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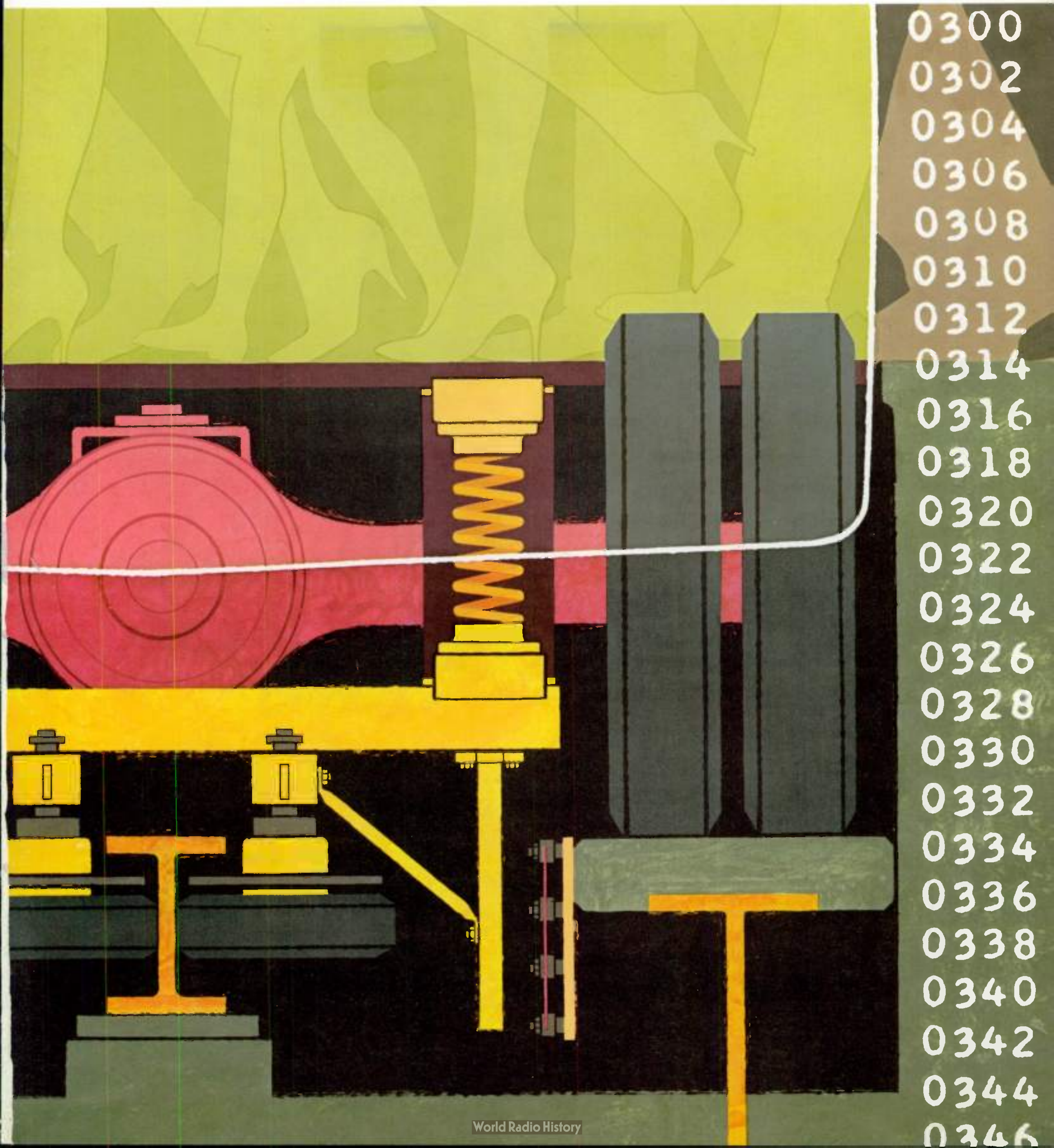

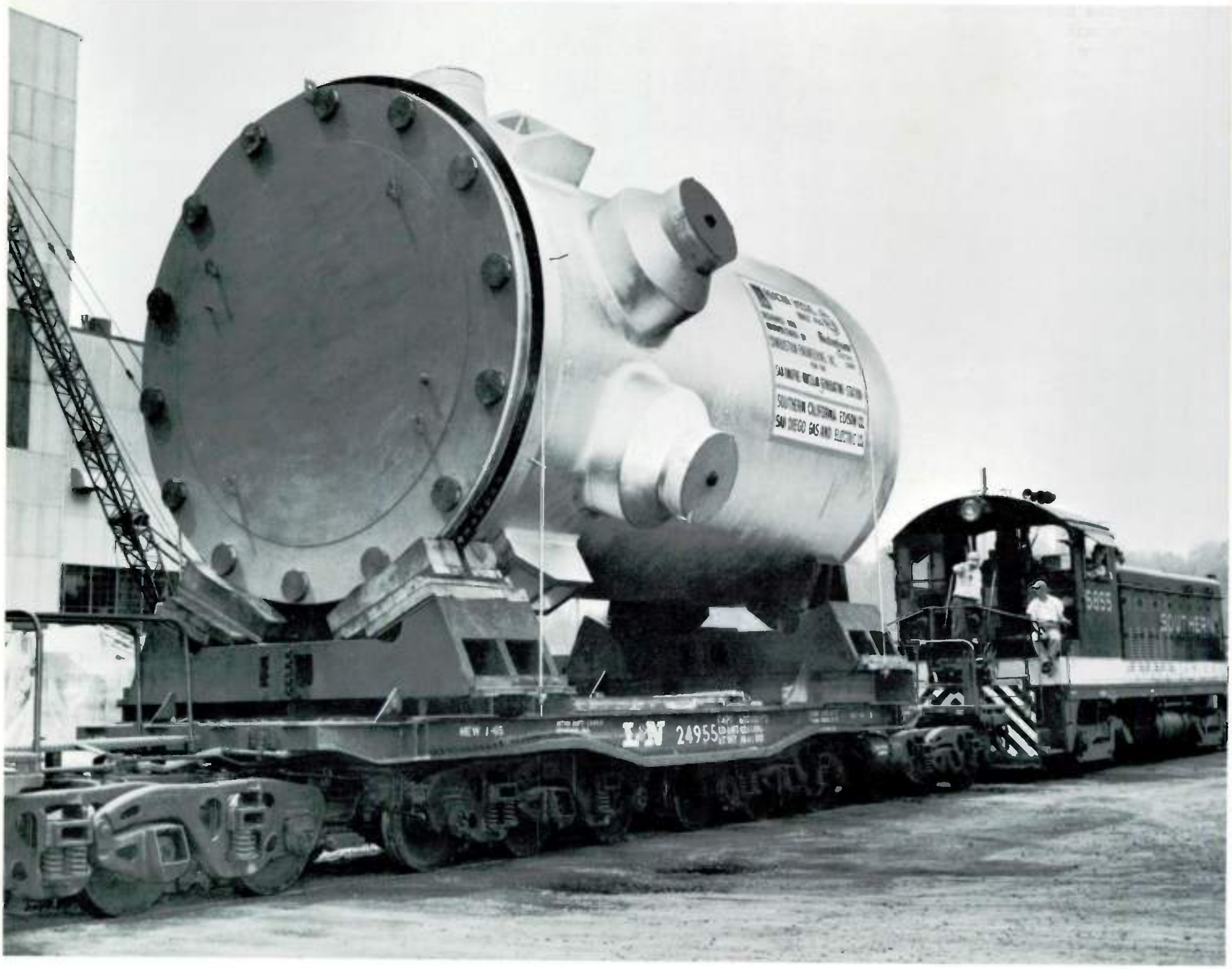

The largest nuclear reactor vessel ever shipped began a 2000-mile journey recently from Chattanooga, Tennessee, to Oceanside, California. The 40-foot 350-ton vessel was loaded on a barge to travel down the Tennessee, Ohio, and Mississippi Rivers. Then it went by freighter through the Panama Canal to Long Beach, California, and by barge again for the short distance to Oceanside. For the final 13 miles, it was transported overland by trailer.

The vessel was designed and manufactured by Combustion Engineering Inc., Chattanooga. It will be part of a 450,000-kw nuclear reactor system that Westinghouse is supplying for the San Onofre Nuclear Generating Station, which will be jointly owned by Southern California Edison Company and San Diego Gas & Electric Company. The plant will be twice as large as any present United States nuclear plant. Estimated completion date is early 1967.

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Cover Design: People in motion and a new mass-transit system being developed to move them quickly and efficiently are the elements in artist Thomas Ruddy's design. The Transit Expressway system, described in this issue, has rubber-tired automotive-type vehicles propelled electrically on a special track under automatic control.

Transit Expressway...A New Mass-Transit System

by William J. Walker
John K. Howell

A test installation of a new concept in automated transit systems has been made. Its many technical innovations are now undergoing extensive functional and economic evaluation.

Most urban areas face, or soon will face, serious and growing traffic problems because urban travel has been taken over largely by the private passenger automobile. Growing populations, development of suburbs, more and better highways, inadequate public transportation, and the comfort of automobiles bring more and more automobiles into the heart of the city. At best, the facilities for handling this flood of traffic have not improved at the rate at which modern man has been conditioned to expect technological improvement.

As a consequence, urban officials, city planners, and industrial leaders have been giving renewed attention to rapid-transit systems. Unfortunately, rapid-transit design has for many years been affected strongly by the extremely high traffic density (passengers per hour) of such cities as New York and Chicago and the consequent massive and expensive central transit systems needed for such cities. Most other urban areas, however, do not have such traffic density, and some will never have it, so the traditional systems are not well suited to them. Moreover, no single transit concept can possibly serve all the transit needs of any major urban area; effective balancing and coordination of several modes of passenger movement are needed for maximum use of the transit system and maximum benefit to the area. New concepts in mass transit are needed, both for areas of medium traffic density and for auxiliary service in high-density areas.

To be economically feasible, a rapid-transit system has to be good enough to induce people to use it in preference to their automobiles. The minimum essentials are frequent service around the clock—not just at peak hours—and vastly improved riding comfort. Both improvements would attract riders, and they would also produce revenue from otherwise idle capacity during off-peak hours.

To produce revenue from every fare at all hours, a system must cost relatively little to acquire and operate. Since most of the *first cost* of a transit system for medium-density traffic is in roadway and structures, an effective way to minimize system cost is to reduce structural requirements by reducing the loads imposed by the vehicles. Vehicle weight (and cost too) can be minimized by adapting automotive components and practices, especially in wheels, tires, suspension, and drive line. *Operating cost* of a vehicle or train in the system must be reduced to its absolute minimum—ideally, the incremental cost of propulsion energy. A fundamental key to this kind of operation is equipment automation.

These, in brief, are the conclusions from several years of Westinghouse studies aimed at significant improvement of rapid transit. They have been the guidelines in development of a new concept known as the Transit Expressway system.

The Transit Expressway concept consists essentially of the operation of many small quiet-running rubber-tired vehicles over a continuous loop at short intervals 24 hours a day. The vehicles are operated singly during off-peak hours. During peak hours, additional vehicles are added and connected into trains to increase the load-carrying capacity of the system. Trains are assembled and disassembled by mechanical transfer devices and are operated automatically under precise control of interval, speed, acceleration, and stops. Roadway geometry, vehicle guidance, and suspension design are carefully coordinated for unusually safe and comfortable ride quality. The vehicles are electrically powered, with automotive type running gear (Fig. 1). They are operatorless, although an actual service installation probably will have station attendants who will be able to view each vehicle inside and out at the stations.

The system is engineered to provide service every two minutes. Its specially designed roadway can be elevated, at grade, or underground. When elevated, the roadway structure can be made attractive and relatively light in appearance.

South Park Project

The initial installation is the South Park Transit Expressway Project, a demonstration and test project designed and constructed by Westinghouse for the Port Authority of Allegheny County and the Housing and Home Finance Agency of the United States Government. Its purpose is to determine whether the system can meet the mass transportation needs of an urban area of medium traffic density. The project is located in South Park, Allegheny County, near Pittsburgh, Pennsylvania. It is administered by the Port Authority under the Housing and Home Finance Agency's Demonstration Grant Program. Additional funding was supplied by Westinghouse, by other industrial companies, by Allegheny County, and by the Pennsylvania State Department of Commerce.

Extensive engineering tests and measurements are being made at this installation; the resulting data will be the principal product of the project. All engineering and operating test data and project cost data will be evaluated for the Port Authority by the M.P.C. Corporation, an organization formed by the Mellon Institute, University of Pittsburgh, and Carnegie Institute of Technology to provide independent scientific, engineering, economic, and management services to public enterprise in the Pittsburgh area.

To obtain maximum information for future revenue systems, the South Park installation was designed to permit testing and evaluation of the engineering, operating, economic, and public-acceptance factors of the Transit Expressway concept. The roadway, for example, is arranged to provide for testing of single-vehicle and train behavior over a variety of grades and curvatures, elevated and surface alignments, and single- and double-track configurations. The project includes

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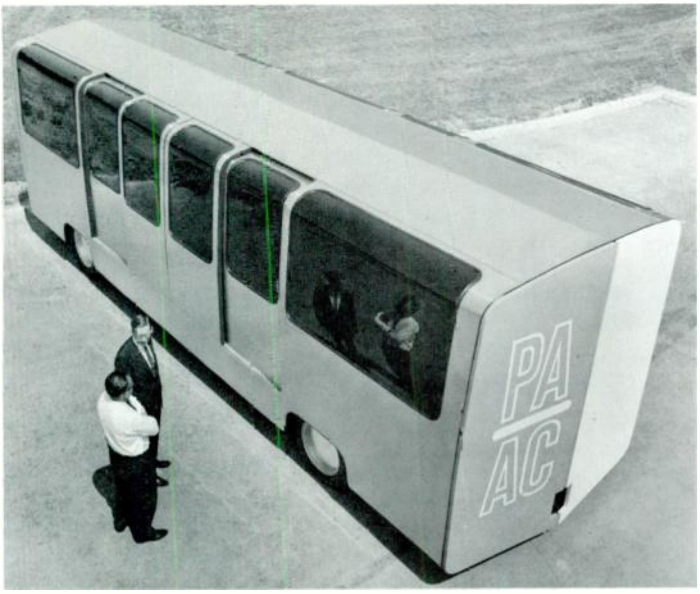
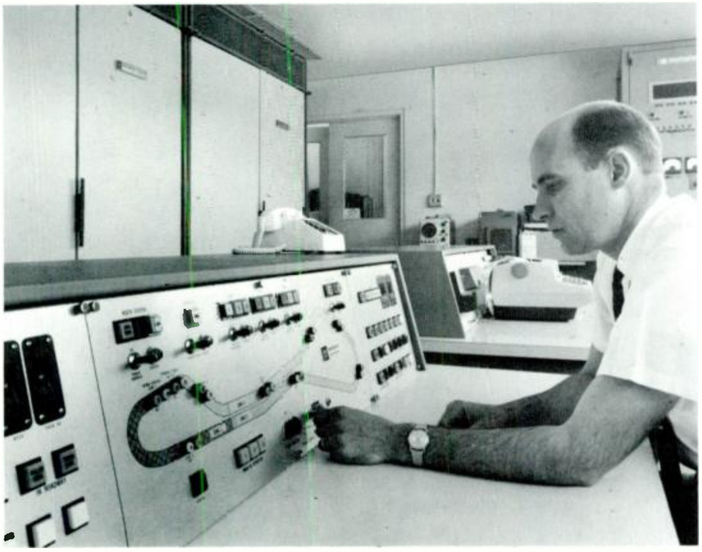




1—The Transit Expressway consists essentially of rubber-tired vehicles, with electrical propulsion, operated over a closed-loop roadway under automatic control of speed, stops, and interval. Vehicles are relatively small and light for economical single-vehicle service during off-peak hours, a design factor that permits frequent service around the clock. They are coupled in trains of the required length to expand capacity during peak traffic hours. This is a full-size model of the South Park Project vehicle.

2—Operator's control console at the South Park Project displays and logs the overall status of the system, including location and movement of vehicles and any abnormal conditions. It also has control devices for initiating automatic system operation or controlling vehicles manually. Other devices enable the operator to control the number of trains or vehicles operating, modify running time and dwell time at stations, and talk with people on the vehicles. Cabinets at left house the control computer.

9340 feet of roadway (mainly elevated), three vehicles capable of operating singly or coupled together, and two stations. One of the vehicles, called the test vehicle, carries test instrumentation. The South Station is a simple elevated platform; the North Station is at grade and is combined with a maintenance shop, transfer table, and control room (Fig. 2).

The main tests and measurements being carried out are discussed briefly in the following paragraphs.

Roadway—Foundation displacement, structural sway, and structural flexing will be measured to evaluate the adequacy of the structural designs and dimensions. Joints and surfaces will be evaluated for resistance to wear and corrosion. Vehicles will be operated during severe winter weather to evaluate their performance on the roadway and to demonstrate the effectiveness of heating cables for snow and ice removal.

Vehicle—Acceleration and "jerk" (rate of change of acceleration) will be measured during starting and braking to evaluate vehicle performance and ride comfort. Tractive effort required will be measured to determine propulsion requirements, and the tractive capacity of the propulsion system will be evaluated for adequacy under maximum load and extreme service conditions. The axle assemblies and guidance mechanism will be evaluated under various operating conditions for running steadiness. Comfort factors—accelerations, vibration, noise, lighting, heating, and air conditioning—will be measured and evaluated. Power consumption for propulsion and auxiliaries will be measured under the range of conditions expected in service.

System—Short-circuit and overload tests will determine if the selective tripping of electrical system protectors is correct. Radio interference and any other communication interference radiated or conducted from the system will be measured. Frequency and amplitude of sound will be measured alongside the track under various operating conditions. The transfer table will be tested for ability to operate properly under adverse conditions. Electric shock hazard will be evaluated. The control system's ability to safely operate three vehicles simultaneously will be determined.

Roadway Design

The special roadway consists essentially of concrete track slabs on stringers with an I beam mounted between the tracks to guide the vehicles and keep them from overturning. It was designed along with the vehicle suspension and guidance system for compatibility of the two. Roadway geometry, vehicle design, and vehicle speed are such that accelerations sensed by passengers are limited to 0.13 g, which is below the threshold of discomfort. The roadway design also was chosen for minimum first cost, annual cost, and depreciation compatible with good appearance. Concrete track slabs were chosen for their good tire traction qualities over a wide range of weather conditions.

The stringers used in the elevated portion of the South Park Project are steel I beams. (Boxed steel stringers or prestressed concrete stringers also could be used.) The 500-foot section at grade is constructed of reinforced concrete stringers supported by concrete cross ties laid on ballast (Fig. 3).

Average span length of the elevated portion is 60 feet, with the longest span 130 feet. Expansion joints are provided at each span. Caisson-type foundations with pedestals on them were used because the major loads are lateral rather than vertical. All horizontal curves are spiralled and superelevated, generally following the requirements of the American Association of State Highway Officials.

Power Distribution

Three-phase power for the vehicles is distributed through copper rails mounted along the inside of one roadway slab. Nominal supply voltage of 565 volts is supplied by two 300-kva pad-mounted transformers near the stations. Current is collected by two articulated pantographs on each vehicle arranged to insure continuity of pickup without sparking during all vehicle maneuvers. A short section of aluminum power-distribution rail capped with stainless steel is included for performance comparison with the copper system.

Vehicle Design

The basic requirements of operating economy, flexibility, and frequent-service operation 24 hours a day dictated that the vehicle be relatively small and light in weight. The vehicle seats 28 people and can comfortably accommodate 70 when necessary. Styling, suspension, air conditioning, lighting, and seats (together with roadway geometry) were designed to produce a high-quality ride. In fact, the ride quality objective was that of a fine automobile on a new interstate highway.

Since all wheels are driven and have dual rubber tires, the adhesion margin is several times that required for normal conditions and normal programmed accelerations and braking. Positive-traction axles minimize wheel slippage in the most adverse road conditions. A steel safety disc mounted with each guide wheel prevents the guide tires from bottoming and locks the vehicle on the road in the event of an overturning force (Fig. 4).

Two 60-horsepower series-wound dc motors, each driving an axle through a drive shaft with universal joints and a differential, provide propulsion and dynamic braking. For propulsion, the armature and field currents for both motors are supplied by a propulsion thyristor bridge that rectifies the ac supply power and also provides stepless control of the dc voltage. For dynamic braking, the propulsion bridge is turned off, a dynamic-braking thyristor bridge supplies reverse field current, and armature current is dissipated in braking resistors. As dynamic braking fades out at low speed, air braking blends in. Deceleration is limited to 2.5 miles per hour per second for a normal service brake.

The double-acting, two-leaf doors are automatically controlled and have safety edges. Their operation is similar to that of elevator doors. At stations, the vehicle doors are coordinated with automatic platform gates.

The suspension system consists of a single-axle assembly at each end of the car. To negotiate curves, these axle assemblies must swivel with respect to the vehicle body. The minimum roadway curve radius of 150 feet induces a swivel angle of almost 3.5 degrees, and a completely new and unique suspension system had to be developed to accommodate this amount of swivel with a single-axle assembly. An automotive-type axle was selected and modified to mount a guidance and support structure. The axle is steered by two pairs of pneumatic-tired guide wheels. One pair is mounted well in front of the axle assembly and the second behind the axle assembly.

The axle assembly is attached to the vehicle body by a swivel-bar arrangement that allows the assembly to swivel while at the same time taking torque reaction forces and permitting vertical and lateral movement of the body with respect to the axle. The body rests on a system of mechanical and air springs that permit the axle to swivel without developing appreciable forces at the guide wheels. Provision also is made for lateral movement of the body with respect to the axles. The

3—Concrete track slabs *(left)* are the running surfaces of the exclusive right of way. The roadway can be elevated, at grade, or underground. This section is part of the South Park Project.

4—An I beam between the concrete track slabs *(right)* guides the vehicles and keeps them from overturning. Power-system conductors are located on one side of the roadway, and the inductive-loop circuits that transmit control and communication signals to and from the vehicles are mounted on the other side.

lateral stiffness is relatively low to isolate lateral axle movement due to guide-beam irregularities. Automotive-type shock absorbers provide lateral and vertical damping.

Because of the relatively soft suspension springs, an antiroll device similar to an automobile roll bar is included between axle and vehicle body to prevent excessive roll on curves and thereby permit higher curve speeds than would otherwise be possible. The antiroll device accommodates vertical, lateral, and swivel motions. It functions only on roll. Lateral and vertical safety stops secure the body to the axle assemblies in event of an abnormal condition.

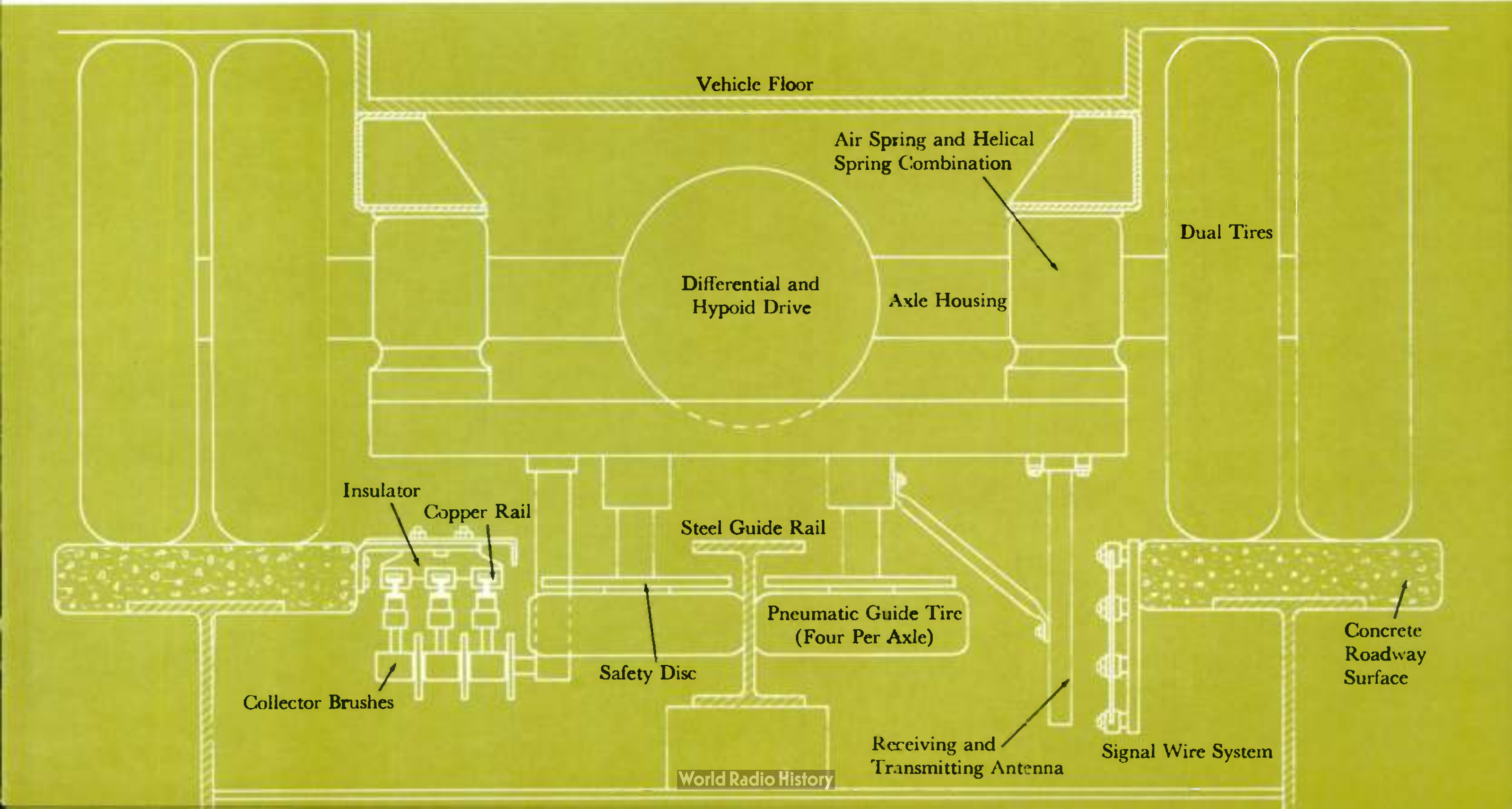
Automatic Train Control

Most of the decision-making and sequencing functions for automatic vehicle control and monitoring are located at wayside controllers, so that each vehicle need carry only a minimum of control circuitry. The South Park Project has one wayside controller; in larger systems, wayside controllers would be placed at each station, normally about a mile apart. Each wayside controller contains a small digital computer, which *controls* the operation of vehicles coming toward it from both adjacent stations (Fig. 5). The computer also *monitors* the operation of vehicles going away from that controller (those that are being controlled by the adjacent controllers). If either of the adjacent controllers fails, the monitoring station assumes control of the vehicles it has been monitoring, while continuing to direct those it normally controls.

All control and communication signals are transmitted between the wayside controllers and the vehicles by square-wave inductive-loop circuits mounted on the roadway. For a station spacing of one mile, five inductive-loop circuits would usually be required. Each loop is connected to the wayside controller by a hybrid coil and amplifier unit that separates incoming from outgoing signals. Control and communication circuits aboard the vehicles are coupled to the inductive-loop circuits by antennas under the vehicles.

With two-minute vehicle spacing, each wayside controller will always be directing two vehicles coming toward it from each adjacent station. The controllers will not permit more than one vehicle at a time on any inductive loop, thereby insuring safe spacing at all times.

The wayside controller receives all information necessary to control a vehicle from two signals generated by A and B oscillators aboard the vehicle. These oscillators operate continuously at two different (but constant) audio frequencies. As the vehicle moves along the roadway, the square-wave pattern in the inductive loop causes the A and B transmitting antennas to alternately couple the inductive-loop circuit. Thus, the A and B signals received at the wayside controller vary alternately in amplitude and provide A and B interrupt signals to the digital computer. In the vicinity of stations, the square waves in the loop are less than two feet long to provide precise stopping control of the vehicle; on open runs, where less precise control is needed, the square waves are about 15 feet long.



With single vehicles, both the *A* and *B* oscillators are energized. When several vehicles are operated in a train, the *A* oscillator operates on the lead and the *B* oscillator on the tail vehicle; all other oscillators are de-energized.

From these *A* and *B* interrupt signals, the computer can control all vehicles in its section according to the programmed speed-distance profiles stored in its memory. The beginnings of all loops are stored as distances from a common mileage post; these distances and the interrupt count give the exact location of each vehicle or train. The computer determines train length from the difference between *A* and *B* interrupt counts, and it determines speed from the counting rate.

With this information (location, train length, and speed), the computer makes logical decisions and initiates the proper command signals to the trains to control speeds, stops, operating intervals, and the opening and closing of doors. Commands to the trains are transmitted from the wayside controller by audio-tone signals back over the inductive wire loop. A command consists of a signal encoded from three of six available tones. (There are 20 possible signal combinations.) The signals are received at the vehicle through the receiving and transmitting antenna.

The signals are demodulated, amplified, and checked to be sure that no more and no less than three tones are received; if there are more or fewer than three, the controller stops the vehicle. A decoder unit outputs the command to the propulsion and braking controls or to the door control.

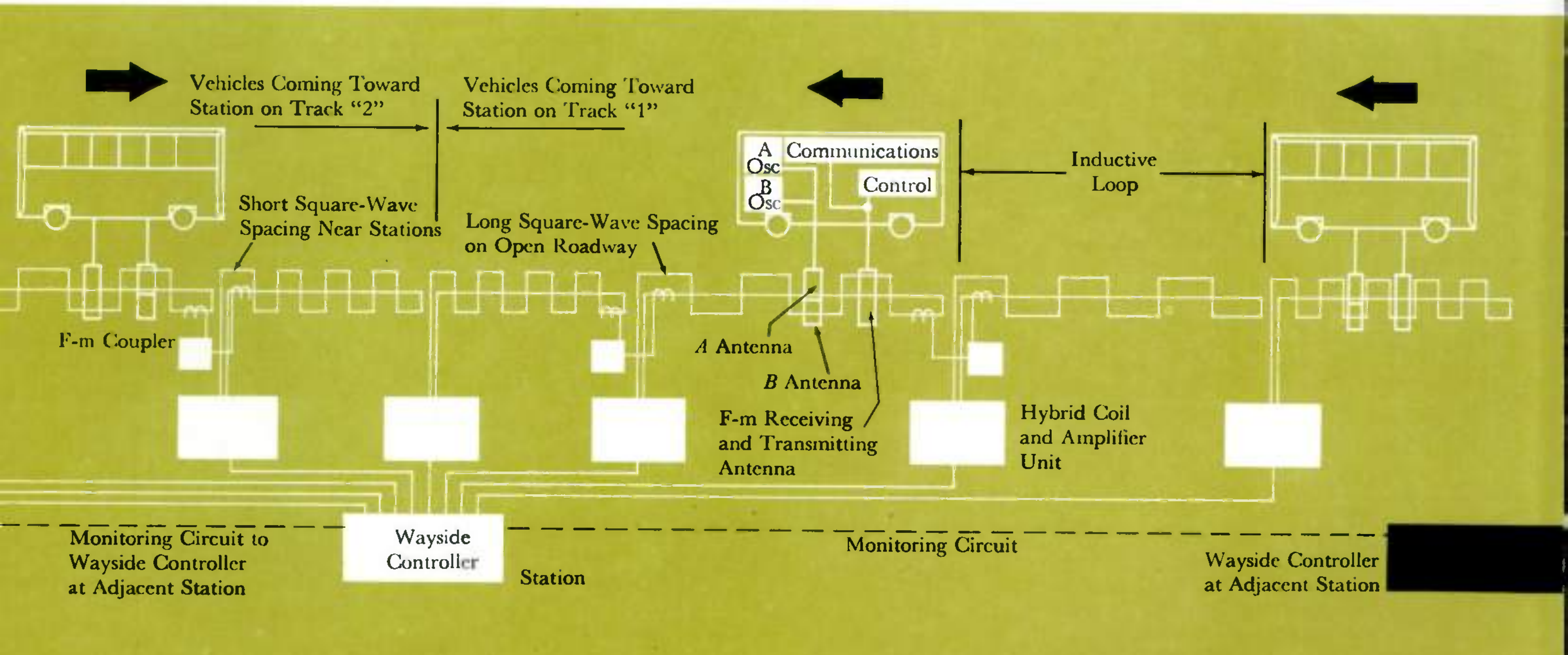
A seventh tone, a safety check tone, is transmitted from the wayside station to the vehicle at definite intervals. Since this tone periodically resets circuits on the vehicle to prevent emergency braking, the wayside controller can execute an emergency stop merely by stopping the output of the tone.

The South Park Project roadway consists of a single track that, in effect, is folded back on itself to form a closed path. A single wayside controller directs the three vehicles all the way around the loop, including the starting and stopping at the two passenger stations at opposite ends of the loop. Total roadway length is just under two miles, requiring nine inductive-loop circuits for *A* and *B* signal control. The loops are interconnected with f-m couplers into three communication zones.

Communication and Equipment Monitoring

A microphone mounted at one end of each vehicle sends voice signals to a transmitter and then to the receiving-transmitting antenna beneath the car, which couples with the wayside communication wire and transmits through the hybrid coil to the wayside controller. The signals are separated from the oscillator tone signals by a coupling unit and sent to an f-m receiver, which transmits them to speakers in the control room. The operator can communicate with any train on the system by means of a microphone on his console desk and an f-m transmitter.

An equipment monitor circuit on each vehicle is coupled into the voice communications channel to report vehicle equipment malfunctions to the wayside controller. Sensors detect such abnormal conditions as low air-reservoir pressure, oscillator failure, battery undervoltage, drive-motor overload, wheel slip, air-conditioning failure, and thyristor cooling-



5—Wayside controller, containing a small digital computer, controls vehicles coming toward it (on separate roadways) from the adjacent stations. It also monitors trains going away from it and takes over their control if an adjacent controller fails. Control and communication signals are transmitted to and from vehicles by track-mounted inductive-loop circuits and vehicle-mounted antennas.

system failure. A signal from a sensor is transmitted to a monitor panel in the vehicle, or to the head-end vehicle in a train, where relays turn on one or both of two tone generators coupled into the f-m transmitter. In the event of a monitored malfunction, the operator can tell which communication zone the vehicle is in—and also what class of failure has occurred—by indicator lights on his console. (The operator can also communicate with all the vehicles in a zone.) Abnormal conditions are divided into three classes. A Class 1 malfunction causes the wayside controller to apply emergency brakes, a Class 2 malfunction causes the controller to reduce its operating profile to low vehicle speed, and a Class 3 malfunction simply causes the controller to notify the operator.

Transfer Tables and Switches

The South Park Project includes a transfer table to insert vehicles into the system and remove them, one vehicle at a time. The table consists of a section of roadway mounted on wheels that run on transverse tracks. The table is sequenced by the computer and powered by gearmotors. When it is out of the roadway, a filler section replaces it so that vehicles can pass while the transfer section is delivering a vehicle to the parking area or to the maintenance shop. Transfer of vehicles on and off the roadway is automatic after the operator pushes a button on his console to initiate the transfer. Since total time required to make a transfer is only about 20 seconds, through trains would not be delayed by the transfer operation. Transfer tables could be built to handle two or more vehicles at a time.

On large systems, especially those whose track layout must be adapted to established right-of-way and branch-line patterns, a transfer switch may be preferred to a transfer table at certain locations to permit running access into spurs, yards, and branch lines. Switches would be comparable to transfer tables in cost and complexity.

Operator's Console

The operator's console is the central control point for the South Park Project. In addition to the communication equipment, it has a mimic display of the system that indicates all nine control loops. An *A* and *B* indicating light for each loop is included on the mimic panel. Each time a vehicle in one of the loops induces a maximum *A* or *B* signal, the corresponding light on the console is illuminated. The frequency of blinking indicates the speed of the vehicle in that loop.

The operator can operate the trains manually from the console, although he is restricted to operating only one train at a time and at a top speed of 20 miles per hour. Headway selection digit switches enable the operator to select any headway from 75 to 300 seconds, and another digit switch is for dialing the desired dwell time at stations. Four pushbuttons select the desired operating profile: slow speed (20 miles per hour), lose time, normal, or gain time. Other switches energize the typewriter for logging the system status, reset the alarms, energize roadway heating elements, and energize the north and south power center controls.

The control console also contains the equipment for operating the transfer table. Two dial switches are provided to tell the control whether a vehicle is to be added or taken off, and the train identifying number is dialed in with another digit switch. Ordinarily, the transfer table is operated automatically by the computer, although a pushbutton enables the operator to switch control to a manual station near the transfer table. Indicating lights show the positions of the filler section and the transfer table.

Conclusion

The Transit Expressway system has been designed to provide an unusually high level of service at any hour of the day or night with capital and operating costs substantially below those of conventional systems supplying frequent 24-hour service. The chief factors in reducing costs are the use of lightweight vehicles, consequent lightweight roadway structures, and the ability to dispatch the required number of vehicles or trains to satisfy fluctuating passenger loads without a fluctuating labor force.

A Transit Expressway system would usually be integrated with other modes of transportation. For a very large city, for example, it might be an outlying feeder for the central rail rapid-transit system. For smaller urban areas, it would be the central system. In the latter application, feeder buses would take passengers to and from the outer parts of the loop, or automobile parking areas would be provided at the stations. The entire complex would be built for flexibility to accommodate changing traffic patterns and increased traffic volume as the urban area grows. For example, trains could be made longer, up to the practical limit, and stations would be so built that they could be lengthened to accommodate the longer trains. Intervals between trains could be shortened to as little as 1½ minutes. Feeder buses could be routed as required to properly distribute passenger loads at the various stations.

Use of transfer switches could efficiently provide extra service on the inner portion of a loop, where traffic is heaviest. Every other train might, for example, turn around before reaching the outer end of the loop, providing twice as many trains on the inner part as on the outer part.

The simple roadway could readily be extended outward as an area developed. An alternative means of extending a route would be building a new loop, adjacent to an existing loop at one point. A station would be provided at that point to enable passengers to transfer from one loop to the other.

One of the most significant elements in the Transit Expressway concept is this potential for variation and adaptation to meet various urban mass-transit needs, either as a central system or as a feeder system. Even more significant is the Transit Expressway's ability to utilize invested capital (equipment and roadway) to near-maximum capacity without proportional increase in operating cost. This ability is the result of the monitoring and control system that gives automatic and absolute control of vehicle speeds, stops, and intervals.

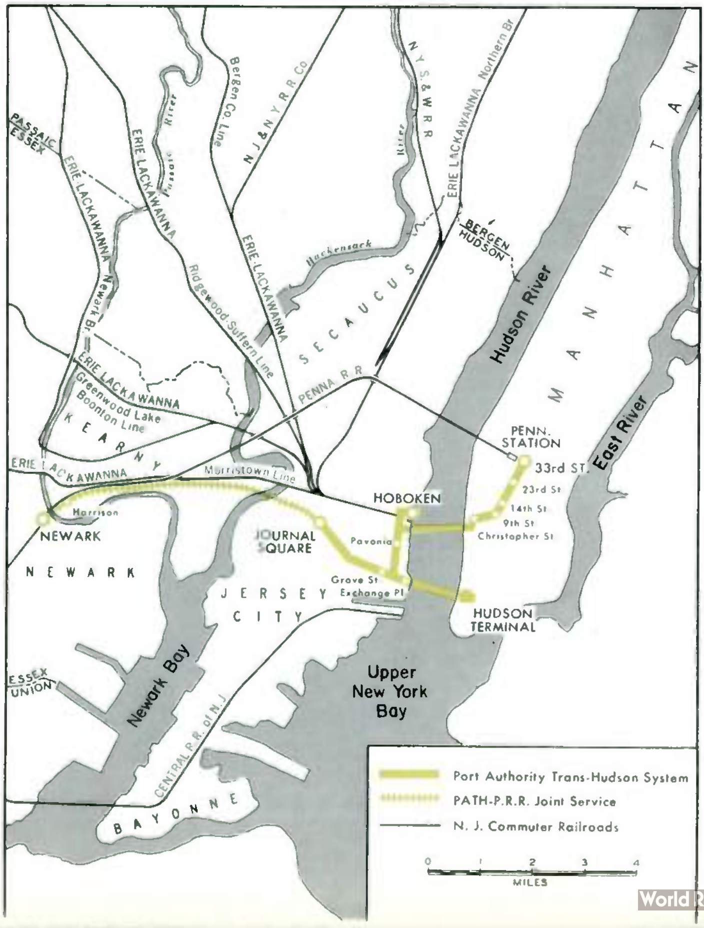
A New Transit-Car Propulsion System for PATH

by R. C. Flanagan
K. H. Fraelich, Jr.

An advanced traction drive and a control system utilizing the latest developments in static-circuit technology optimize performance of the new transit cars for the PATH commuter system linking New York City, Jersey City, Hoboken and Newark.

An unusual advance in rapid-transit car design was made possible when the Port Authority Trans-Hudson Corporation (PATH), a subsidiary of the Port of New York Authority, decided to replace most of its old existing rolling stock in a single move. PATH asked car builders to design a car that best met functional requirements, free from the usual restricting specifications necessary to keep a new car compatible with existing equipment. From a number of completely different car designs submitted by builders, Port Authority engineers selected a modern, lightweight car developed by General Steel Industries, Inc.—St. Louis Car Division. A major feature of this car is the propulsion system developed by Westinghouse transportation engineers to provide the acceleration and braking characteristics desired by the Port Authority. Within a few months, 162 of these new transit cars will be operating over the PATH system.

R. C. Flanagan and K. H. Fraelich, Jr. are with the Transportation Equipment Division, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.



1—PATH (Port Authority Trans-Hudson Corporation) is a subsidiary of The Port of New York Authority created in 1962 to acquire, modernize, and operate the former Hudson Tubes under authorization from the states of New York and New Jersey. PATH operates a 14.2-mile system and carries about 100,000 passengers each weekday between New Jersey and New York.

PATH System Requirements

Before developing the electrical propulsion package, Westinghouse engineers made a detailed study to determine the drive characteristics needed in the PATH car to optimize system performance. The PATH system is unusual in that two distinctly different modes of car operation are required: (1) High-speed, 70-mph operation above ground from Journal Square to Newark, and (2) low-speed operation of less than 40 mph in the tubes, with numerous speed restrictions. Since the analysis showed that more than 70 percent of the actual operating time of a car is in the tubes, the ride characteristic most conducive to increased commuter acceptability is smooth operation through the various limitations of tube operations.

The tubes have a variety of operating restrictions, such as grades ranging from 2.0 to 4.6 percent, and curves of 200-foot radius and less. These physical limitations, combined with a multiplicity of track crossovers, impose numerous speed restrictions on tube operation. Thus, for optimum overall system performance, the PATH cars must have acceleration and braking characteristics tailored to provide the best possible tube operation, but with no appreciable sacrifice in high-speed performance.

The acceleration requirements of the drive can be satisfied by combining the speed-torque characteristic of the high-speed dc drive motor with a suitable output gear ratio to produce the desired overall performance. In addition to acceleration requirements, the motor for the PATH system must provide good speed regulation in tube operation to maintain speed on adverse grades, yet minimize on-off operation at 40 mph; the motor must also have good high-speed characteristics for surface operation.

TRACPAK Propulsion Drive

An examination of the characteristics of existing traction-drive motors revealed that none had the exact characteristics necessary to match all performance objectives of an ideal drive for the PATH car. Therefore, a new 100-hp motor (Type 1460-A) was developed, especially tailored to the unique speed-tractive-effort requirements of the PATH system.

This new traction motor and a parallel double-reduction gear unit with a gear ratio of 6.53 to 1 are combined into a

2—The new aluminum, air-conditioned PATH rapid-transit car has a propulsion system designed for specific application to the varying conditions of the PATH system.

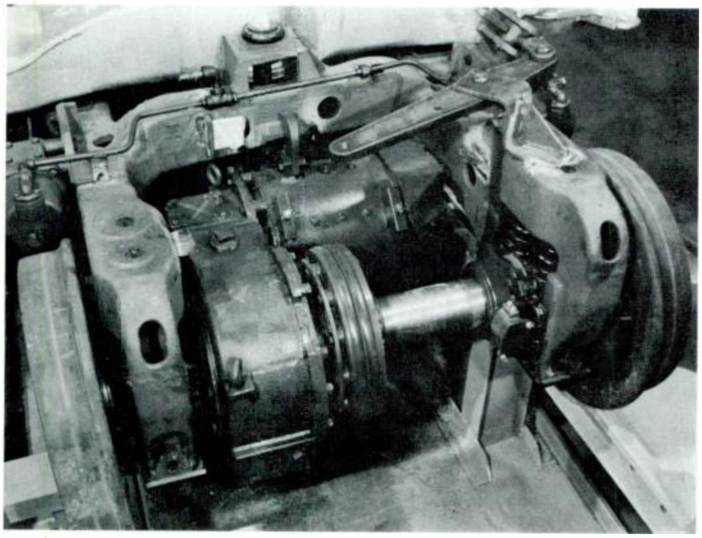
single compact, lightweight traction package (TRACPAK) for propelling and braking the car efficiently and smoothly over a wide speed range. This TRACPAK drive system, recently developed by Westinghouse, makes it possible to combine a high-speed dc traction motor and a parallel gear unit into a single assembly that will fit into an inside-journal truck. Previous to the TRACPAK design, inside-journal truck drives had the traction motor positioned at right angles to the axle, and a drive shaft was connected to the motor and coupled to the input pinion of a right-angle gear unit mounted directly on the axle. The new TRACPAK drive is a much more desirable arrangement because alignment problems with separate components are eliminated.

A unique feature of the TRACPAK drive is the method of driving the axle. The drive unit does not mount solidly on the car axle, but instead, drives a hollow output quill with clearance over the axle. The quill bolts to a fully resilient axle coupling. This coupling consists of two round rubber rings molded to both sides of a steel central plate, which is part of an axle hub that is pressed on the axle. One of the drive plates is fastened to the gear unit output quill and torque is transmitted from the output quill to this drive plate, then through the rubber rings to the hub. The resilient rubber coupling cushions the rate of change of acceleration and dynamic braking by acting as a large torsion spring, and also protects the gear unit from rail shock and vibration.

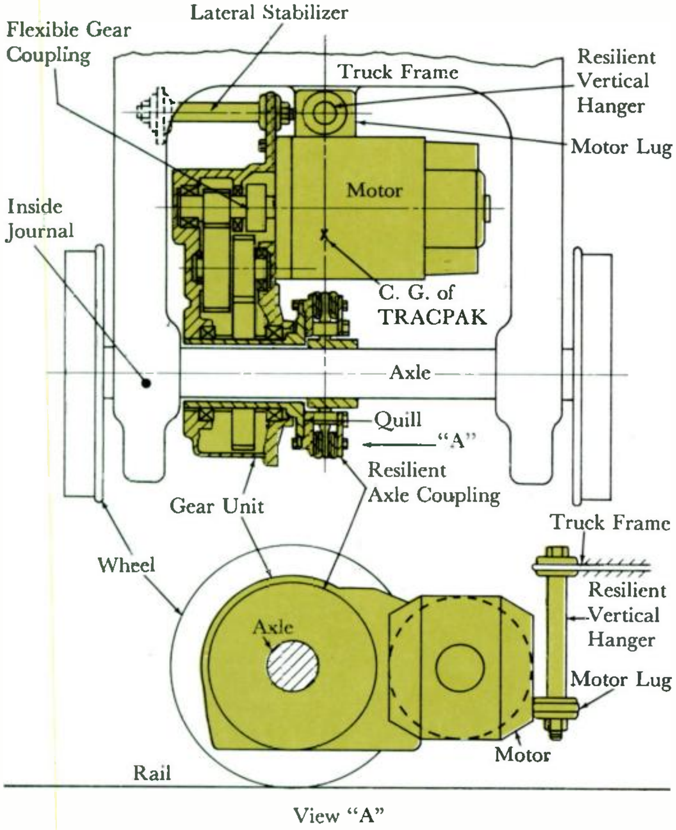
The gear unit is a double-reduction type with parallel helical gearing. Both high-speed and low-speed gear sets have large helix angles and precision quality tooth-form tolerances. These features provide a smooth, quiet drive in which dynamic tooth load is minimized. Fixed center distances eliminate shimming of gears for backlash adjustment. All gears are interchangeable since lapping is not required at assembly. Gears are straddle-mounted between high-capacity bearings to provide good load distribution and long bearing life.

Lubrication of the gear unit is by a directed oil-splash system. Adequate feed of lubricant to the high-speed components in both directions of rotation is assured by a large-capacity reservoir located directly above these components. This reservoir also feeds the motor-gear unit coupling and the rear motor bearing, thereby providing maintenance-free operation for two points that would otherwise require periodic relubrication. Two large magnets continually cleanse the oil of metallic particles, insuring longer gear-unit life. All bearing housings and caps are positively sealed with neoprene O-rings.

The drive assembly is supported from the truck frame by one vertical hanger and one lateral stabilizer, both of which are fully resilient. This suspension arrangement permits con-



3—TRACPAK unitized traction drive unit fits compactly in an inside-journal truck.



4—TRACPAK drive consists of high-speed dc motor and parallel gear unit, which drive the axle through a resilient axle coupling.

siderable motion between the axle and truck. The TRACPAK drive is designed so that points of vertical support—the axle coupling and the truck hanger—are positioned in line with the center of gravity, thereby minimizing eccentric vertical loading.

Assembly and disassembly of the TRACPAK drive on the truck are simplified because only one package is handled, rather than separate motor and gear units. The complete drive package is slipped over the axle and simply bolted to the resilient coupling. A motor can be removed from the gear by unfastening eight bolts and uncoupling the motor shaft; no adjustment, line-up, or separate handling of a coupling is required. With this arrangement, the complete motor-gear unit can be assembled, tested, and shipped as a unit.

Static Current Control System

The PATH transit cars are of two types: Single-cab (A type) cars equipped with a console-mounted master controller at one end only, and motorized (C type) trailer cars. Trains are made up with A cars on each end. Both ends of C cars are similar, and couple to the noncab ends of A cars. The master controller in the head-end A car establishes train-line circuits, and sequences the propulsion control on all cars in unison.

The four dc motor drives on each car are automatically controlled during acceleration and braking by a static current control (SCC) system on the car. This control is arranged to provide automatic series-parallel acceleration and dynamic braking. All components of the propulsion control, with the exception of accelerating and braking resistors, are assembled in a compact unit mounted on the center sill of the car. The master controller in the head-end car supervises the SCC propulsion control in each car. With the master controller, any one of four power positions can be selected:

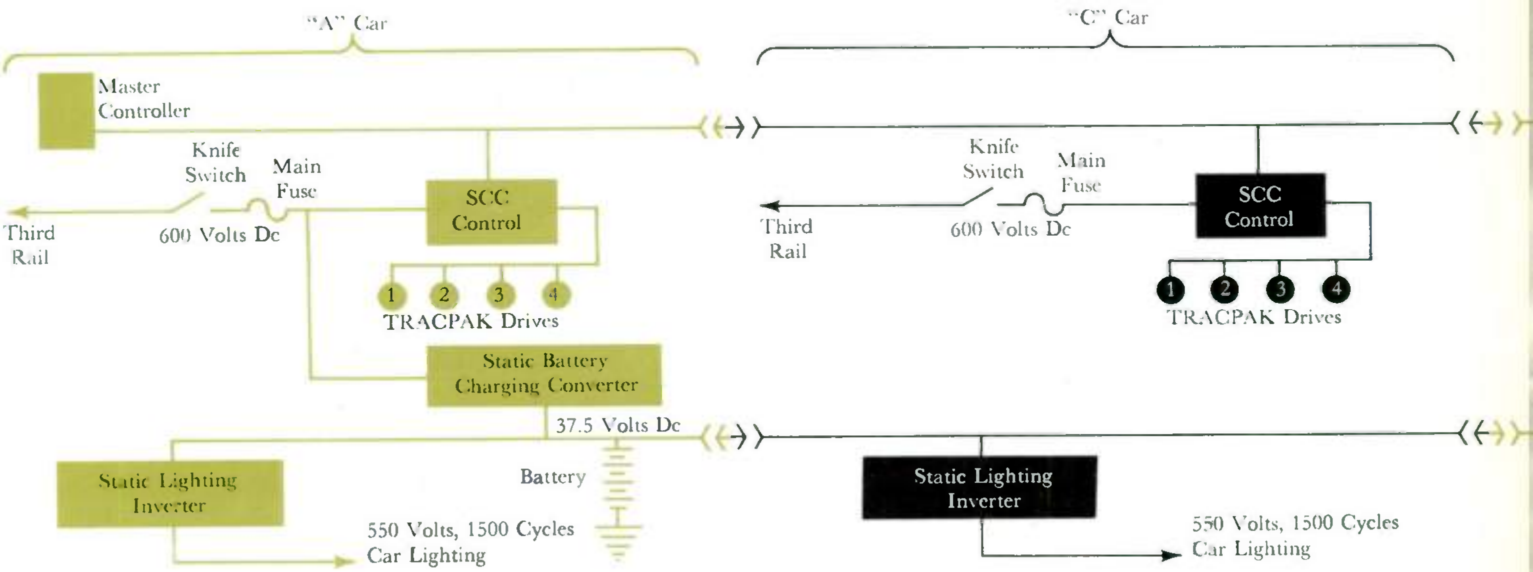
Switching—This position connects the four traction motors on each car in series, with full accelerating resistance inserted, thereby providing low-speed operation for yard maneuvering.

Slow—This position allows the control to advance, at 1.5 miles per hour per second (mphps) accelerating rate to full-series operation (i.e., four motors in series, no external resistance). This medium-speed position is ideally suited for operation through speed restrictions in the tubes.

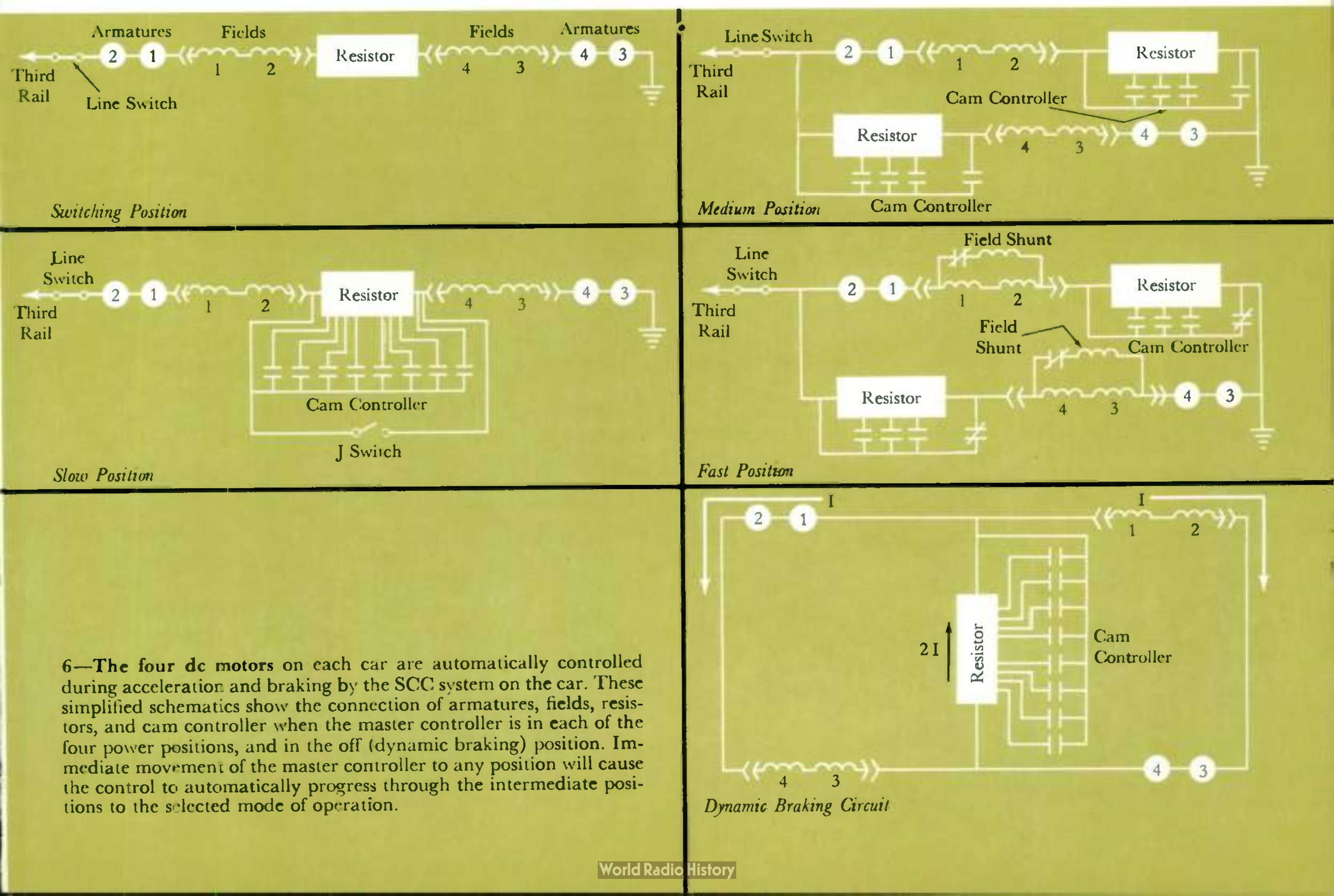
Medium—This position allows the control to advance, at a 2.5 mphps accelerating rate, from four-series to two-series, two-parallel, full-field operation. This medium-high-speed operating mode can be used for the high-speed sections of tube operation.

Fast—This position allows the control to advance, at a 2.5 mphps accelerating rate, to two-series, two-parallel, shunt-field operation. The high-speed operation that is provided at this position is ideally suited to surface operation from Journal Square to Newark.

When the *Off* position is selected at the master controller, dynamic braking circuits are automatically set up on each car. Movement of the brake handle initiates dynamic braking and establishes the desired braking rate in the range of 1.0 to 3.0



5—Electrical propulsion and auxiliary apparatus for the PATH cars are shown in this simplified block diagram.



6—The four dc motors on each car are automatically controlled during acceleration and braking by the SCC system on the car. These simplified schematics show the connection of armatures, fields, resistors, and cam controller when the master controller is in each of the four power positions, and in the off (dynamic braking) position. Immediate movement of the master controller to any position will cause the control to automatically progress through the intermediate positions to the selected mode of operation.

mphps. This braking rate will be maintained down to fadeout at 10 mph; at this point, the air brake is automatically blended in to provide a smooth stop.

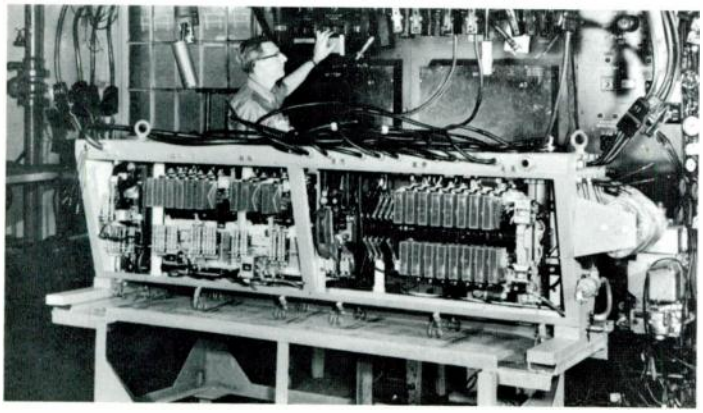
Type SCC control employs spotting and back spotting when the car is coasting so that instant build up of dynamic braking can be provided, or power can be instantly reapplied. This anticipatory circuit keeps the control in a "ready for anything" position, providing smooth transistion to any mode of operation. Separate accelerating and braking resistors and switches are used to permit instant transition from power to brake, and from brake to power.

Constant accelerating and braking rates are maintained by a static-limit relay system in each SCC control unit. This static-limit relay is the heart of the control system since it regulates the rate of progression of the cam controller in each mode of operation, in response to signals from the head-end master controller. Motor current is measured and the cam controller is positioned, inserting or removing resistance from the motor circuit to maintain constant motor current during car acceleration and dynamic braking. This produces the constant-torque motor characteristic necessary to maintain the desired accelerating and braking rates. Load weighing is employed to recalibrate the limit relay to maintain rates, regardless of passenger loading. The solid-state devices used in the limit-relay circuit are mounted on two plug-in cards to simplify maintenance procedures.

Each SCC control package has an electro-pneumatically operated resistance cam controller, line switch, series-parallel controller, power-brake controller, and reverser. These electro-pneumatic devices were chosen because of their extreme reliability, which result from their inherent simplicity and fail-safe characteristics.

Simulated car operation is a part of the standard commercial test given each SCC propulsion control unit. Four Type 1460-A traction motors are mounted in a test stand, driving flywheels sized to simulate a fully-loaded PATH car. Each package unit must successfully complete a series of test runs, duplicating actual operating conditions on the PATH system. Accelerating and braking rates are preset so that only minor tuning is needed when the cars are placed in operation.

7—**Each SCC control package** is completely tested under simulated operating conditions before leaving the factory.



Auxiliary Power Supplies

All auxiliaries on the PATH cars, with the exception of car heating and air conditioning, are powered from two solid-state power supplies. Completely static designs are extremely reliable, and eliminate the maintenance required by rotating auxiliary power supplies.

Battery-Charging Converter—Each of the A type cars is equipped with a 4.5-kw battery-charging converter, which provides all low-voltage power requirements of the A car and one C car, including all lighting on both cars. This unit converts 600 volts dc from the third rail to 37.5 volts dc for battery charging. The converter is inherently stable and self-protecting during third-rail gap operation, during third-rail surges, and under fault conditions. The converter is current-limiting when charging a completely discharged battery. Essentially constant output voltage is maintained with third-rail voltage variation from 450 to 750 volts dc. The converter uses completely static devices throughout.

Lighting Inverter—All PATH cars are equipped with a 1.2-kw static lighting inverter. This unit converts 37.5-volt dc battery power from the trainline (low-voltage lines between cars) to 1500-cycle, 550 volts for fluorescent lights. Lighting ballasts are a coordinated part of the inverter system to insure maximum system efficiency. A high degree of circuit simplicity provides a lightweight, readily accessible package. A special time-delay circuit prevents light flicker during third-rail gap operation. This circuit permits the inverter to continue to feed from the battery during the period that the car is passing over the third-rail gap, when the battery charging converter is momentarily de-energized. To prevent battery drain if a converter is de-energized for some reason other than third-rail gap, the fluorescent lights are shut off after a preset time interval, and the 32-volt-dc emergency lighting system is energized. This circuitry eliminates annoying light flicker and fluorescent tube failures caused by third-rail gaps. It also eliminates the need for train-lining high-voltage alternating current, direct current, or both.

Toward Static Control

The TRACPAK drive combined with recent developments in static control technology have provided the PATH cars with a safe, fast, smooth propulsion system. The control system used on the PATH car is another step in the direction of completely static control for rapid transit cars. Testing of an even newer concept in propulsion control is presently in progress on the San Francisco Bay Area Rapid Transit District's test track. In this new system, Westinghouse engineers have replaced the main power switches with silicon controlled rectifiers. Developments such as this will provide even further improvements in speed control and smoothness of operation for transit systems of the future.

Commuter Railroad Simulation

by John Kostalos, Jr.
Donald N. Dewees

Simulation can be a powerful aid to management in planning and operating commuter railroads. With this technique, the effect of changes in existing systems can be examined before they are made; similarly, new system designs can be tested before construction.

"What would happen to our on-time performance if we added six trains to our commuter schedule between 8 and 9 a.m. on weekdays?" "Can the proposed schedule for our new rapid-transit system be maintained?" "Could different routings of trains improve our on-time performance?" These and similar questions about the operation of complex systems are now being answered by computer simulation.

These questions can be answered by relying on intuition, by engineering analysis, by observing the effects of making small changes, or by a combination of these methods. While accurate answers can be obtained by analysis, the procedure is long and tedious and, therefore, used only for simple systems. The usual approach has been to select small changes based on experience and intuition and try them on the system. Major changes in an existing system—or full capacity operation of a new system—usually reveal many "bugs" in the plan, which require extensive review and replanning, plus further trial.

Digital computers and new programming techniques now make it possible to obtain accurate answers to such questions quickly and inexpensively by simulation of the commuter railroads and rapid transit systems.

This is parallel to the problem of simulation of electric power systems, which is accomplished by the Westinghouse Powercasting method, initiated about five years ago. This method uses simulation of power plants, transmission networks, distribution systems, and electrical load growth to forecast the needs of electric utility systems.[1] More recently, portions of a steel mill have been simulated. Now, the Transportation Systems Department has sponsored the development of a commuter railroad simulation.

Railroad simulation will help management improve the operation of existing transit systems, but, equally important, it is an economical tool for predicting the future behavior of systems in the planning and design stages. Various track layouts and station locations can be studied to provide the basis for design decisions. Alternate operating patterns can be examined and compared before actual construction and operation.

What Is Simulation?

Simulation is a method of providing detailed operating information about a real system by imitating the system with a computer. Basically, it is a tool for engineering and management personnel to help them plan, design, and operate actual systems.

Managers normally control the railroad by words and numbers in the form of oral and written instructions and orders (Fig. 1). The results of operating according to their instructions and orders are reported to them in words and numbers contained in daily, weekly, and monthly reports. The simulation technique accepts the same instructions and orders (input) from the managers and, in a short time, returns output reports to them describing how the simulation responded to this input, which should be just as the actual railroad would have responded to it. It is for this reason that simulation is often called a "management tool." The input and output of this simulation are information, just as in the offices of the railroad. When officers of a railroad receive data telling how the railroad has responded to a change in operations, they should be unable to distinguish between data from the simulation and from the actual railroad itself. In summary, simulation utilizes a mathematical and logical model of the railroad, which responds to the same factors and produces the same results as the actual system.

Simulation Model Requirements

The mathematical model represents the actual system by equations and rules. The equations describe mathematically and logically the reactions of the real system to external factors, such as trains entering the railroad from yards or other railroads. They also describe the interactions within the system, such as arrival and departure at stations, behavior of successive trains on the same track, and routing of trains at interlockings. The rules laid down in the model simulate human and machine-made decisions that affect the operation of the actual system.

A simulation model represents only those characteristics of the real system that affect the subject of interest—train movement in this case. For example, the car acceleration and braking performance affect train movement, but the seating capacity of the cars does not. Train performance affects the elapsed time for train movements and, therefore, is included in the simulation model. For train movement, seating capacity of the cars is ignored, although if passenger capacity were also a subject of interest, then seating capacity could be included. The interaction between characteristics included in the model should produce the same changes as in the actual railroad. For example, the signal system on the railroad causes travel times to be increased when trains follow each other closely. The simulation model must also provide for this interaction.

The chief advantage of simulation over real-life operation is the ability to test different layouts, schedules, etc., inexpensively. Therefore, the simulation model and the simulation input are designed to permit changes to be made easily. The output is designed to satisfy the purpose for which the simula-

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Donald N. Dewees is a consultant to the Transportation Systems Department.

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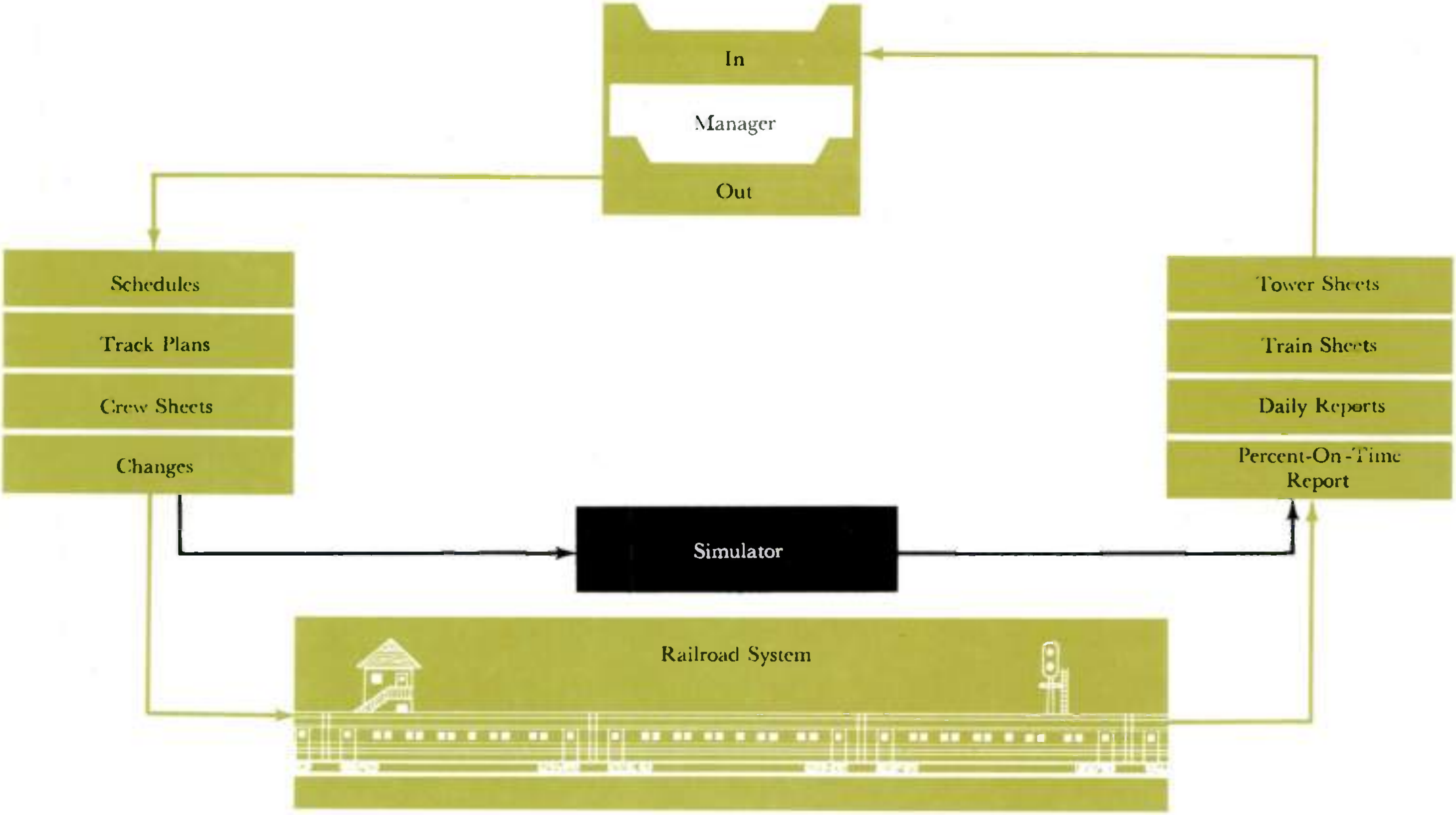
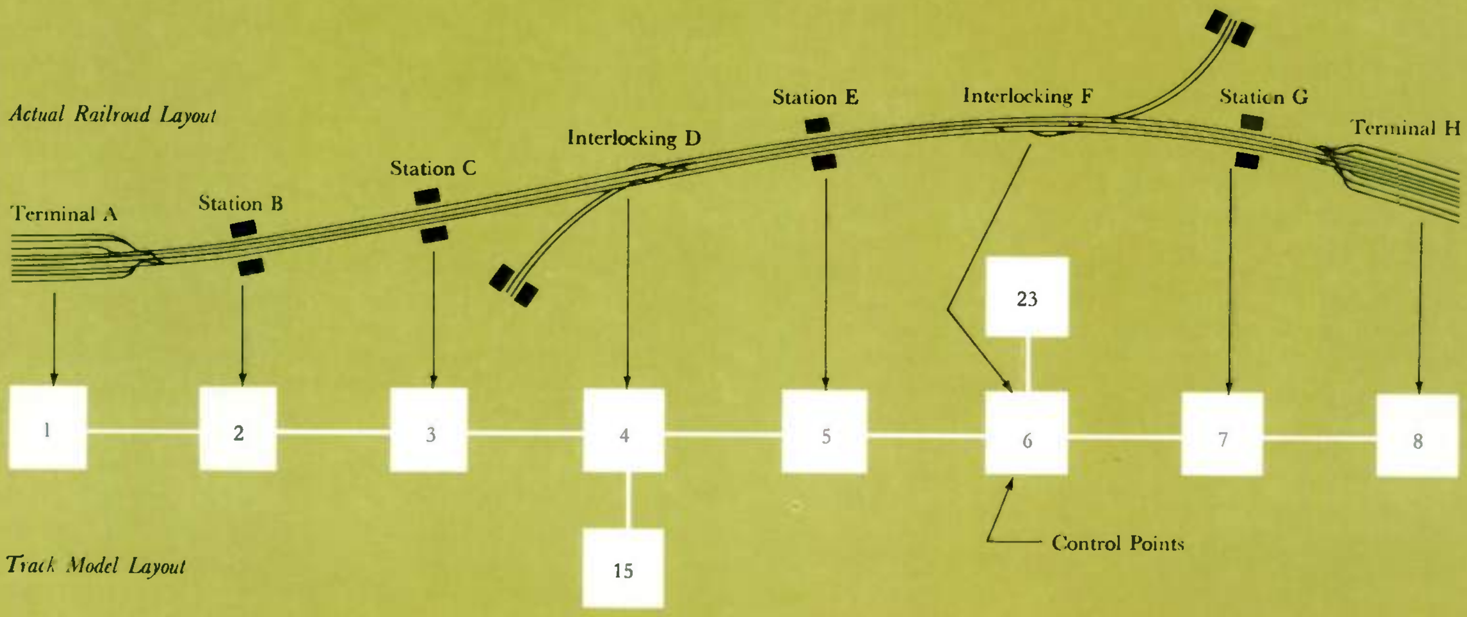
[1] J. K. Dillard and C. J. Baldwin, "System Simulation for Aiding Utility Planning and Operation," *Westinghouse ENGINEER*, Sept. 1960.



1—**An advantage of simulation** is its ability to use information in the same form in which instructions are normally given, and to furnish the manager with results in the same form in which he would normally receive them from operating personnel.

2—**Actual track plan is simplified** in the track model, as shown here. The numbered control points are areas in which the train movements must be considered in more detail than they are between control points.



tion is intended. Where the simulation is intended to study an existing railroad, reports similar to those actually produced on the railroad are provided. Often, however, other reports, which have no counterparts on the actual system, can provide valuable additional information. Here, simulation has a great advantage over actual operation, because usually the data is available in the computer and need only be printed out, while the railroad might have to hire many men to observe and record the data of interest.

The simulation model should require no more running time on a computer than absolutely necessary. The usefulness of the simulation is increased if each proposed change can be run quickly and economically. The present Westinghouse railroad simulation model requires relatively little computer time, usually a matter of minutes, but retains the other features described above.

Event-Based Simulation Languages

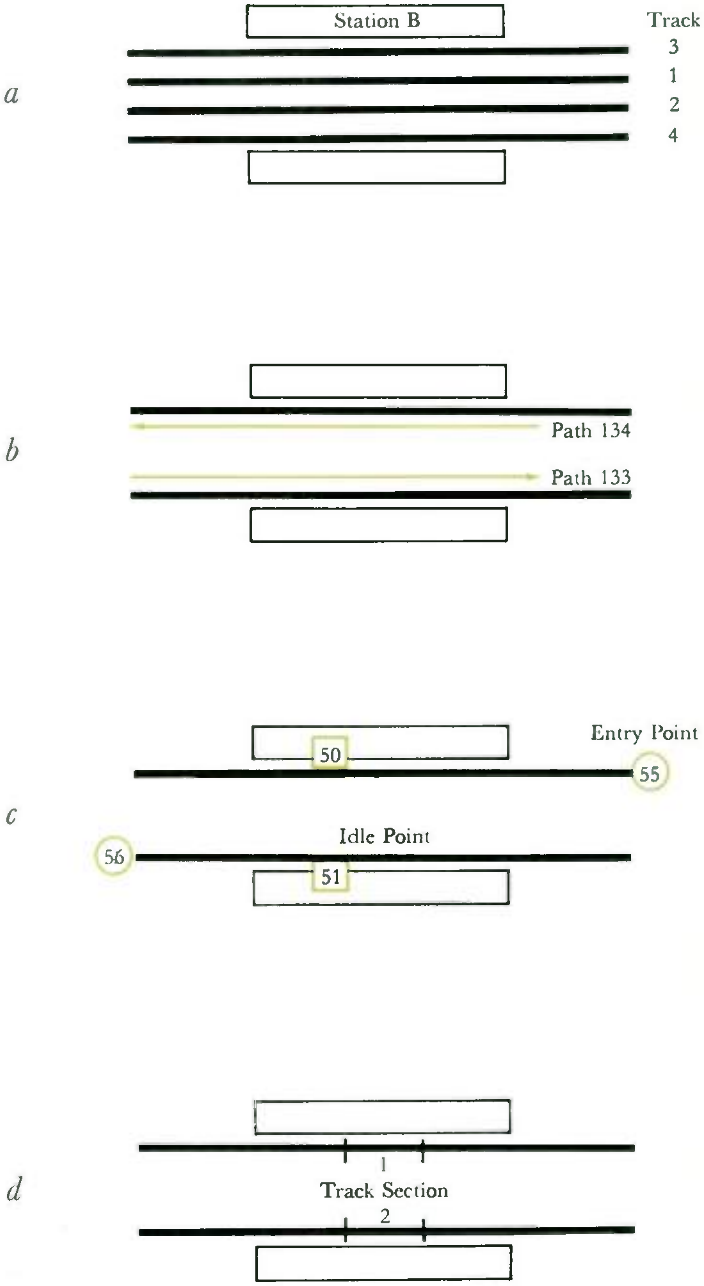
Railroad simulation can be performed in many ways, the two most important of which use a system that changes its status only at discrete intervals of time. The classifications for these two types of simulations are *fixed time interval* and *variable time interval*.

The first type of simulation computes changes in the status of a system at fixed time intervals. If a five-second interval were chosen for computation purposes, and a train required two minutes to arrive at a station after it left the previous station, there would be 24 computations to follow the changes in that train's status between stations. If there are 30 trains in the system at a time, there would be 30 sets of computations for every five seconds of simulated time. This technique often is required to provide detailed information on such things as instantaneous speed and power requirements.

The second, or variable-time-interval, technique is to compute changes in the status of the system when "significant events" occur. The significant events are selected to accomplish the purpose of the simulation.

The simulation described here is primarily concerned with overall train movement and interactions between trains. Therefore, the significant events are trains entering the system, trains leaving the system, and arrivals and departures at stations and interlockings. Changes in the status of the system are only computed when these significant events are scheduled to occur. This method of simulation uses much less computer time for a given problem, but does not provide all of the minute detail (which often is not necessary) of a fixed-time-interval simulation. For the example of the train that takes two minutes between stations, event-based simulation uses four computations instead of 24 for the five-second fixed-time-interval technique. A train performance program, which computes the time required for a train to traverse various segments of its run, can be used to provide some input data to an event-based simulation.

A major factor favoring the use of event-based simulation is the availability of event-based simulation languages that



3—Track model for one control point, number 3, or station C, is shown here (a). Since tracks 1 and 2 are express tracks, which do not affect events at this control point, they are not considered in the control point, as indicated in (b). In (c), numbers in circles indicate *entry points* to control points; those in squares indicate *idle points.* To record track occupancy and describe paths through control points, *track sections* are identified at each control point, as indicated in (d).

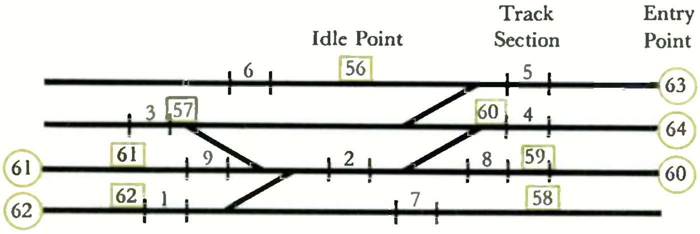
permit the writing of relatively simple programs, which the computer translates into more complex programs in compiler languages (such as Fortran and Algol). An event-based simulation language establishes a calendar for the significant events and provides bookkeeping functions to keep track of entities in the system being simulated.

In summary, an event-based simulation language is used for the railroad simulation because it is adequately powerful and is more economical in both programming and computing time than is a fixed-time-interval technique.

Passenger Rail Transportation System Model

As pointed out above, railroad simulation uses a mathematical model that contains the desired characteristics of the railroad; this means that the railroad is represented as a set of numbers that can be used by the digital computer.

The simulation model consists of submodels for the track, trains, and train movement. The amount and type of detail included in a simulation model depends on the purpose of the simulation. For simulation of an entire railroad, only the most significant characteristics that affect and measure the performance of the entire railroad are needed. In the present model, the arrivals, stops, and departures of trains at important points along the right-of-way are considered the significant events to be simulated. The effects of grades, curves, speed restrictions, propulsion and braking characteristics, etc., are simulated by their effect on the time it takes a train to travel from point to point. The track plan of the actual railroad, therefore, is simplified, for simulation purposes, as shown in Fig. 2.



Path	Track Sections	Entry	Idle	Next CP
137	9, 2, 8	61	59	6
138	1, 7	62	58	5
139	9, 2, 4	61	60	6
140	5, 6	63	56	3
141	4, 3	64	57	1
142	8, 2, 3	60	57	1
143	5, 3	63	57	1

4—For more complex control points, all paths cannot be shown on one diagram and are thus described by a tabulation, which is summarized here.

Track Model—In Fig. 2, the blocks represent control points within which train movements must be considered in more detail than they are between control points. All of the details of train operation between control points are summarized by using a fixed "travel time" to represent the time to travel between each pair of control points. Within control points, train movement, platform stops, switching movements, and train storage are simulated in more detail.

The track model for control point number 3, Station C, is shown in Fig. 3. This is a simple control point with station stops on the local tracks only. Since there are no events in this control point that affect trains on the express tracks, the express tracks are not considered part of this control point. The routes that trains follow through control points are named "paths." Fig. 3b shows the two paths for control point number 3. Lists of trains traveling from the adjacent control points are required to record movement of trains between control points. Each list is identified by the point at which trains on the list will enter the control point. These are called "entry points" and are identified by the numbers in circles in Fig. 3c. Lists are also required to record trains that are stopped for a station stop or for temporary storage. These lists are identified by "idle points," which are designated by the numbers in squares in Fig. 3c.

In order to record track occupancy and to describe paths through control points, track sections are identified within each control point. Fig. 3d shows the two track sections that are required for the simple control point number 3.

For more complex control points, it is impractical to show all of the paths on one diagram. In these cases, the paths are best described by a tabulation that lists the control point, path number, entry point, idle points (if any), and track sections. The items required by the model to describe the movement of trains through a more complex control point are summarized in Fig. 4. These items are track sections, paths, entry points, idle points, and the control point itself. In addition to the "location" items described for control points, each path has associated with it average lengths of time that a train on that path will require to enter the station, stop at the platform, exit from the station, and run to the next control point. The lengths of time for any specific train are varied from the average to account for variations in performance and the effect of preceding trains.

Train Model—The train model consists of a series of numbers that describe the characteristics of each train. This information is stored in the computer for the simulated time that the train is in operation. After the train has left the simulated section of the railroad or has become another train at a terminal, the stored characteristics are erased to provide room for storing the characteristics of other trains.

The following list describes the characteristics (or attributes) of trains that are used in the present simulation model:

THYME—Time train is originated.
IDENT—The railroad's train identification number.

TYPEE—The type of equipment in the train and the mixture of equipment.

NRCAR—The number of cars in the train.

SERVIC—The stations served by the train.

WAITFOR—The identification numbers of trains that this train is scheduled to meet.

INTRN—A sequential number used to identify the train within the computer.

SCHED—The schedule LEAVE times for the train at each of the stations where the train must wait for schedule.

Train Movement Model—Since this is an event-based simulation, the movement of trains is not simulated on a second-by-second basis. The location of trains is changed at specific times when events are said to occur. The events used in the model are:

ORIGIN—A train appears at a specific time and location in the system and the next event for this train is scheduled.

APPROACH—A train approaches a control point. The routing to the platform or through the control point must be checked to determine when the train will arrive at either the platform or a specific point in an interlocking. After the checks have been made, event ARRIVE is scheduled.

ARRIVE—The train arrives at the platform or specific point in an interlocking. After a predetermined dwell time at the platform or zero time in an interlocking, event LEAVE is scheduled.

LEAVE—The train leaves the platform or passes the interlocking. Event DEPART is scheduled after the time required to clear the control point.

DEPART—The train clears the control point. Event APPROACH at the next control point is scheduled.

Several additional events and procedures are used to mark track sections when they are occupied and to free them when they are no longer occupied. These are called MARK and CLEAR. Procedure STORE records the quantity and types of cars stored at platforms or in yards.

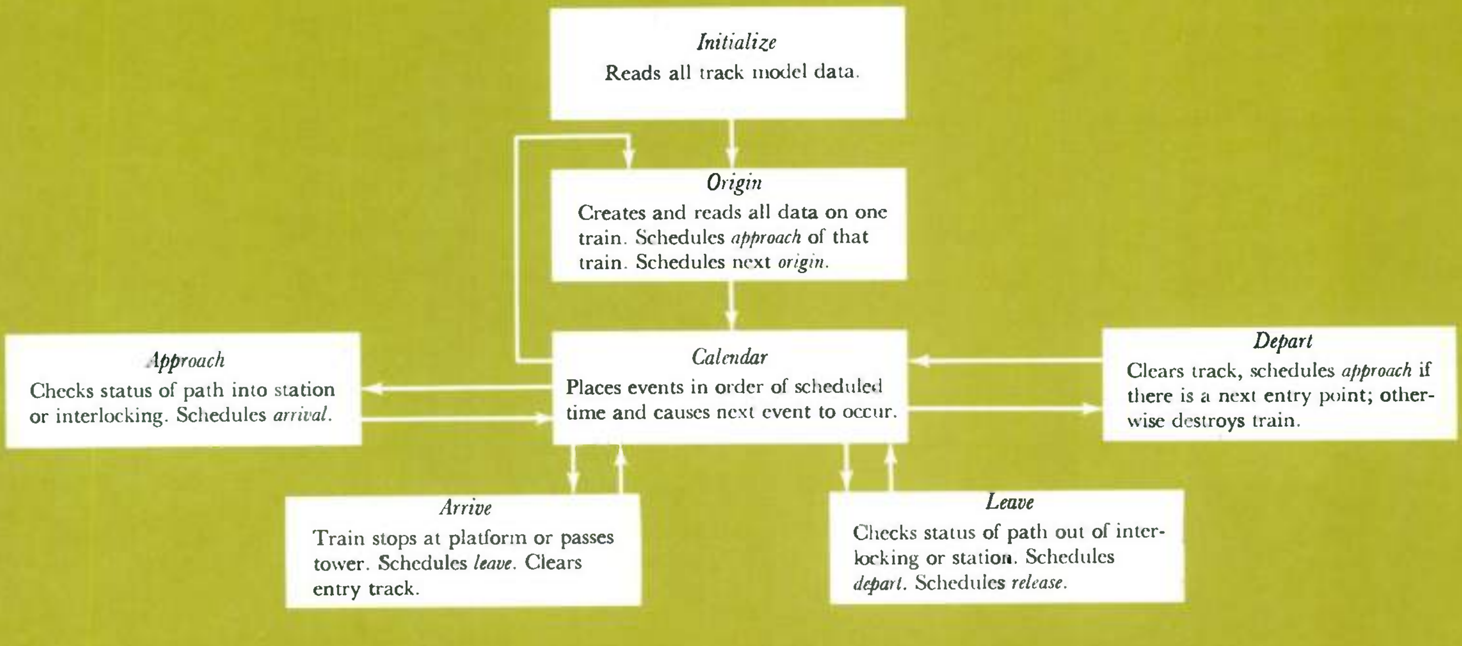
The use of the model is summarized in Fig. 5. The numbers for the track and train models are used when events occur to describe the movement of trains. This figure shows the relationship between the events and the way that the event-based simulation language organizes a calendar to cause events to occur in the proper sequence.

The movement of a commuter train through the simulated operation consists of a succession of events—APPROACH, ARRIVE, LEAVE, DEPART, APPROACH, ARRIVE, LEAVE, DEPART, etc., with the proper time intervals allowed between each event.

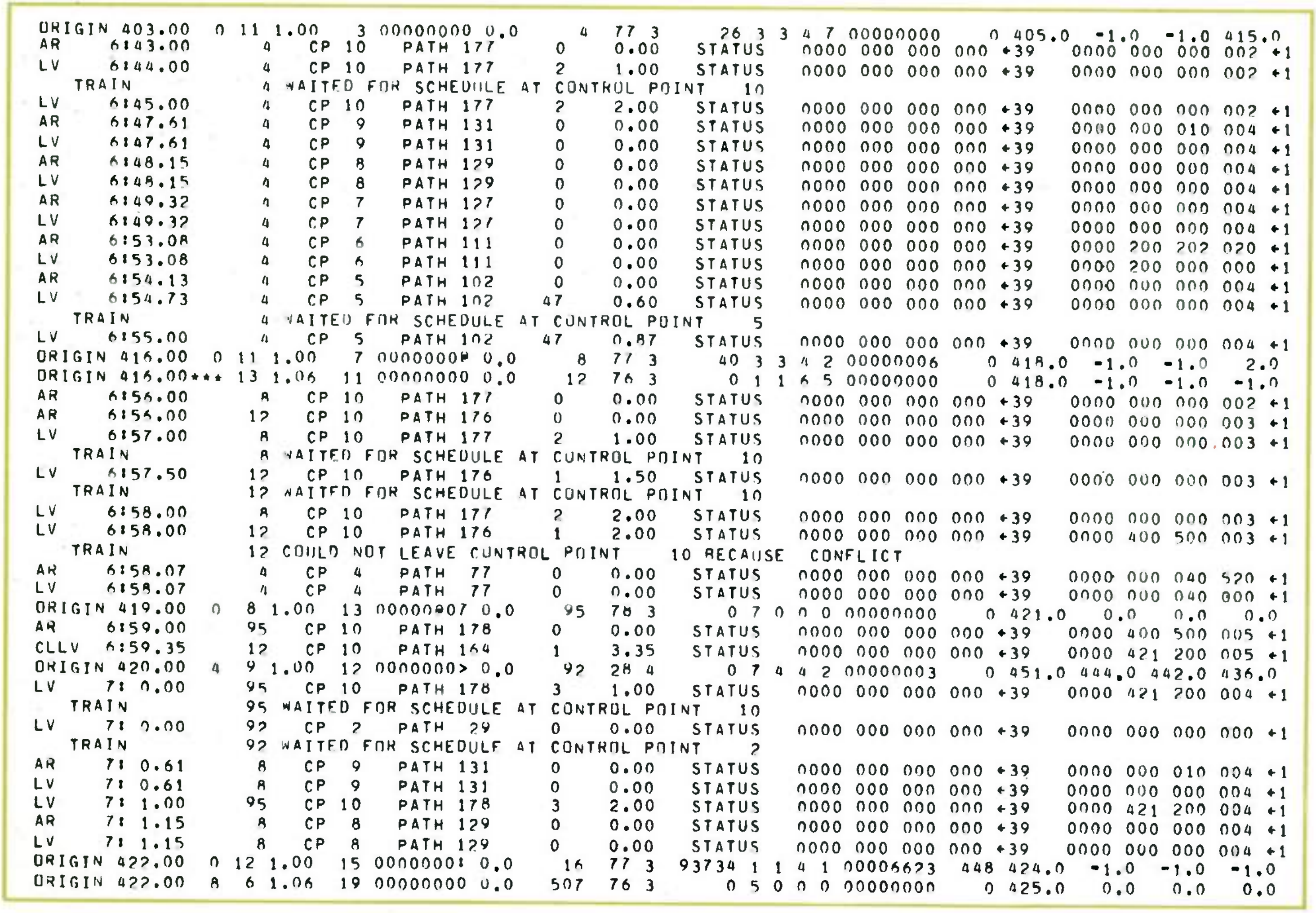
On an actual railroad, the time between the same events is never exactly the same each time the events occur. Variations in cars, power systems, weather, motormen, etc., cause the times to vary.

These variations in time are simulated by using a random-number generator to produce small random variations in the time between events. In this way, most of the small variations, which cause different interactions to occur on the actual railroad, can be simulated on the computer.

5—This master flow chart summarizes the use of the model. Note that the calendar is a key element that causes all events to occur in proper sequence.



Simulation Process Provides a Detailed Chronological Report



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ORIGIN 403.00  0 11 1.00   3 00000000 0.0     4  77 3      26 3 3 4 7 00000000     0 405.0  -1.0  -1.0 415.0
 AR     6:43.00       4   CP 10   PATH 177    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 002 +1
 LV     6:44.00       4   CP 10   PATH 177    2    1.00   STATUS   0000 000 000 000 +39   0000 000 000 002 +1
   TRAIN              4 WAITED FOR SCHEDULE AT CONTROL POINT   10
 LV     6:45.00       4   CP 10   PATH 177    2    2.00   STATUS   0000 000 000 000 +39   0000 000 000 002 +1
 AR     6:47.61       4   CP  9   PATH 131    0    0.00   STATUS   0000 000 000 000 +39   0000 000 010 004 +1
 LV     6:47.61       4   CP  9   PATH 131    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 AR     6:48.15       4   CP  8   PATH 129    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 LV     6:48.15       4   CP  8   PATH 129    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 AR     6:49.32       4   CP  7   PATH 127    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 LV     6:49.32       4   CP  7   PATH 127    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 AR     6:53.08       4   CP  6   PATH 111    0    0.00   STATUS   0000 000 000 000 +39   0000 200 202 020 +1
 LV     6:53.08       4   CP  6   PATH 111    0    0.00   STATUS   0000 000 000 000 +39   0000 200 000 000 +1
 AR     6:54.13       4   CP  5   PATH 102    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 LV     6:54.73       4   CP  5   PATH 102   47    0.60   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
   TRAIN              4 WAITED FOR SCHEDULE AT CONTROL POINT    5
 LV     6:55.00       4   CP  5   PATH 102   47    0.87   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
ORIGIN 416.00  0 11 1.00   7 0000000P 0.0     8  77 3      40 3 3 4 2 00000006     0 418.0  -1.0  -1.0   2.0
ORIGIN 416.00*** 13 1.06  11 00000000 0.0    12  76 3       0 1 1 6 5 00000000     0 418.0  -1.0  -1.0  -1.0
 AR     6:56.00       8   CP 10   PATH 177    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 002 +1
 AR     6:56.00      12   CP 10   PATH 176    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 003 +1
 LV     6:57.00       8   CP 10   PATH 177    2    1.00   STATUS   0000 000 000 000 +39   0000 000 000 003 +1
   TRAIN              8 WAITED FOR SCHEDULE AT CONTROL POINT   10
 LV     6:57.50      12   CP 10   PATH 176    1    1.50   STATUS   0000 000 000 000 +39   0000 000 000 003 +1
   TRAIN             12 WAITED FOR SCHEDULE AT CONTROL POINT   10
 LV     6:58.00       8   CP 10   PATH 177    2    2.00   STATUS   0000 000 000 000 +39   0000 000 000 003 +1
 LV     6:58.00      12   CP 10   PATH 176    1    2.00   STATUS   0000 000 000 000 +39   0000 400 500 003 +1
   TRAIN             12 COULD NOT LEAVE CONTROL POINT     10 BECAUSE  CONFLICT
 AR     6:58.07       4   CP  4   PATH  77    0    0.00   STATUS   0000 000 000 000 +39   0000 000 040 520 +1
 LV     6:58.07       4   CP  4   PATH  77    0    0.00   STATUS   0000 000 000 000 +39   0000 000 040 000 +1
ORIGIN 419.00  0  8 1.00  13 00000807 0.0    95  78 3       0 7 0 0 0 00000000     0 421.0   0.0   0.0   0.0
 AR     6:59.00      95   CP 10   PATH 178    0    0.00   STATUS   0000 000 000 000 +39   0000 400 500 005 +1
CLLV    6:59.35      12   CP 10   PATH 164    1    3.35   STATUS   0000 000 000 000 +39   0000 421 200 005 +1
ORIGIN 420.00  4  9 1.00  12 0000000> 0.0    92  28 4       0 7 4 4 2 00000003     0 451.0 444.0 442.0 436.0
 LV     7: 0.00      95   CP 10   PATH 178    3    1.00   STATUS   0000 000 000 000 +39   0000 421 200 004 +1
   TRAIN             95 WAITED FOR SCHEDULE AT CONTROL POINT   10
 LV     7: 0.00      92   CP  2   PATH  29    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 000 +1
   TRAIN             92 WAITED FOR SCHEDULF AT CONTROL POINT    2
 AR     7: 0.61       8   CP  9   PATH 131    0    0.00   STATUS   0000 000 000 000 +39   0000 000 010 004 +1
 LV     7: 0.61       8   CP  9   PATH 131    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 LV     7: 1.00      95   CP 10   PATH 178    3    2.00   STATUS   0000 000 000 000 +39   0000 421 200 004 +1
 AR     7: 1.15       8   CP  8   PATH 129    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
 LV     7: 1.15       8   CP  8   PATH 129    0    0.00   STATUS   0000 000 000 000 +39   0000 000 000 004 +1
ORIGIN 422.00  0 12 1.00  15 0000000: 0.0    16  77 3   93734 1 1 4 1 00006623   448 424.0  -1.0  -1.0  -1.0
ORIGIN 422.00  8  6 1.06  19 00000000 0.0   507  76 3       0 5 0 0 0 00000000     0 425.0   0.0   0.0   0.0
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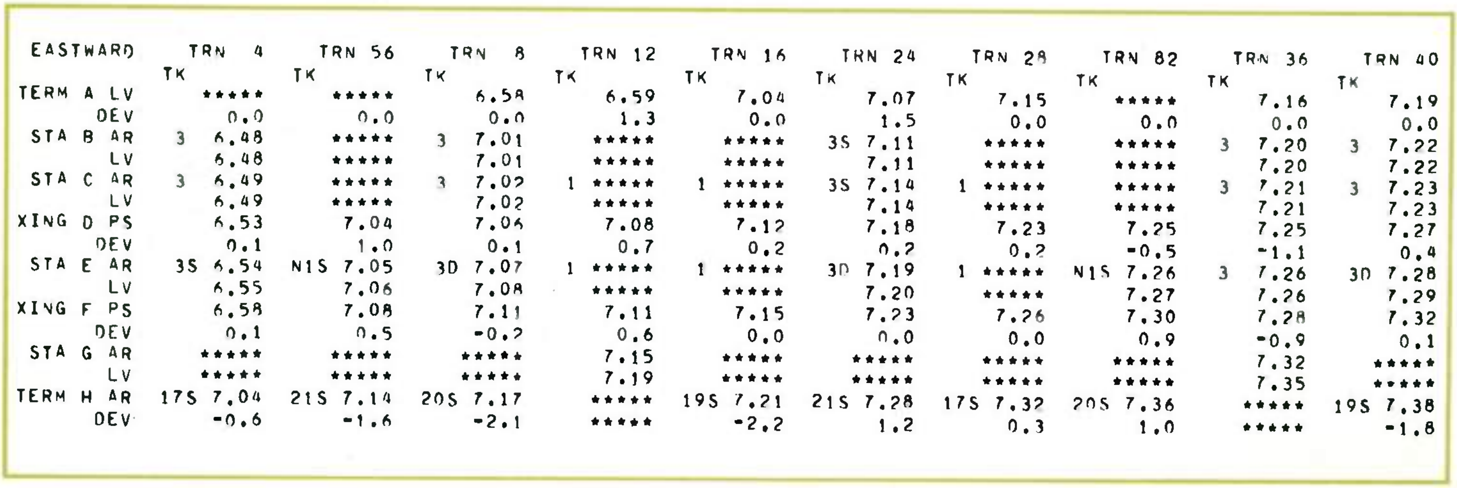
. . . But Also Gives Managers a Conventional "Train Sheet."



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EASTWARD     TRN  4     TRN 56     TRN  8     TRN 12     TRN 16     TRN 24     TRN 28     TRN 82     TRN 36     TRN 40
            TK         TK         TK         TK         TK         TK         TK         TK         TK         TK
TERM A LV       *****      *****       6.58       6.59       7.04       7.07       7.15      *****       7.16       7.19
       DEV        0.0        0.0        0.0        1.3        0.0        1.5        0.0        0.0        0.0        0.0
 STA B AR   3    6.48      *****  3    7.01      *****      *****  3S   7.11      *****      *****  3    7.20  3    7.22
        LV       6.48      *****       7.01      *****      *****       7.11      *****      *****       7.20       7.22
 STA C AR   3    6.49      *****  3    7.02  1   *****  1   *****  3S   7.14  1   *****      *****  3    7.21  3    7.23
        LV       6.49      *****       7.02      *****      *****       7.14      *****      *****       7.21       7.23
XING D PS        6.53       7.04       7.06       7.08       7.12       7.18       7.23       7.25       7.25       7.27
       DEV        0.1        1.0        0.1        0.7        0.2        0.2        0.2       -0.5       -1.1        0.4
 STA E AR   3S   6.54  N1S  7.05  3D   7.07  1   *****  1   *****  3D   7.19  1   *****  N1S  7.26  3    7.26  3D   7.28
        LV       6.55       7.06       7.08      *****      *****       7.20      *****       7.27       7.26       7.29
XING F PS        6.58       7.08       7.11       7.11       7.15       7.23       7.26       7.30       7.28       7.32
       DEV        0.1        0.5       -0.2        0.6        0.0        0.0        0.0        0.9       -0.9        0.1
 STA G AR       *****      *****      *****       7.15      *****      *****      *****      *****       7.32      *****
        LV      *****      *****      *****       7.19      *****      *****      *****      *****       7.35      *****
TERM H AR   17S  7.04  21S  7.14  20S  7.17      *****  19S  7.21  21S  7.28  17S  7.32  20S  7.36      *****  19S  7.38
       DEV       -0.6       -1.6       -2.1      *****       -2.2        1.2        0.3        1.0      *****       -1.8
```

Input for the Simulation

As with most digital computers, the input for the simulation consists of punched cards. Numbers are assigned according to the track and train models and the data is punched on cards. When the simulation is run on the computer, all of the track model data is read and then the data for each train is read when the train originates.

Output of the Simulation

In the simulation of train movement on a railroad, changes occur as events. Therefore, each time an event occurs, information is provided by this simulation program. This output information can be recorded on magnetic tape for later processing, and it can also be printed as soon as the event occurs. A sample of a chronological output is shown at the top of the opposite page; this lists each event as it occurs and gives details on the changes that occurred during the event. The items on the underlined rows are: the type of event; the time the event occurred; train number; control point; path; if a delay occurred, its location and duration in minutes; and track occupancy status. Special statements are printed when trains originate, terminate, or are delayed for any reason. The chronological output provides great detail but is too voluminous for easy use. Therefore, the output tape is processed to provide a "train sheet" which is similar to the dispatcher's record of train movement as kept by the railroads. A sample train sheet output appears at the bottom of the opposite page. In addition to ARRIVE, LEAVE, and PASS times, the train sheet includes deviations from schedule, track and tunnel used, and the type of stop, where a stop occurred. "S" indicates a schedule stop, while "D" indicates a stop to discharge passengers.

Other forms of output can be produced. One item is the "percent trains on time," which is computed when each train reaches its terminal. If required, time-distance plots (train graphs) could be produced on either line printers or x-y plotters. The form of the output can be tailored to satisfy the need of the user.

Use of Simulation

Railroad simulation can be useful both to operating roads and to rapid-transit system planners. The planners of a rapid-transit system have many alternatives to choose from. The optimum system design is not easy to determine. After several track layouts, car characteristics, and operating schedules have been selected, train movement can be simulated to determine what actual operation would be like with each set of parameters. With this information, additional improvements can be made so that the best possible system can be obtained. Information can be obtained in this manner years before actual operation commences.

One method used today to predict operation of a schedule is by manually drawing a train graph of distance traveled versus time. Interferences are revealed when the lines for different trains get too close to each other. Then the schedule is changed and the graph changed again. This process takes about ten times the manpower required to perform the same schedule checking task by computer simulation. In a similar manner, computer simulation can predict the operation with several track layouts and station locations. If desirable, passenger flow and crew assignments and availability can be included in the simulation.

Railroad simulation is of value for existing properties in the same areas as for systems in the planning and design stages. An operating model of the system on a computer permits examination of factors affecting operation in a very short time. Small changes or complete schedule revisions can be tested and perfected before being applied to the actual railroad. Major changes in operating patterns of transit systems, such as operating three tracks in one direction and one return during peak hours, can be tested and optimum conditions determined in advance of application.

The computer time used for a simulation study is a function of the number of trains and the number of events they are undergoing, as well as of the size and speed of the particular computer used.

A simulation of the New York City Transit Authority System, including all of the trains on the whole system during peak hours, might take about the same time as the time period being simulated. Since most other systems have considerably fewer trains running, the computer time is usually much less than the actual time. On a high-speed computer, 200 trains undergoing 20 events each might require about ten minutes to simulate. This same activity on the railroad might represent three hours of operation. In this example, the simulation was accomplished in about 1/18 of the actual time that was simulated.

Conclusion

Digital computer simulation is a technique for imitating the operation of large complex physical systems. The simulation can be made to produce the same results as the actual system as far as a manager in an office is concerned. That is, he will receive reports, as a consequence of his instructions, that show the same results whether he issues them to the simulation computer or to the actual system. The advantage of the simulation is that the manager can try many types of changes and quickly determine their effectiveness before they are put into actual practice.

This article has described the application of system simulation to railroads. Because of their versatility, the same techniques are being applied to many other business and industrial situations.

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Acknowledgement:
The railroad simulation reported here is the result of the efforts of many people at Westinghouse. We gratefully acknowledge their efforts, although it is impractical to name all of them. Recognition of the need for simulation and the definition of the requirements are due to Field Curry. William J. Walker sponsored the development, which was started in 1963 by D. A. Bauerle and D. N. Dewees, who established the basic methods. Others who contributed are Kan Chen, R. K. Dove, T. A. Jeeves, Henry Klein, R. A. Mathias, and W. F. Rousseau.

A New Era for Mercury Lamps

by M. C. Unglert
D. A. Larson

The mercury vapor lamp, long a workhorse in industrial and street lighting, now has much broader vistas because of a new development. This involves the addition of certain chemicals to the mercury discharge; through these additives many different characteristics of the lamp can be changed, some quite radically.

The mercury vapor lamp now widely used for both street lighting and factory lighting is a highly efficient, reliable, and economic light source. This situation is due to a steady series of engineering developments during the past two decades, each of which has contributed to the performance of these lamps.

Now, however, an exciting new development has entered the picture; it promises to open up entirely new areas for mercury lamp application, improve efficiency dramatically, and make possible a relatively simple means of color improvement. This new development involves the addition of various salt iodides to the mercury discharge; each iodide investigated so far produces different results, so that either singly or in combination they can produce an efficiency improvement of up to 100 percent, or a significant improvement in color rendition with no loss—and in many cases an improvement—in efficiency, or various other performance characteristics.

Background of the Mercury Vapor Lamp

The use of the mercury discharge as a light source goes back to the turn of the century. The high-pressure mercury lamp found some acceptance during the thirties. The present phase of rapid growth in the use of the mercury lamp for both street lighting and factory lighting was stimulated in the late forties by two Westinghouse developments: (1) The molybdenum seal,[3] which has since undergone a number of design refinements and vastly improved the life and reliability of the mercury lamp, and (2) OV20 type street-lighting fixtures, which provided an economical, efficient, and attractive luminaire. Further improvements were the use of phosphors, coated on the inner surface of the hard glass outer bulb to improve color;[3] the oxide embedded Lifeguard electrode,[4] which reduced evaporation of filament material and thus retarded blackening of the arc tube and thereby improved lumen maintenance; and the hard glass Weather Duty outer bulb, which eliminated deterioration of the glass, a previous problem under many operating conditions.

These developments have produced the highly efficient, reliable, economic mercury lamp in wide use today. Typical is the popular clear 400-watt lamp, which is rated at 21,500 lumens, over 16,000 hours life, with 18,900 mean-lumens through 16,000 hours.

Development work with additives has been concentrated on this lamp size. Before considering the effect of additives, consider briefly the operation of the standard 400-watt mercury lamp.

The quartz arc tube is the heart of the high-pressure mercury lamp. A sketch of the 400-watt arc tube, showing its shape and dimensions, appears in Fig. 1. The arc tube contains a starting gas such as argon at a pressure of about 25mm of mercury and a measured quantity of mercury, which in this lamp is 66 mg. When operating at rated wattage, the mercury is completely vaporized and has a pressure of about two atmospheres. At this pressure, the voltage drop is 135 volts at 3.2 amperes.

If the amount of mercury in this lamp could be completely vaporized at room temperature, it would have a pressure of only one-third of an atmosphere, but because the temperature of the discharge is very high, the pressure is increased.

The temperature of the gas at the center of the discharge has been measured by various people in the lamp field and found to be greater than 6000 degrees K.[5] The temperature of the gas decreases in a gradual manner to about 1000 degrees K at the wall. The wall operates at this temperature except in the region behind the electrodes where the temperature is somewhat lower.

At the temperature of 6000 degrees K, some of the collisions between electrons and mercury atoms result in the transfer of sufficient energy to leave the mercury atom in an excited state; this subsequently results in radiation of discrete wavelengths characteristic of the mercury atom. The visible portion of the mercury spectrum is shown in Fig. 2. It consists of four principal lines, a doublet at 5770–5790 angstroms, which appears as a single line in the yellow, a green line at 5461 angstroms, and a blue line at 4358 angstroms. In addition, there are a number of lines in the nonvisible regions of the ultraviolet and infrared. The intense light of the mercury arc is restricted to a cylinder about one-half the diameter of the arc tube because the number of collisions resulting in excited states of the atom decreases rapidly with gas temperature.

Both the high-pressure mercury discharge and the low-pressure mercury discharge used in the fluorescent lamp radiate at the same wavelengths; but the relative intensity of the lines differs greatly. In the low-pressure discharge most of the radiation is in the resonance line at 2537 angstroms—i.e., in the ultraviolet region—which a phosphor converts to visible light. The visible mercury lines are very inefficiently produced, yielding only 5 lumens per watt. In the high-pressure discharge, the resonance radiation is absorbed by the mercury vapor and is trapped within the discharge. The intense lines become those in the visible region and the luminous efficiency increases to 54 lpw. The color of the discharge is in both cases lacking in red radiation and considerable effort has been expended in the past to remedy this situation.

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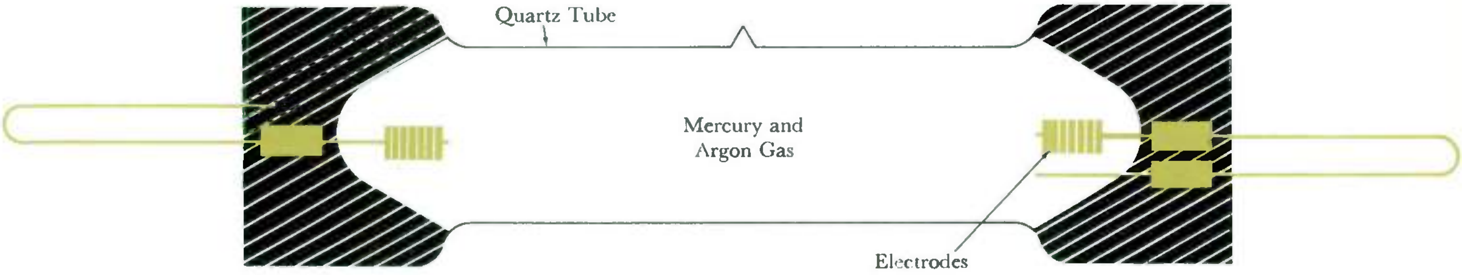
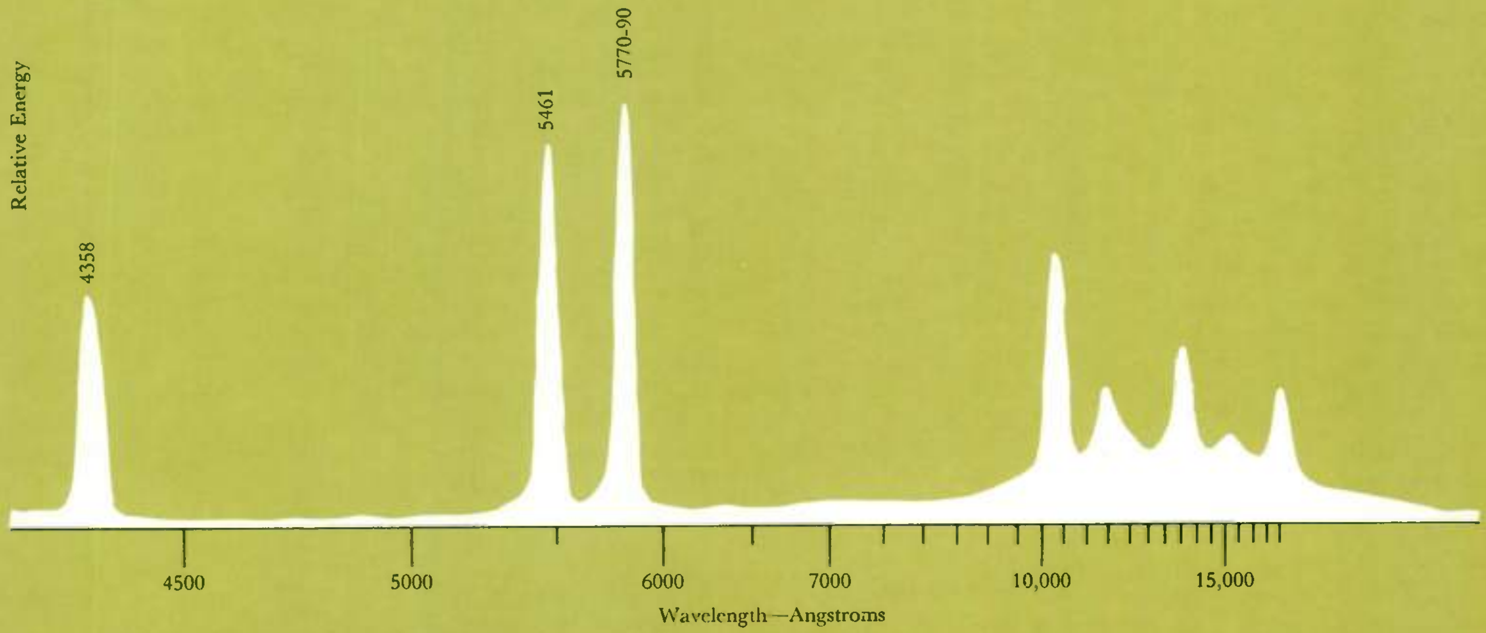


1—**The standard quartz arc tube** of a high-pressure mercury lamp. In addition to mercury, the tube contains a starting gas, such as argon. The temperature at the center of the discharge of this lamp is more than 6000 degrees K and about 1000 degrees K at the tube wall.

Conventional Mercury Spectrum



2—**The visible portion of the mercury spectrum** consists of four principal lines, one of which appears as a single line in the yellow region. Mercury also produces lines in the nonvisible ultraviolet and infrared regions.

Over the years, many attempts have been made to improve the red output of the mercury lamp. Among these was the addition of cadmium metal to the discharge. This, however, was unsuccessful because of the disappearance of the cadmium during the life of the lamp and because the addition of cadmium severely reduced the lamp efficiency.

The most successful means of red production, until the development of the iodide additive concept, involved coating the outer envelope of the lamp with a red-emitting phosphor, which is activated by absorbing ultraviolet radiated from the arc tube. Although this system is in general use today, it has increased the source-size to the dimensions of the outer envelope which makes it more difficult to control the light pattern. In addition, the output is reduced by the absorption of visible light by the coating. Thus, although this method improves the color, it reduces the lamp's efficiency.

All other efforts to improve the color or efficiency by the addition of various elements to the discharge met with even less success either because improved color resulted in too great a loss in efficiency or because spectrally desirable elements had too low a vapor pressure or too high a chemical reactivity with the envelope material.

The Use and Effect of Additives

When the iodides of a number of metals were recently investigated, it was found that they could be used to introduce the metal component into the discharge without the iodine having pronounced effects on the arc. Metals like lithium, potassium, and sodium, which were highly reactive, could be introduced as iodides and no longer rapidly reacted with the quartz. Metals like indium, gallium, and thallium, which had low vapor pressures, could be readily introduced into the arc as iodides at reasonable bulb wall temperature. Thus, it is now possible to modify the spectrum of the high-pressure lamp to a previously unimagined extent.

In the beginning of this article, it was mentioned that in the high-temperature core of the discharge, some of the electrons had sufficient energy to raise the mercury atoms to excited states which radiated the various wavelengths characteristic of the mercury atom. For the visible lines of the mercury spectrum this amount of energy is 7.7 electron volts. The fraction of electrons having this much energy is extremely small, and relatively few of the atoms are present in this state. At the temperature of 6000 degrees K, an excited state at 4.0 e.v. would have a population approximately 1000 times as great. Most of the additives have the radiation that is desirable to add coming from states which lie between 2 and 4 e.v. This permits very pronounced modifications of the mercury spectrum at additive densities that are a small fraction of the mercury density. The iodide vapor pressure at the bulb wall temperature need only be several millimeters of mercury in almost any case, and for those atoms having the lower energy excited states it can be much lower.

The spectrograms obtained for a number of interesting additive lamps are shown in Fig. 3a-f.

The spectrum obtained with the addition of about 10 mg of thallium iodide to a discharge containing 66 mg of mercury is shown in Fig. 3a. The mercury lines at 5780 angstroms appear barely detectable, and the 5461-angstrom line is lost in the tail of the 5350-angstrom thallium line. The discharge is pronouncedly green and very efficient, yielding as much as 100 lpw. A similar effect, shown in Fig. 3b, occurs when about 2 mg of indium tri-iodide is added to the discharge. In this lamp the discharge is very blue, but the color rendition is good since some continuum extending from the blue through the red is present. In this case, the efficiency is only 20 lpw since most of the energy is radiated in the blue region of the spectrum to which the eye is less sensitive than the green and yellow region.

The effect of the addition of sodium is shown in Fig. 3c. The sodium contribution is limited by the fact that its vapor pressure is low and although 20 mg are normally added, probably less than 1 mg is in the vapor phase. The luminous efficiency is approximately 70 lpw, and the light has a yellow-orange color. The addition of lithium iodide is shown in Fig. 3d. The spectrum for the lithium lamp was obtained at higher than normal loading to obtain sufficient vapor pressure. Because of its low vapor pressure, its desirable red radiation cannot be used to give strong reds in the practical combination lamps shown in the next two figures.

Development of a Commercial Lamp

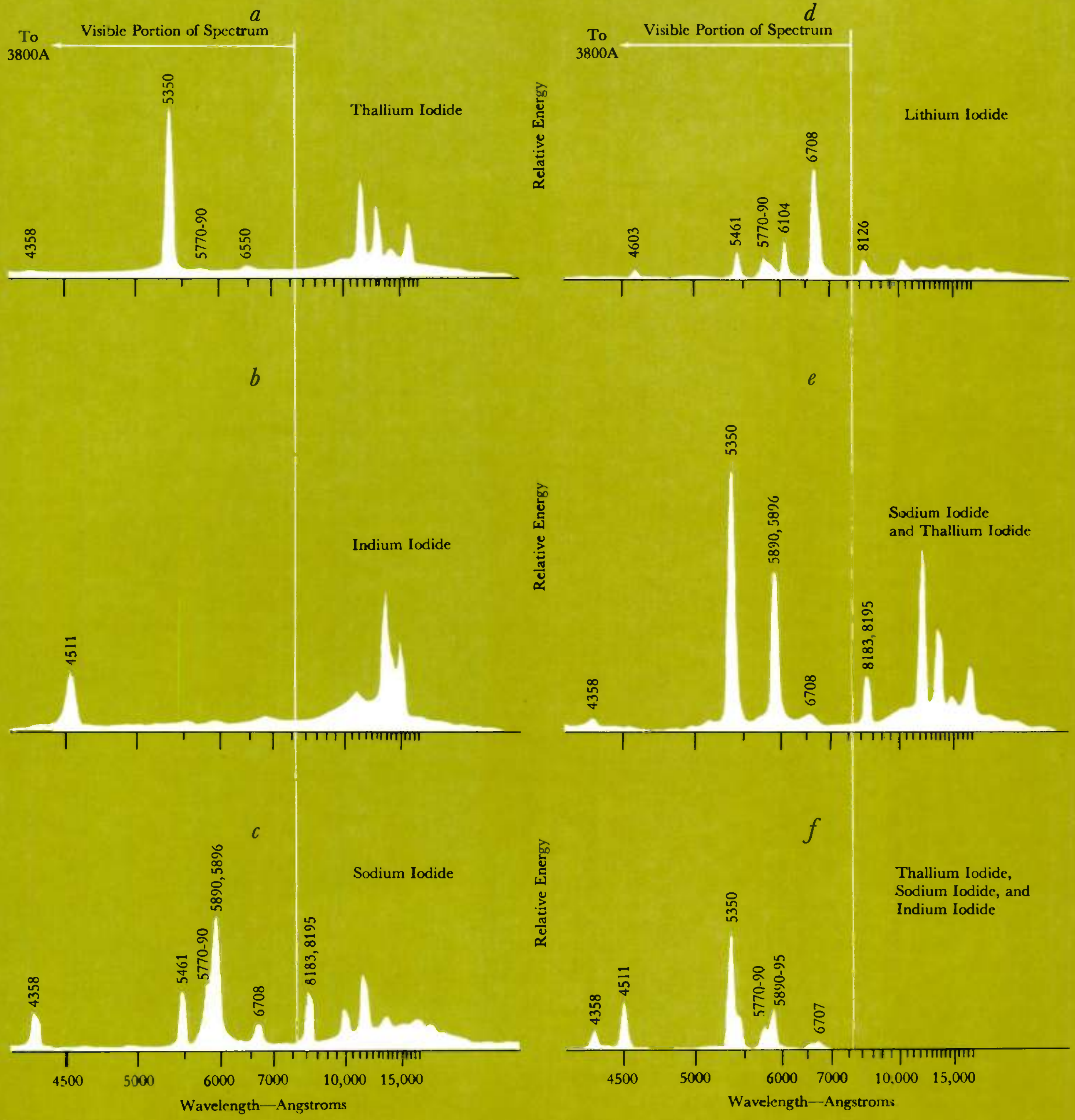
The first step in producing a highly efficient, acceptable-color, general-purpose lamp was the combination of sodium and thallium iodides in a single lamp. This discharge has a yellow-green cast with energy in all regions of the spectrum (Fig. 3e) so that color rendition is improved considerably over the mercury lamp. An efficiency as high as 120 lpw has been obtained in the laboratory, and a practical lamp having 90 lpw at 100 hours has been developed.

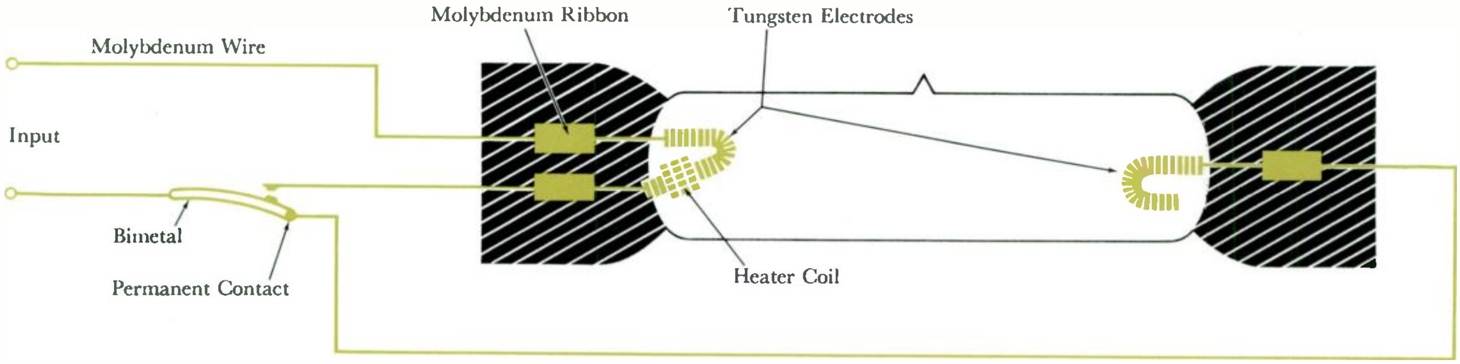
A second lamp is being tested which combines the three additives, indium, thallium, and sodium and has the spectrum shown in Fig. 3f. The amounts of indium and thallium iodides have been reduced to provide a more balanced spectrum, and this lamp has white appearance and an efficiency of 80-85 lpw.

The new 400-watt lamp with sodium and thallium iodide additives having an initial output of 36,000 lumens is almost 1¾ times as efficient as the present lamp, and therefore offers the user a substantial increase in light output in the same package using the same power that previously provided only 21,500 lumens. This lamp is designed to operate on the same auxiliary equipment used with the standard 400-watt mercury lamp in the vertical position, and with the addition of only a simple electromagnet in the horizontal position. The development of such a lamp was not without difficulties. The addition of sodium iodide into the lamp created four problems: (1) sodium iodide vapor pressure was too low at existing bulb wall

3—**The effect of different additives** is shown in this series of spectrograms. Note the dramatic shifts with different iodides.

Effects of Additives on Mercury Lamps





4—A new electrode design is required for additive lamps; its primary function is in starting the lamp.

temperatures; (2) the iodide attacked some lamp parts; (3) lamps were more difficult to start; (4) horizontal operation was not practical.

Providing sufficient heat for sodium iodide vaporization has required the use of a highly evacuated outer envelope to reduce the heat loss from the arc tube by convection and also the use of metal end caps with an insulating, low vapor pressure, high melting point, white reflecting surface material to raise the temperature of the arc tube ends.

At the arc core, the sodium iodide breaks down to sodium and iodine. These atoms move out of the core toward the wall. Most recombine before they reach the wall, reforming sodium iodide, which prevents attack of the quartz by sodium. To assure complete recombination, the arc tube diameter was increased 4 mm as compared with the standard lamp, and the arc lengths proportionately reduced to maintain the same arc tube wall loading.

Since both sodium and iodine are very active chemically, the normal oxide type emission material cannot be used for electrodes. Thus far, only tungsten has proven satisfactory as an electrode material for this lamp. Elimination of the emission material from the electrode has caused an increase in lamp starting voltage. To overcome this problem, a new electrode design was required. In this design the starting resistor, probe electrode type starting circuit is replaced by a heater coil electrode combination as shown in Fig. 4.

The circuit includes a bimetal switch that cuts out the heater coil after 10-20 seconds and allows the arc to operate normally from the main electrodes. The lamp current passes through the bimetal at all times, heating the bimetal, and thereby keeping the switch opened. The starting coil provides initial heat to warm the lamp under cold starting conditions, and also acts as an emitter that helps to start the lamp.

When a mercury lamp is operated in the horizontal position, the arc is bowed upward by the convection currents in the lamp. This causes the iodide material to condense at the cool lower portion of the arc tube. To correct this condition, a simple electromagnet added to the lamp fixture applies a magnetic field; this field forces the arc to return to a position at the center of the arc tube, which results in satisfactory vaporization of the additive materials and color uniformity.

The use of these techniques for high efficiencies and improved color should open new fields for the applications of the high-pressure discharge lamp. In addition to making this type light source even more attractive for street and roadway lighting, high-bay factory lighting, and flood lighting, broader applications can be expected in the fields of office lighting, commercial lighting, and other areas where the color of the mercury discharge has previously proven unacceptable.

Since the spectral radiation of the discharge can now be controlled, sources can be made rich in the near ultraviolet and infrared as well as in the visible region of the spectrum. Such sources will be of interest in the photocopying and the photochemical fields. With more efficient ultraviolet generators, the photochemical process may become more prevalent in industrial applications.

There are still improvements to be made, especially in the area of cost and lumen maintenance, but these can be expected as the development of lamps of this type continues.

The lamp described may be considered at the same stage of development as the standard mercury lamp was in 1948, so that engineers look forward to a revolution in lighting of magnitude similar to that which was precipitated by the development of the fluorescent lamp in the thirties.

Westinghouse ENGINEER
July 1965

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Application of Induction Heating Power Systems

by W. A. Emerson

The selection of a motor-generator set versus a radio-frequency generator for an induction heating application can usually be determined by considering the effects of frequency and power on performance.

Induction heating, with its inherent advantage of quick, selective heating of the workpiece from within, has applications that range through heat treating, forging, welding, and melting. Two fundamental parameters are adjusted to accommodate this wide variety of applications—frequency and power. Frequency selection is based upon such considerations as the ability of a particular frequency to do the required job, equipment cost, voltage across the induction coil, radiation problems, and others of lesser importance. Power requirements are determined by the amount of material that must be heated, the desired rise in material temperature, and losses. Other factors may be involved, but frequency and power are always basic considerations in the selection of induction heating equipment. Careful evaluation of these two parameters will usually indicate the superiority of either a motor-generator set or a radio-frequency system for a given application.

Frequency

For economic reasons, the frequencies available for induction heating are largely limited to those used in standard equipment. However, this range of frequencies is such that selection of the desired frequency for a given job is normally no problem. Most common frequencies used in induction heating are: 4 megacycles; 450, 10, 3 and 1 kilocycles; and 60 cycles. Other frequencies sometimes used, but restricted by the scarcity of available power sources, are: 20 kc and 4200, 400, 180, and 25 cycles.

Since current distribution in the workpiece is a function of frequency, the choice of frequency can have a considerable effect on performance. Current distribution is usually considered in terms of the *effective depth* of penetration (δ), which is, by definition, the distance at which, if total current were evenly distributed from the surface, the heating effect would be the same as that provided by the actual current distribution (Fig. 1). The effective depth of current penetration in inches is given by the relationship,

$$\delta = 1.98\sqrt{\frac{\rho}{\mu f}}$$

where ρ is electrical resistivity in microohm-centimeters, μ is permeability, and f is frequency in cycles per second. Thus, optimum heating performance can be obtained by selecting δ to suit the application. For example, surface hardening jobs require a thin, or "skin" heating depth, which is most easily obtained with high frequencies; brazing and forging applications need the more uniform heating obtained with low frequencies.

Where through heating of the workpiece is needed, the most efficient heating is obtained with a depth of current penetration (δ) less than one third the diameter of round stock, or less than one third the thickness of flat stock. Thus, optimum frequency will depend upon the size of the workpiece.

Since resistivity changes during the heat cycle, depth of current penetration should be determined for both minimum and maximum resistivity. For nonmagnetic materials, or magnetic materials that reach the Curie point (temperature at which a magnetic material becomes nonmagnetic), permeability will be unity.

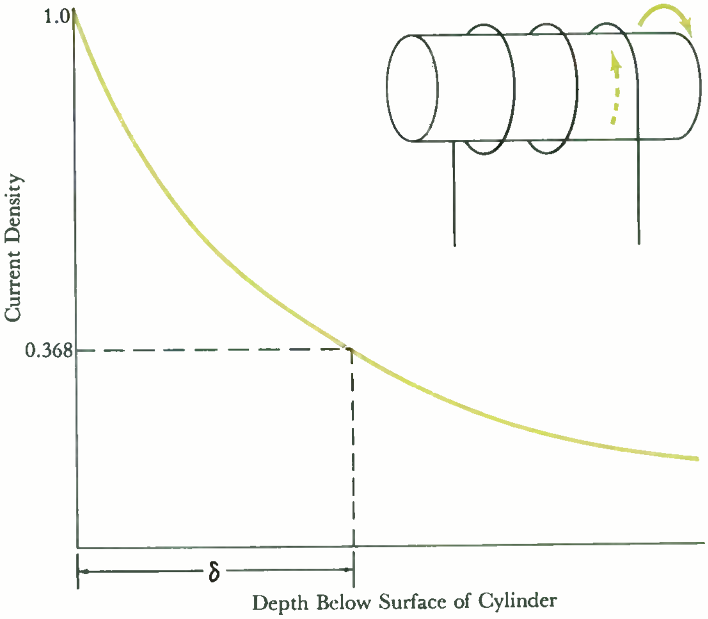
Power Requirements

The total power required will be that power actually used to heat the work plus additional power originally induced into the work but subsequently lost through radiation, convection, and conduction. There will also be power losses between the generator and the work.

The power required in kilowatts to bring the work up to a proposed temperature in a specified time can be calculated from the formula:

$$P_t = 2.93 \times 10^{-4}\, MK\Delta T$$

where M is the material heating rate in pounds per hour, and K is the average specific heat of the material over the desired temperature range ΔT in degrees F.



1—Current density distribution in a cylinder. Current distribution is usually considered in terms of the effective depth, δ.

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For working temperatures under 1200 degrees F, thermal losses through radiation and convection usually can be disregarded. If higher temperatures are required, or if the workpiece is large and heating time is long, these losses become significant and must be calculated.[1] In still air, convection losses are considerably smaller than radiation losses.

Conduction losses occur when only part of the workpiece is heated, or when the workpiece is in contact with a relatively good thermal conductor. In either case, conduction loss results in the heating of extra material; it can be accounted for by calculating the equivalent amount of additional material that is heated to the desired workpiece temperature, and adding this amount to the material that is being heated for working.

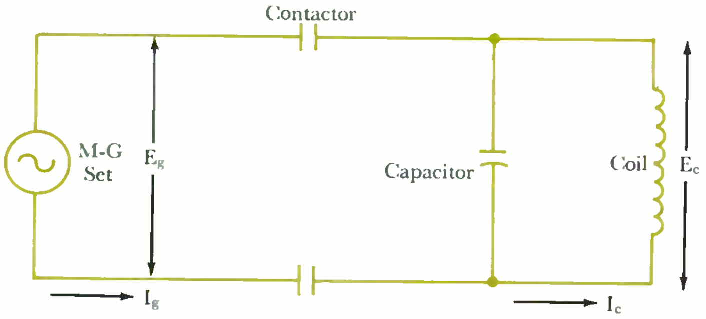
And finally, total generator power requirements will be determined by system operating efficiency, which is defined as the ratio of power going into the work to power output of the generator. This efficiency can be calculated accurately, but the values given in Table 1 for the most common materials are reasonably accurate for most estimates. The efficiencies listed are a function of coupling, which must be defined to be meaningful. In this case, coupling is considered "good" when the work is inside a solenoid coil, and radial clearance between work and coil is not more than 1/16 inch for diameters under two inches, nor more than 1/8 inch for diameters over two inches; coupling is "poor" when the work coil is not a solenoid type and spacing between work and coil is 1/16 inch or less. If, under these poor coupling conditions, distance between coil and work is over 1/16 inch, coupling is very poor, and little energy is transferred to the work unless the work is highly magnetic.

Table 1—System Efficiency in Induction Heating

Material Heated	*Coupling*	*Temperature*	*Efficiency (%)*
Iron & Steel	Good[1]	Below Curie	80-90
Iron & Steel	Poor[2]	Below Curie	60-70
Iron & Steel	Good	Above Curie	60-70
Iron & Steel	Poor	Above Curie	30-50
Copper	Good	Any	30-40
Copper	Poor	Any	10-20

[1] Solenoid coil, close coupled to workpiece.

[2] Coil other than solenoid, or solenoid coil not close coupled to work.



2—**Basic output circuitry** used with a motor-generator set for an induction heating application.

R-f or M-g Equipment?

If induction heating is to be used for a particular application that calls for some definite frequency, then the choice between r-f and m-g equipment is simple: r-f generators will be used at 4 megacycles and 450 kilocycles; m-g sets will be used at 10,000 cycles and below. Also, r-f generators, from a practical standpoint, are generally limited to about 100 kilowatts, whereas m-g sets are generally limited to 500 kw. However, r-f generators are available commercially at the 1200-kw power level, and m-g sets are available up to 2500 kw.

In cases where the application is not determined by frequency or power requirements, other differences between m-g sets and r-f generators may affect the choice.[2] For example, a motor generator operates at a fixed frequency, and must operate at rated voltage and current into a unity power factor load to produce full output. An r-f generator, on the other hand, can operate at variable frequency, and does not require operation at rated voltage or current, and does not have to feed a unity power factor load. Other differences, such as coil design, will be discussed.

Motor-Generator System

The basic output circuitry of an m-g set is shown in Fig. 2. Typical operating voltages of m-g sets are 200, 400, and 800 volts, usually in dual-voltage arrangements: 200/400 and 400/800 volts. Current rating is based on kva rating: for example, a 50-kva, 400-volt generator can supply 125 amps if the system has the correct impedance, equal to 400 ÷ 125, or 3.2 ohms. Since the generator supplies rated kva, it must operate into a unity-power-factor load to provide rated watts. Work coil impedance is inductive and must be balanced by capacitive reactance to obtain unity power factor and to make kw equal kva.

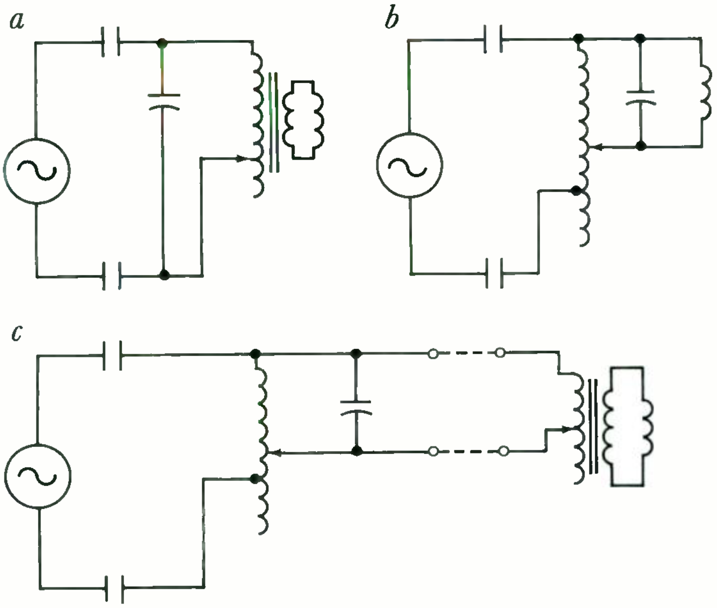
With parallel tuned power factor correction, current circulating in the "tuned" portion of the circuit is higher than that in the generator circuit. Load coil current can be estimated by assuming a coil power factor of 10 to 50 percent for a solenoid type coil, the high value corresponding to close coupling between coil and workpiece. Coil current will be:

$$I_c = \frac{P}{E \times PF}$$

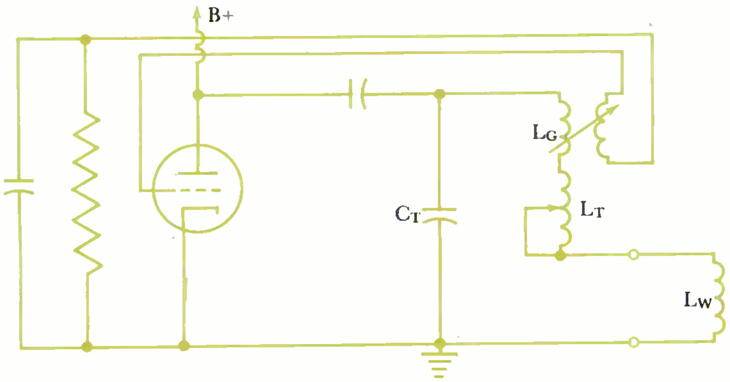
where I_c is current in the coil, P is rated power of the generator, E is rated generator voltage, and PF is power factor of coil. Thus, in the basic circuit shown in Fig. 2, if the power factor of the work coil is 10 percent, coil current will be 10 times generator current when the power factor of the total load is unity. More exact methods for calculating coil current are available,[3] but the above is usually sufficient for normal performance estimates.

With the load corrected to unity power factor, the generator must see the correct resistance to provide rated power. Although the work coil will have some resistance, maximum heating efficiency will be obtained only if most of the resistance is that of the work, reflected by the transformer effect between coil and the work. This reflected resistance will be a function of the number of coil turns.

If load power factor is allowed to lag because of insufficient capacitance, the voltage drop due to line impedance will cause coil voltage to be lower than generator voltage. If system power factor is leading, a condition of series resonance is established between line inductance and the capacitance effectively in series with line inductance, and coil voltage will exceed generator voltage.



3—Typical transformer arrangements for induction heating: *(a)* Uses capacitors to greatest advantage; *(b)* accommodates high work-coil voltages; *(c)* versatile approach for research and laboratory use.



4—R-f oscillator circuit has work coil in series with generator inductance so that frequency may vary over considerable range.

To a limited extent, leading power factor is desirable because this condition permits some flexibility in matching the coil to the generator. However, if power factor lead is excessive, voltage buildup may be great enough to damage the capacitor. Under extreme leading conditions, the generator can become self-excited so that normal control by field excitation is lost. The overload will trip the line at this point, but the possibility exists of damaging the generator and other system components before tripping occurs.

Heating Coils—For a given heating application, there is only one correct number of coil turns, and standard systems of coil calculation can be used to determine this number. For any single repetitive operation, the heating coil is calculated and then modified to give desired performance.

For laboratory and research use, it is desirable to be able to match the system to coils that are not precisely designed. This may be done in three ways:

1) Use of additional capacity to establish leading power factor and thus change overall system impedance;

2) Use of an oversized generator to allow a certain amount of mismatch;

3) Use of a variable-ratio output transformer between generator and work coil.

The first method, although limited in range, is sometimes useful. The second method can be expensive if a large generator is required for a small job. Therefore, the third method is usually preferred, from both a technical and economic standpoint. However, for each different coil, a different transformer ratio and a different amount of capacitance across the transformer or work coil will be required.

Typical transformer arrangements are shown in Fig. 3. The capacitors are used to the greatest advantage in Fig. 3a, but the transformer must handle high currents, which reduces efficiency somewhat. In Fig. 3b, more capacitance is required at the low coil voltages. Hence, the first system is preferred for systems with low coil voltages, the second for high coil voltages. An excellent approach for research and laboratory use is a combination of the two, shown in Fig. 3c. It can be used in place of either of the basic systems, and it makes available a large number of coil voltages as the effective number of taps it provides is the product of the number of taps on the two transformers.

Radio-Frequency System

A typical circuit for an r-f oscillator is shown in Fig. 4. Since the work coil is in series with the inductance inside the generator, frequency may vary over a considerable area. However, in calculating the effective depth of current penetration (δ), it is usually safe to assume that the frequency is the nominal frequency of the generators, 450 kc or 4 mc.

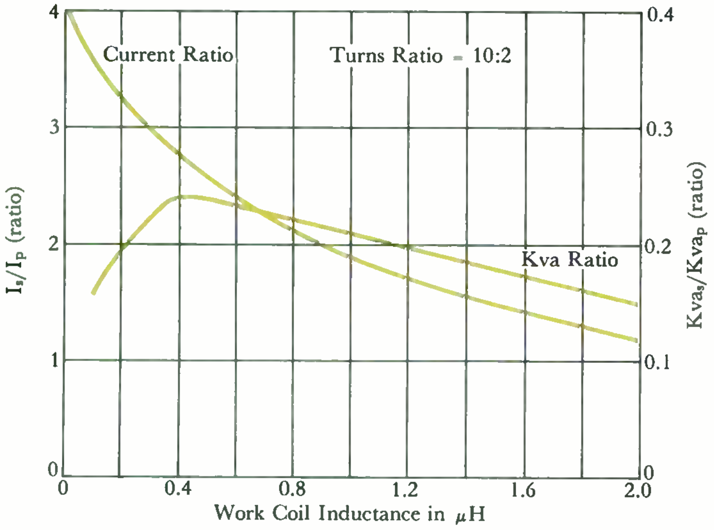
Since an r-f generator does not require operation at rated output voltage or current and does not have to feed a unity power factor load, the application of an r-f generator is considerably less complex than an m-g set. The most common r-f frequency is 450 kc because it is the easiest of the r-f frequencies to handle from the standpoint of coil design, ease of heating, and radiation problems. Although it is possible to calculate coil designs that will produce desired results, this procedure is seldom necessary because of the flexibility of the generator and because of the ease of modifying the coil. At 450 kc, without the use of a load-matching transformer, the work coil usually consists of 5 to 15 turns of copper tubing—the larger the diameter, the fewer the turns. Coil length should extend beyond the length to be heated by about half the coil diameter. The usual range of standard tubing sizes for kilowatt rating is shown in Table 2. The sizes shown will handle most applications, although in unusual conditions, it may be desirable or necessary to use other sizes. Also, it is sometimes desirable to use square or rectangular tubing, or partially flattened round tubing.

Radial clearance between work and coil should be kept to a minimum to maintain a high power factor and maximize coil efficiency. Clearance is increased only to provide electrical insulation or to produce more uniform heating.

From the above, it is apparent that there is little flexibility in building an r-f work coil. The simplest procedure is to select a convenient tubing size and wind the coil to cover the area to be heated. Spacing between turns should be about half the diameter of the tubing. With the work in place, reduced power is applied to check frequency, which must not be in the range of 490 to 510 kc due to possible radio interference at the distress frequency of 500 kc. Acceptable frequency range of a nominal 450-kc generator is normally 250 to 490 kc.

Table 2—Standard Tubing Sizes for R-f Work Coils

Up to 2 Kw	1/8″ or 1/4″ OD
5 Kw	1/4″ or 5/16″
10 Kw to 20 Kw	1/4″, 5/16″, 3/8″
25 Kw	5/16″ or 3/8″
35 Kw	3/8″ or 1/2″
50 Kw to 70 Kw	1/2″



5—Typical characteristic curves for load-matching r-f transformer.

If frequency is too high, internal inductance is added by adjustment of tank taps; if frequency is too low, it may be corrected by reduction of internal inductance. If after removal of all internal inductance the frequency is still so low that the generator does not operate properly, then it may be necessary to reduce the number of turns in the work coil. Frequency is not too critical in the operation of an r-f generator. The main criterion in adjustment of tank taps and coil inductance is to get the proper loading of the generator.

In some special cases, the desired work coil will have only one or two turns. If such a coil is connected into the tank circuit, the magnetizing force developed may not be sufficient to perform the required heating. Magnetizing force can be increased only by increasing coil current. If the generator cannot accomplish this, a load-matching transformer is used to step up output current. A transformer can also be used to decrease the voltage across a work coil. But the application is valid only if the coil is designed with fewer than normal turns.

R-f transformers have a poor coefficient of coupling between primary and secondary, limiting current step-up to about 4 to 1; the ratio is dependent on the inductance in the secondary of the transformer. Secondary inductance must be kept to an absolute minimum for the transformer to be effective, since transfer of kva from primary to secondary is only about 25 percent at best.

Current flow through the work coil is directly proportional to the voltage across the coil and inversely proportional to the impedance of the coil. Lowering impedance makes it possible to obtain a higher current at a somewhat lower voltage, but the characteristic curves of the transformer being used (Fig. 5) must be examined to determine whether the desired current can be obtained.

Summary

For most induction-heating applications, technical and economic considerations dictate whether an m-g set or an r-f generator should be used. There are a number of applications in the power range of 5 through 25 kilowatts where the cost of equipment is equal, or may even favor r-f generators in certain ratings. In these cases, the decision often follows personal preference. But the basic advantage of each type of system still exists; an evaluation of available systems will usually determine the better choice.

Westinghouse ENGINEER
July 1965

References:
[1] Emerson, W. A., "Major Parameters of Induction Heating," *The Tool & Manufacturing Engineer*, Jan. 1965, pp. 59-61.
[2] Emerson, W. A., "Power Systems for Induction Heating," *The Tool & Manufacturing Engineer*, Feb. 1965, pp. 59-61.
[3] Baker, R. M., "Design and Calculation of Induction Heating Coils," *AIEE Transactions*, Paper No. 57-4.

Reversing Cold Reduction Mill Is First With All-Static Power

A reversing cold reduction mill to be installed at Kaiser Steel Corporation, Fontana, California, will be the first in the metals industry with a completely static main power supply. A thyristor system, instead of the usual motor-generator sets, will convert ac power to dc power for the drive motors. Stand screwdown positioning, mill speed, tension, and automatic mill slowdown and reversal will be preset through a Prodac control system. The mill will also have an automatic gauge control system.

The 68-inch four-high cold mill will reduce steel strip before final processing. It will be capable of producing coils up to 62 inches in width and 62,000 pounds in weight at speeds up to 3000 feet per minute. Strip thickness at the delivery end will range from 0.172 to 0.0125 inch.

A new 60-inch galvanizing line will receive coils from the cold mill for processing at speeds of 300 to 400 feet per minute. A shearing section will enable the line to produce sheets as well as coils. The facilities are scheduled for completion in the first half of 1966.

Refuse Reclamation Plant To Be Built in Florida

A nuisance-free refuse reclamation plant that can dispose of more than 100 tons of trash and garbage a day will be built at St. Petersburg, Florida. Unlike other disposal facilities, the new plant will use a method that disposes of trash and garbage by reclamation rather than destruction. Essentially, the operation consists of salvaging marketable items such as metal, glass, paper, and rags and processing the remaining material into a soil-conditioning compost. Since the operation does not involve fires, there are no odors or smoke. Flies and rodents are not attracted because the plant is completely enclosed.

The plant will be built by Westinghouse for International Disposal Corporation, Shawnee, Oklahoma. The St. Petersburg city council awarded the disposal corporation a 20-year contract for construction and operation of the million-dollar plant. Under the terms of the contract, the city guarantees delivery of a minimum of 100 tons of trash and garbage a day to the plant, paying a set amount per ton for disposal. The plant is expected to be in operation by the first quarter of 1966.

The first step in the process is a completely enclosed receiving station where collection trucks quickly dump unsorted refuse into a conveyor hopper. The refuse is then moved to the salvage section where marketable materials are salvaged. The remaining matter is then readied for organic decomposition by grinding, and the completely enclosed composting section makes use of a patented system to decompose the refuse in days instead of weeks, and without the offensive odors that usually accompany such processes.

Automatic Maintenance Information

As electronic systems have increased in complexity, their maintenance has become an ever more serious problem. Examples of such complex systems are in radar control centers, ship and shore naval control stations, military and space command and control centers, communication centers, and some automated industrial plants.

Now, however, an automatic maintenance system that helps keep large electronic systems in operation and in good repair has been developed. The system, called ADMIRE (for *A*utomatic *D*iagnostic *M*aintenance *I*nformation *Re*trieval), reduces the amount of time required to diagnose and repair a fault because it makes maintenance information available immediately. Since it also provides on-the-job instruction, much less training of maintenance personnel is necessary. It also reduces the need for test equipment and training simulators.

The new maintenance system was developed by the Surface Division of the Westinghouse Defense and Space Center. It consists of five parts: the equipment to be maintained, a monitor with sensors to isolate and indicate malfunctions, diagnostic circuits that relate the symptoms to a minimum number of faults, a control computer to diagnose and select applicable maintenance information, and a display device that presents programmed instructions to guide the operator in repairing the fault. Data from the malfunction sensors is converted to digital form. As long as the data is in specified operating ranges, outputs are interpreted as binary zero. Otherwise, the output is interpreted as a binary one, which indicates a fault symptom. The system diagnoses fault symptoms through programmed instructions or by means of the control computer and selects the most probable fault. Its presentation device then provides the required instructions.

The programmed instructions, which include technical manuals and other maintenance information, are stored in film-reel magazines. This type of storage is advantageous because the reels are an integral part of the machine, they can be stored easily and updated quickly, and their information is readily available. A five-inch reel of 16-millimeter film, for example, can be scanned in eight seconds. The more complex the system, the more magazines necessary.

In the most advanced ADMIRE system, information is automatically projected in still or motion picture frames on a screen. In a simpler version, only the first frame is shown, and the operator is told which other frames to retrieve.

Gemini Rendezvous Radar Tested by Simulation

Two Gemini rendezvous-radar test systems have been delivered to McDonnell Aircraft Corporation, prime contractor to the National Aeronautics and Space Administration for the Gemini spacecraft. The systems can simulate almost every type of operating condition likely to be encountered by the radar in space.

The test equipment, designed and manufactured by the Aerospace Division of the Westinghouse Defense and Space Center, will test every function of the Gemini radar unit and the Agena vehicle transponder before the first rendezvous attempt. (In that attempt, a Westinghouse radar unit in the Gemini spacecraft will guide it to a rendezvous with an unmanned Agena vehicle for the first American manned experiment in joining two vehicles in space.)

A radio-frequency simulator console, heart of the test system, simulates either radar or transponder transmitter signals in terms of power, range, range rate, and acceleration. These simulated signals are radiated into a free-space environmental chamber when testing the rendezvous radar, and they are direct-coupled when testing the transponder. Transmitted signals from the system under test are analyzed by the test set.

In rendezvous-radar tests, for example, the test equipment simulates the transponder. As the radar receives the transponder signals, it emits range and angle information in digital form and emits range and range-rate information in analog form. Analog information is read out on meters on a range and range-rate panel. Digital equipment converts digital readouts to decimal form, which is presented on display tubes. Power level, frequency, and pulse shape of the radar and transponder emissions are measured with a power meter, frequency meter, and oscilloscope built into the system. Voltages from the radar and transponder are brought out to panels for monitoring.

Transformer Windings Dried Quickly and Uniformly

The trend toward larger shell-form and core-form power transformers necessitates faster and more uniform methods of drying the insulation before impregnating it with oil. A highly effective process has been adopted for this purpose at the Westinghouse Power Transformer Division plant in Muncie, Indiana.

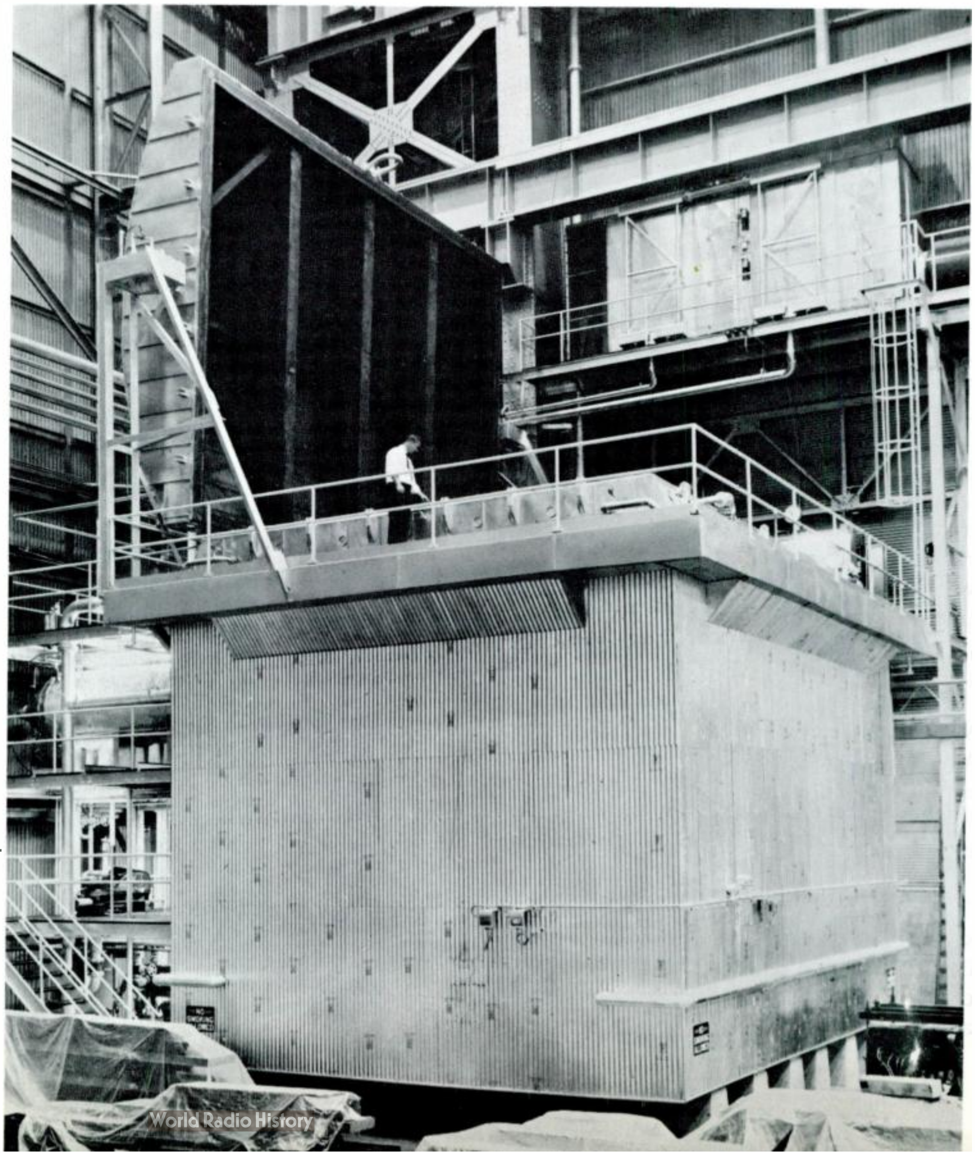
A petroleum solvent is boiled at reduced pressure in a closed vessel, and the hot vapor serves as the medium for heating the material to be dried. The process transfers heat to the insulation more rapidly and more uniformly than an oven can, so the time required to dry the insulation is considerably reduced. Moreover, the partial vacuum increases the rate of moisture removal. Complete unit drying and oil impregnation are done in the same vessel. Since the entire process is accomplished without oxygen present, higher temperatures can be used without deterioration of the insulation.

Continuous Cold Mill for Aluminum

The first continuous tandem cold mill in the aluminum industry is being built for a West-Coast aluminum producer. The five-stand mill will be programmed and controlled by a Westinghouse Prodac 50 computer control. The mill and control will allow changes in the material being rolled without emptying the mill. This is done by welding coil ends at the entry while stored material in looping pits between the welder and the mill maintains metal flow into the mill.

A shear at the delivery end cuts the strip when the diameter of the winding-reel coil builds up to the specified size. The strip end is then automatically guided into a second winding reel while delivery tension in the fifth mill stand is maintained by pinch rolls. Air-operated loopers between stands control tension.

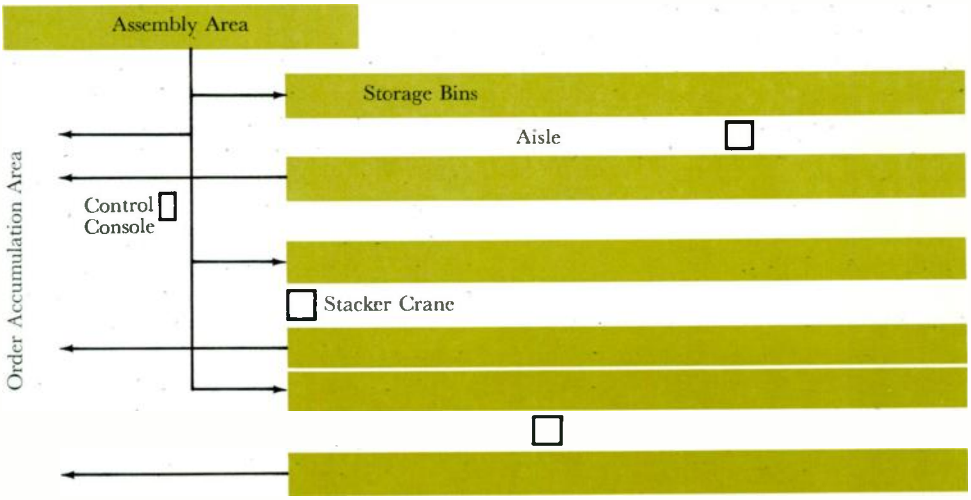
Each main stand is driven by motors rated 1250 horsepower at 300/720 rpm and supplied from 1000-kw generators in individual generator-motor loops. Top speed is 2000 fpm. Maximum strip width



is 52 inches, and delivery thickness range is 0.030 to 0.006 inch. Work rolls are 14 inches in diameter and backup rolls 46 inches in diameter.

The computer will record rolling schedules as they become optimized through manual experience. Then at some later time it can set up the mill to any recorded schedule called for. Up to 75 schedules can be recorded, with 7 digital inputs and 15 analog inputs read into the computer. The values for any schedule can be read out of the computer's memory on a typewriter for evaluation and can be changed manually if desired. The computer will be used first as a programmer, but since it is a computer, arithmetic operations can be added if needed.

The control system includes automatic gauge control by screwdowns on four stands, and also looper tension compensation to minimize production of off-gauge material during acceleration. Speed regulators on all stands make maximum torque available for a particular speed.



Automated warehouse will store items in random fashion for efficient handling of material and efficient utilization of storage space.

Semiautomatic Warehousing System

One way to use a given warehouse volume most efficiently is to store items in it in random fashion instead of assigning specific locations for specific items. Logical flow patterns can then be used, and fluctuations in the relative quantities of items do not affect the utilization of storage space. Improved control systems and mechanical devices now have made random storage feasible even for large warehouses—the control system keeps track of the locations of items and dispatches unmanned stacker cranes to place and retrieve them.

Such a warehouse system will serve the Westinghouse Lighting Division plant at Vicksburg, Mississippi. It was designed and is being installed by the Westinghouse Materials Handling Projects group of the Industrial Systems Division.

The warehouse will receive lighting fixtures from the adjacent assembly area, storing 100,000 of them on pallets in 2352 8-foot bins served by automated stacker cranes. The bins are arranged along aisles, seven tiers high. An operator at a control console will control the flow of products from receipt through order accumulation. Operation will be semiautomatic at first, but the facility can be converted to fully automatic operation. It is also planned for future expansion.

When a pallet load of cartons is delivered by lift truck to the warehouse, the warehouse operator will tell the truck operator either to take the load directly to the order accumulation area or to take it to storage. (See illustration.) If the latter, the warehouse operator chooses a card from his master bin location file, tells the truck operator which aisle to take the pallet to, and punches the card with the style number, quantity, and date. (These cards are arranged in a sequence that fills the most accessible bins first.) He then instructs the proper crane by dialing the *Store* instruction and the desired bin location. Finally, he files the card by style number and aisle in his warehouse inventory file.

To take a pallet out of storage, the operator looks up the desired style number in his warehouse inventory file. (Cards in that file are arranged in reverse chronological order so that the oldest pallet loads in storage are the first taken out.) He dials the *Retrieve* instruction to the proper crane, which brings the pallet to the head of the aisle to be picked up by the lift truck. The operator then prepares a new card with a duplicating printer punch for the emptied bin and files it in his master bin location file. Use of the duplicating printer punch assures that the data in the inventory files will be "clean"; that is, data that can be interpreted by different operators without difficulty.

For orders that require less than a pallet load of a style, two men will pick cartons manually. The bottom row of bins on both sides of a central aisle are reserved for this manual picking, with the bins closest to the front holding the most active styles.

When an order is completed, the lift truck takes the pallet or pallets to the loading dock.

The cranes will be able to store or retrieve a load, on the average, in 2¼ minutes. They will be able to store one load and retrieve another, on a single trip, in 3⅓ minutes average time. A transistorized wired logic system activated by a 26-bit command word dialed from the central console will control each crane. The four basic commands possible are *Store*, *Retrieve*, *Store and Retrieve*, and *Transfer* (from one bin to another). Each bin is coded, and a built-in program will cause the crane to serve a selected position by bin recognition in accordance with the code dialed in by the operator.

A unique feature of the warehouse is the use, throughout, of bins that are eight feet deep. Either an eight-foot load or two four-foot loads can be stored in any bin, an arrangement that requires fewer cranes than if separate bins had been provided for the two sizes.

Products for Industry

Unicode supervisory control system provides remote control of up to ten locations, over one pair of telephone wires, by transmitting pulse codes between control station and remote station. When a remote device is selected, the selection is automatically checked and indicated to the operator before an operation can be performed. Each remote-station unit closes and trips one device, such as a motor contactor, and a continuous lamp indication tells whether the device is closed or tripped. A remote-station unit can also be used for supervision only. The system operates on 115 volts ac or 125 volts dc. *Westinghouse Relay-Instrument Division, Plane & Orange Streets, Newark, N.J. 07101.*

New 0.0012-henry ac inductor limits surge current in rectifier circuits. It has two air gaps in each leg of the type "C" core for high-current low-inductance operation. At rated current of 160 amperes, reactance drop is 75 volts. Weight is 100 pounds. *Westinghouse Specialty Transformer Division, Greenville, Pa. 16125.*

W-200 line of diode transistor logic (DTL) integrated circuits for commercial computer applications is patterned after standard line of military DTL circuits. Performance characteristics include switching times of 25 nanoseconds, power consumption of 7.5 milliwatts, and fan-out of 11 per gate function. (Fan-out is output capacity of a single gate in terms of the number of gates it in turn can drive.) Operating temperature is 0 to 75 degrees C. The circuits are packaged in standard Westinghouse flat-packs measuring ¼ inch by ⅛ inch, with 14 leads, and also in type TO packages. *Westinghouse Molecular Electronics Division, P.O. Box 1836, Elkridge, Md. 21203.*

Type PA 2000-ampere molded-case circuit breaker is designed for use in switchboards and individual enclosures for feeder, branch, and heavy equipment circuits in commercial buildings and industrial plants. Size is 22 by 12 by 9 inches. Back connectors can be rotated 90 degrees for horizontal or vertical connection. Thermal-magnetic ac trip units are interchangeable, and magnetic trips can be field-adjusted for desired instantaneous-trip ampere setting. Interrupting ratings are 150,000 amperes asymmetrical at 240 volts ac, 100,000 at 480 volts, and 75,000 at 600 volts. *Standard Control Division, Beaver, Pa. 15009.*

Calibrator supplements or replaces standard relay methods for testing static-controlled reclosers. Designed for field or shop use, the unit facilitates calibration and testing of time-current curves and reclosing times. It operates from the 240-volt power source stepped down to 5 volts, with test current up to 30 amps. A double plug prevents errors in the calibrator between the static control and the recloser. *Westinghouse Distribution Apparatus Division, P.O. Box 341, Bloomington, Ind. 47402.*

New Literature

Environmental Analysis by Computer (SA-9538) is an illustrated booklet describing a service for making rapid calculation of building heating and cooling loads and energy requirements. The technique employs a load program to determine heat gains and losses for each zone or conditioned space within a building. Through a complex heat-transfer analysis, the program correlates all variables to give total peak load. The energy program employs a mathematical model of the building with the computer programmed to simulate expected conditions. Calculations account for variations in parameters for every hour of every month throughout the year, an impossible undertaking with slide-rule calculation. Copies are available from Computer Calculation Service, 24 E, Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh, Pa. 15230.

Westinghouse Superconducting Magnet Systems (TB 99-550) is a 16-page illustrated booklet defining superconducting magnet terms and describing magnet systems. Advantages, operating procedures, specifications, and characteristics are also covered. Magnet and dewar types are discussed, along with guarantees, tests, and capabilities. Information is included on magnet support and flange assemblies, power supplies, controllers, and other accessories. *Application Guide for Superconducting Magnets* (B-9014) is an illustrated 20-page booklet describing typical applications, operating procedures, and economic advantages. Copies of both booklets are available from Westinghouse Cryogenic Systems Department, P.O. Box 8606, Pittsburgh, Pa. 15221.

About the Authors

W. A. Emerson has had a thorough background in induction heating, ranging from design experience in systems and elements to field experience with applications.

Emerson is a graduate of the University of Texas, where he earned his bachelor's degree in physics in 1951. Shortly afterward, he joined the Induction Heating Department at Baltimore, where he served as an engineer until 1956. He was then transferred to Los Angeles as a product specialist in induction heating for the West Coast. He remained there until 1964, when he returned to Induction Heating Engineering at Baltimore. His design responsibility has included induction heating systems, heating coils, control circuits, and r-f tin reflow equipment. He currently has 25 patent disclosures and holds five patents—all in the field of induction heating. Emerson is presently a senior engineer in the systems design group of the Induction Heating Department.

John K. Howell brings a varied background to his position as project engineer of the Transit Expressway South Park Project. He served in the U.S. Navy from 1941 to 1945, and part of that time he attended Kansas State Teachers College and Southern Methodist University on the V-12 officer training program. He graduated from SMU in 1946 with a BS in electrical power and joined Westinghouse on the graduate student course. He was assigned to the Engineering and Service Department and served first in the St. Louis office as a consulting and application electric utility engineer.

In 1950, Howell was made a Westinghouse technical representative supervising electrical maintenance of B-36 aircraft at Carswell Air Force Base, and a year later he was transferred to the Dallas office to work with utility, industrial, and aviation industries. He returned to St. Louis in 1954 as regional engineering supervisor and was made regional engineering manager in 1957. He was transferred to the Electric Utility Group Power Control Division in 1962, responsible for application of computers in power-system dispatching and in the marine industry. He came to his present assignment in 1963.

Howell is a prolific writer and a frequent speaker at engineering societies and technical groups. He is coauthor, with E. E. Hogwood, of the book *Electrified Oil Production.*

William J. Walker began his engineering career in the U.S. Navy and then in the Merchant Marine, where he became a chief engineer. Between his Navy and Merchant Marine service, and again after the war, he took courses at the University of Southern California while working as a dry-land steam engineer. He graduated with a BE in mechanical engineering in 1949, joined Westinghouse on the graduate student course, and was assigned to the marine and aviation section of the former Industry Engineering organization.

Walker served from 1950 to 1957 as project engineer for Westinghouse on the U.S. Air Force Propulsion Wind Tunnel at Tullahoma, Tennessee, coordinating assembly of the drive motors, control, and compressors for the world's largest wind-tunnel facility. Along the way, he took graduate work in mathematics, physics, and electrical engineering at the University of Pittsburgh. He also guided other major test-facility projects during that time and was made engineering manager of the Public Works Province when that organization was formed, as Walker puts it, from a rib of Industry Engineering and Sales in 1962. Further evolution produced the Transportation Systems Department, with Walker as manager of Transit Systems.

R. C. Flanagan joined Westinghouse in 1948 after graduation from the University of Pittsburgh (BSEE). Upon completing the graduate student course, he was made an application salesman on equipment for diesel-electric and electric locomotives. In 1955, he became sales manager of the transportation sales section of the Transportation and Generator Division, responsible for both light traction and heavy traction equipment.

When the Power Rectifier Section joined the Transportation Group in 1958, Flanagan was made manager of rectifier and traction sales. In mid-1963, the transportation activity was made a division and he became marketing manager for the Transportation Equipment Division, handling equipment for mass-transit vehicles.

K. H. Fraelich, Jr. joined Westinghouse in 1959 after graduation from the University of Pittsburgh (BSEE). Prior to graduation he had worked as a student engineer with the Bettis Atomic Power Laboratories on the AIW Project. Upon completion of the graduate student course, he was made a division salesman with the Rectifier and Traction Division in East Pittsburgh, with assignments on both product lines. When the Transportation Equipment Division became a separate entity in 1963, he was made a sales engineer handling equipment for mass transit vehicles.

John Kostalos, Jr. and **Donald N. Dewees** joined forces to write the railroad simulation article in this issue. Kostalos is a project engineer for computer simulation studies of transportation systems, and Dewees is a consultant to the same group.

Kostalos is a graduate of City College of New York, where he earned his BEE in 1945. After serving two years in the U.S. Army Signal Corps, he returned to school and earned his MA in physics from Columbia University in 1949. Later the same year he joined Westinghouse at the Bettis Atomic Power Laboratory, where he worked on nuclear reactor instrumentation and control development until 1960. He then transferred to the Industrial Group, where he is a project engineer in the Transportation Systems Department.

His principal field of professional interest is instrumentation and control, and application of digital computers to analysis and control of transportation systems. In addition to the simulation studies of which he writes in this issue, Kostalos also worked on the automatic control for the Transit Expressway, also described in this issue.

Dewees is a graduate of Swarthmore College, where he earned his BSEE in 1963; he has since completed one year of Harvard Law School, where he also served as a programming assistant at the Harvard Computer Center. For the past three summers, Dewees has worked at special assignments at Westinghouse, in the areas of traffic flow control using computers, and simulation of commuter railroads using computers. He is presently serving in a consulting capacity to the Transportation Systems Department.

Melvin C. Unglert and **Daniel A. Larson** represent a natural team to describe the new mercury lamps with special additives. Larson's major interest has been in research on gas discharges, while Unglert's has been in the engineering area of gas discharge lamps.

Unglert received his BEE from the City College of New York in 1940, and his MS degree from Stevens Institute of Technology in 1944. He joined Westinghouse in 1940 on the graduate student course, and the same year went to work at the Lamp Division in Bloomfield, New Jersey, where his first assignment was in the engineering department working on fluorescent lamps. During the period from 1942 until 1945, he worked on a variety of special lamps for military use. His major efforts since about 1946 have been directed to the development and design of the mercury vapor lamp. In 1957, he was made a section manager in Vapor Lamp Engineering, and in 1964, manager of that department.

Larson is a graduate of St. Peter's College, where he received his BS in physics in 1944. He also completed a two-year electrical engineering course at North Carolina State under the Army's ASTP Program. In 1956, he earned his MS in physics from Stevens Institute of Technology.

He joined Westinghouse in 1952 at the Lamp Division's research department, where he promptly went to work on gas discharge research on fluorescent lamps. In 1960, he started research on high-pressure discharge lamps, and is currently Senior Research Engineer in the advanced development department of the Lamp Division, where he is working on the effects of additives.

TV Pictures on a Record

Up to 400 TV pictures and 40 minutes of sound can be recorded on the two sides of a 12-inch long-play record in a new system called Phonovid. Both the visual and the sound portions of the system come from the grooves of the record, which is played on a standard turntable and seen on a standard TV receiver. Electronic circuitry is housed in the small compartment under the pulled-out turntable. Phonovid system has wide potential use for instructional purposes.