the Power Transformer Division.

James H. McWhirter is a development engineer in the new products group of the Transformer Division, and has the responsibility for development of the cast-resin transformer. He earned his BS in electrical engineering from Columbia University in 1945, and three years later was awarded his master's degree from Carnegie Institute of Technology. McWhirter joined Westinghouse in 1948 and was assigned to the insulation development section of the Transformer Division. In 1953 he was assigned to a group working on long-range development, the forerunner of his present department. In addition to the cast-resin transformer, McWhirter has participated in many other developments, including a computer method for determining impulse voltage distribution in transformer windings.

Daniel Berg is manager of Physical and Inorganic Chemistry at the Research Laboratories, and his responsibilities include research and development in dielectrics, lubricants, electrochemistry and similar areas. Berg earned his BS in chemistry and physics from City College of New York in 1950, and his master's degree (1951) and doctor's degree (1953) from Yale University. His first work at Westinghouse in 1953 was research on electrical properties of dielectrics, and he has since played a part in many developments in this field, including the vapor-cooled transformer, SF_6 circuit breaker, and electroluminescent lamp. He is also an active member of several professional societies, including the American Chemical Society and the American Physical Society.

Newton C. Foster is perhaps best known for his development in 1943 of Fosterite compound, a solventless resin used for electrical insulation, but since that time he has contributed to many other developments in the fields of plastics and resins. Foster is a graduate of Michigan State University, where he earned his BS in chemistry in 1937. His first assignment was to help in the development of a bond for type C transformer cores. Since then, his major activity has been in the area of solventless resins but he has also supervised groups working on carbon brushes, wire enamels, and elastomers. Foster's current assignment is as manager of the Cast and Molded Insulation section at the Research Laboratories.

Charles F. Hofmann is a project engineer in the Insulation and Chemical Technology Department, where he is responsible for the development and application of epoxy resins for electrical insulation systems. Hofmann is a graduate of Bethany College, where he earned his BS in chemistry in 1953; he has also done some undergraduate work in electrical engineering at the University of Pittsburgh. He joined Westinghouse in 1953 on the Graduate Student Course, and became a project engineer in the materials engineering laboratories; when this activity was incorporated into the Research Laboratories, Hofmann became a part of his present group.

R. P. Derrick received his BE degree in electrical engineering from Vanderbilt University in 1954. After his training on the Westinghouse Graduate Student Course, he joined the Industry Engineering Department (now Industrial Systems) as a pulp and paper mill systems engineer. He is now engineer in charge of pulp and paper mill systems engineering, responsible for application of major processing equipment and systems for the industry.

Derrick has taken advanced work in servomechanisms and feedback control at the University of Pittsburgh. He is a registered professional engineer and a prolific writer on drives, systems, and datalogging.

He is also a member of the American Institute of Electrical Engineers and the Technical Association of the Pulp and Paper Industry, and he holds national committee posts in both organizations.

W. H. Watson is a senior design engineer in the General Mill Control Group of the Systems Control Division. He has contributed to the development of many of the division's controls and drives, including the T-100 regulating system described in this issue.

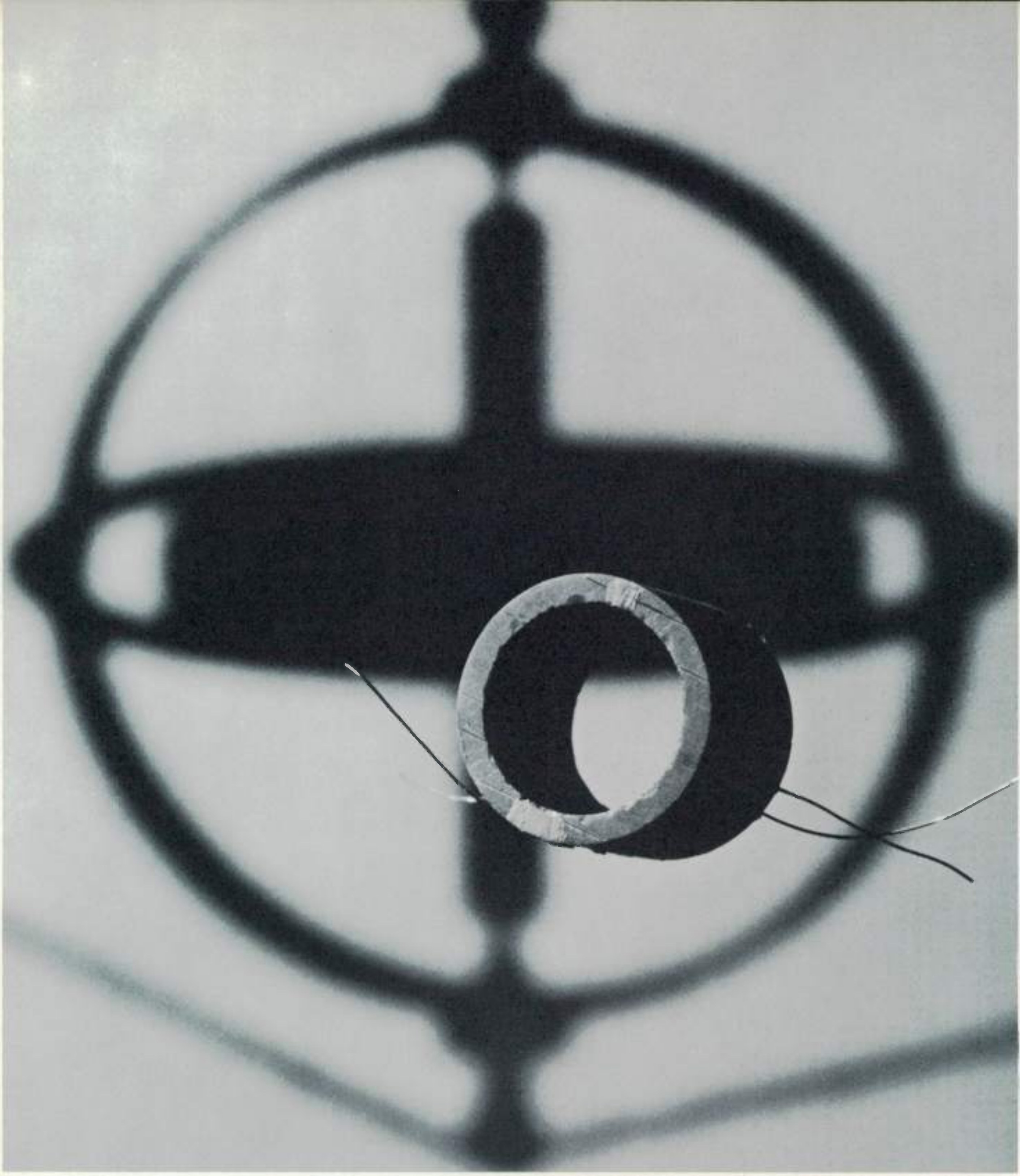
Watson served as a radio operator in the U. S. Merchant Marine from 1944 to 1947. He then entered Louisiana State University and graduated with a BS in electrical engineering in 1951. He joined Westinghouse on the graduate student program and was assigned to the Control Engineering Department in 1952. The Army called him to service in 1954, and he spent two years working on antiaircraft radar fire-control systems. He is now taking graduate work at the University of Buffalo.

J. H. Bednarek graduated from the University of Delaware with a BEE in 1951, and came with Westinghouse on the Graduate Student Course.

He joined the Switchgear Department, where he has worked on supervisory control systems, low voltage switchgear, and ac network calculators. In 1959, he started handling turbine supervisory instruments, which he describes in this issue.

Edgar S. Keats served as an officer in the U. S. Navy from 1935 until 1958, and retired with the rank of Rear Admiral. He joined Westinghouse in 1959. His first assignments were in the Air Arm Division, where he worked in the missile subsystems project, and the electronic warfare project. He was Assistant Director of Space Programs Office when he transferred to the Electronics Division in April 1961. Here, he is presently Systems Manager for the *Transit* project.

Keats is a graduate of the U. S. Naval Academy (BS, 1935), and holds an MS from the Massachusetts Institute of Technology (1948). Assignments during his Navy duty include service in the Bureaus of Ordnance and Aeronautics, Commander of Carrier Air Group Five, Commanding Officer of Attack Squadron Fifty Four, and Director of Armament Testing at the Naval Air Test Center.



GYROSCOPE THAT DOES THE TWIST

This small hollow cylinder—enlarged in this photograph about four times—performs the same basic functions as the familiar spinning gyroscope silhouetted behind it. Developed at the Research Laboratories, it is the first successful solid-state gyro and is particularly suited for applications in space. Microscopic vibrations set up in the cylinder correspond to the spin of the wheel of a conventional gyro. Any move to rotate the cylinder out of position adds a lengthwise twist to its vibrating motion. This twist can be used to control the attitude of a satellite or other vehicle in space. The cylinder is made from a material, such as barium titanate, which can convert the applied voltage into mechanical vibrations, and, inversely, mechanical vibrations back to electricity.