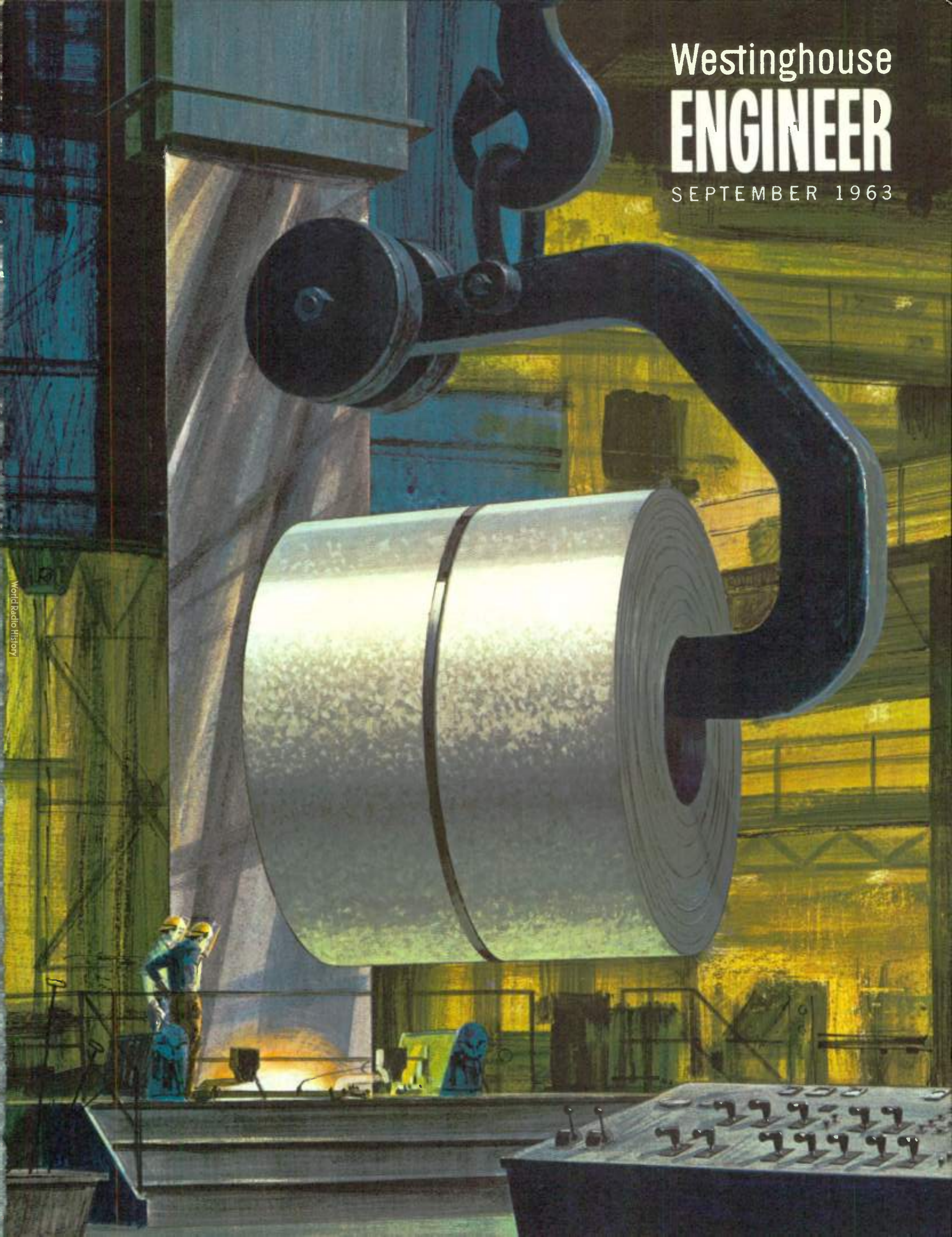

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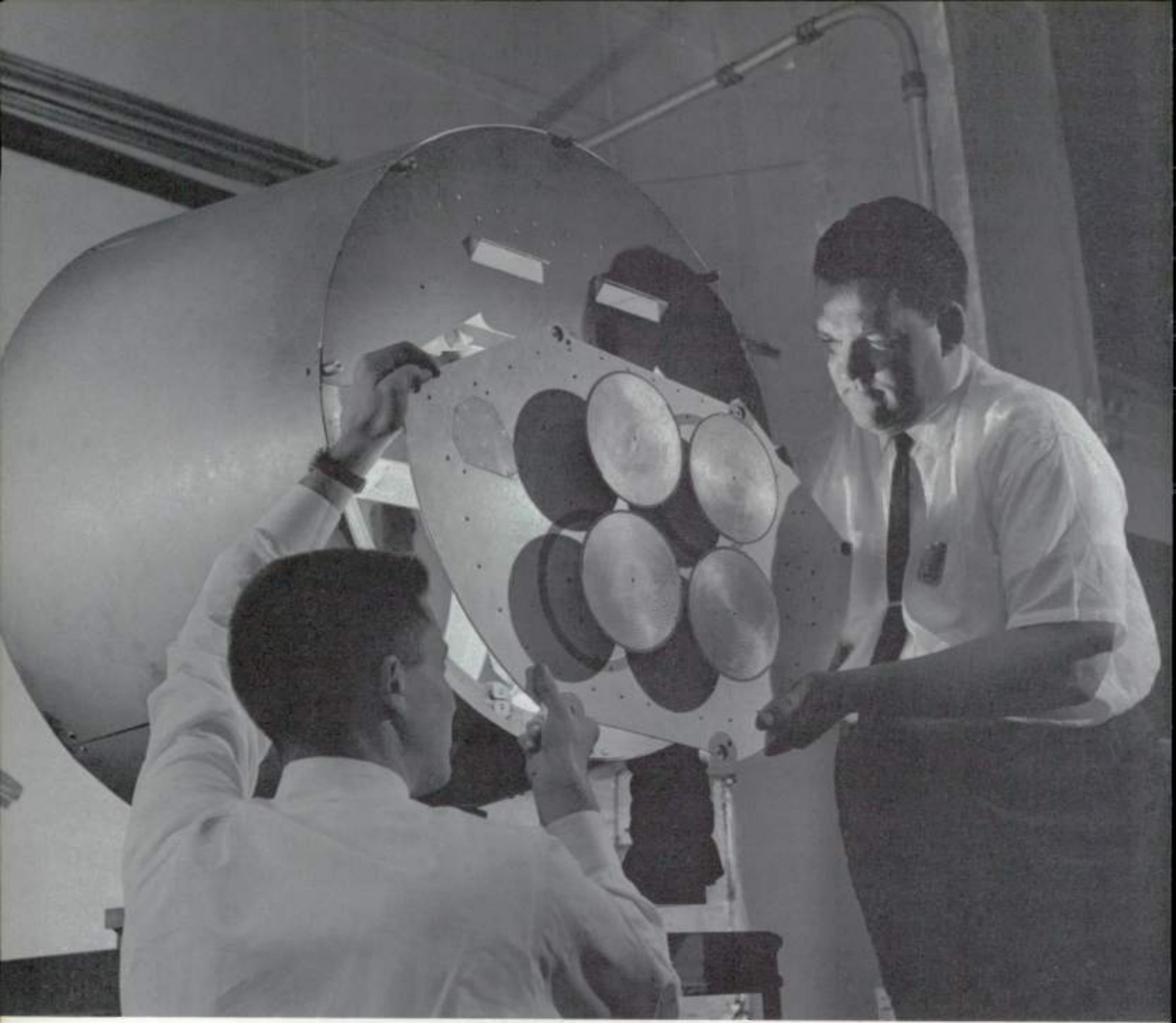

Radar for Gemini

This mock-up illustrates the installation of the antenna of a unique radar system on the front of the Gemini spacecraft. The two astronauts in the Gemini satellite will use the radar and its associated display equipment to seek out an orbiting Agena rocket vehicle, determine its range and bearing, and make necessary changes in orbital velocity to complete the rendezvous operation. During the rendezvous mission, the Gemini crew will use a command communications system to maneuver the Agena by remotely starting and stopping its control rockets. This system is an integral part of the radar and allows simultaneous use of the transmitting and receiving equipment as both a radar and digital command link.

Project Gemini is under the technical direction of the National Aeronautics and Space Administration's Manned Spacecraft Center in Houston, Texas. Westinghouse is building the radar and digital command link under contract with the McDonnell Aircraft Corporation, the prime contractor for the Gemini spacecraft.

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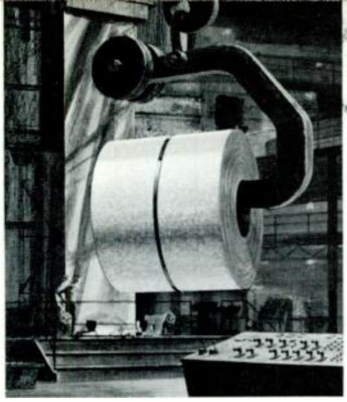

VOLUME 23 • NUMBER 5

Cover Design: Continuous hot-dip galvanizing is the subject of this month's cover design by Thomas Ruddy of Town Studios, Pittsburgh. Steel strip rises out of the molten zinc bath in the background and, in the foreground, a crane hook holds a finished coil of galvanized strip.

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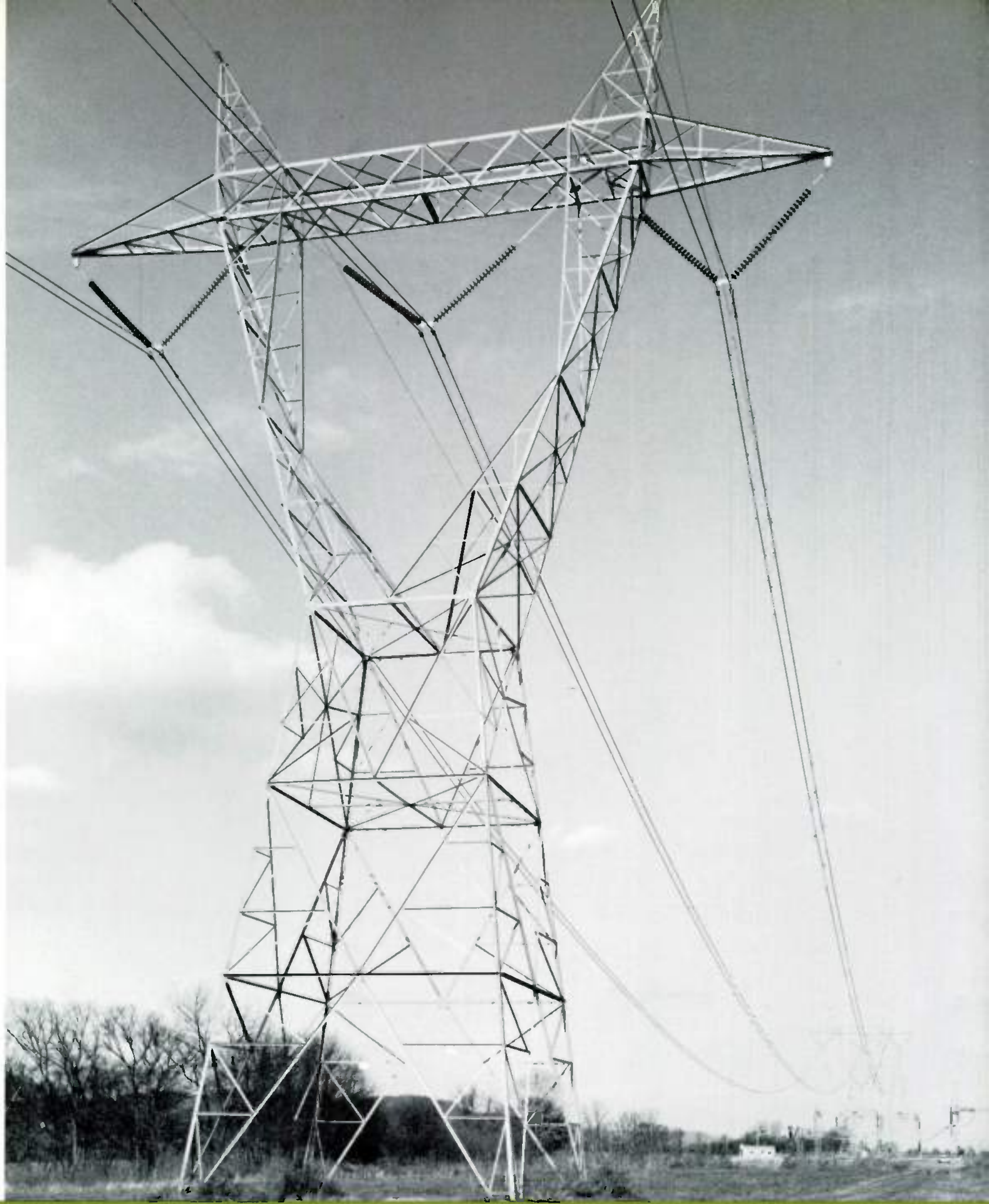
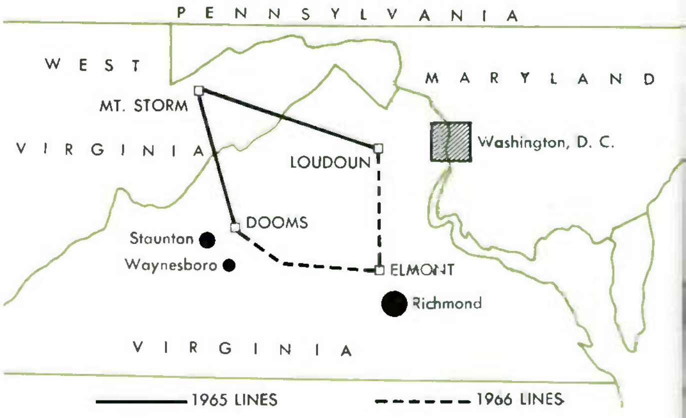


A 500-kv line and suspension arrangement is shown during tests on the extra-high-voltage test transmission line at the Apple Grove test facility.

The VEPCo 500-Kv System

The proximity of VEPCo to the vast West Virginia coal fields suggested energy transportation over the 100 miles from Mt. Storm to the Washington load area and approximately 170 miles to the Richmond load area. The mine-mouth power plant at Mt. Storm will consist of two 540-mw units, one scheduled for service in May 1965 and the other in May 1966. When completed, the 500-kv transmission system will form a 350-mile loop from the generating station to the Washington, D.C. suburbs, south to Richmond, and back by way of the Waynesboro-Staunton area. Construction of the first legs from Mt. Storm to Loudoun, and from Mt. Storm to Dooms are scheduled to be completed in late 1964 and early 1965; the entire project is expected to be in operation in early 1966.



A Systems Engineering Approach to 500 Kv

J. A. **Rawls**, *Manager, Engineering and Construction, Virginia Electric and Power Company, Richmond, Virginia.*
J. K. **Dillard**, *Manager, Electric Utility Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania.*

The transmission system and apparatus for the Virginia Electric and Power Company's 500 kv project were developed jointly by a utility-manufacturer team.

The 500-kv transmission system for Virginia Electric and Power Company has been engineered and designed as a complete unit in advance of construction. VEPCo chose this total-system approach for three reasons: to insure that the EHV design would be based on the very latest research results from various industry test projects; to obtain the most reliable system at a minimum cost; and to achieve maximum coordination in the design and application of the first commercial 500-kv equipment.

The decision by the Virginia Electric and Power Company to pioneer commercial 500-kv transmission was based entirely on economic considerations. The proximity of VEPCo to the vast West Virginia coal fields suggested an economic investigation of transmitting energy electrically rather than in the form of coal. However, more than just a comparison of point-to-point energy transmission methods is required for establishing a new voltage level on a rapidly growing utility system. Long-range economic studies of the entire system, taking into consideration subsequent plants, ultimate transmission requirements, and interconnections with neighbors led to the final decision in favor of 500 kv over other transmission voltages.

Once 500 kv was justified economically, the next question was technical feasibility. Westinghouse has been participating in research programs at 500 kv and above for nearly 17 years. This experience, coupled with the industry-wide participation in EHV research today, convinced VEPCo that 500 kv was ready technically for commercial use.

Project Organization

In January 1962, VEPCo awarded contracts covering engineering and equipment for the 500-kv transmission system. The effort was divided into three phases: system design, construction, and verification. Westinghouse was given the contract for engineering studies and substation equipment. Ohio Brass Company was given a contract for line insulators and hardware and was to perform any surge testing on this equipment required for the engineering studies; Stone & Webster was given the contract for the mechanical design of the towers and station structures, the writing of equipment specifications, and the construction of the transmission system. Reynolds Metals Company was given a contract for the line conductors and associated mechanical tests. VEPCo reserved final decision on all matters concerning the ultimate system.

The first step in the electrical design phase was to identify the major development areas for separate study groups. These were as follows:

1) *System Analysis*—Establish detailed system parameters such as shunt and series compensation requirements, equipment requirements, equipment ratings and operating voltages.

2) *Conductor Specifications*—Establish size, type, and bundling arrangement.

3) *Line Insulation*—Establish the number and configuration of line insulators from a lightning and switching surge standpoint.

4) *Equipment Insulation*—Establish the BIL requirements for all equipment.

5) *Relaying, Metering, Communications*—Establish any special requirements of the 500-kv system voltage level.

6) *Tower and Substation Design*—Establish the tower and substation material and structural configuration.

Each study group operated as a separate entity, and a coordinator assured the necessary information interchange between groups. The results of one group often depended upon the results of another, so that initial efforts began with simple assumptions. For example, to select final conductor size, radio influence levels must be known. To study RI, phase spacing of the conductors must be determined, and this dimension must be set by the lightning and switching surge subgroups working on line insulation. The switching surge study cannot be completed until system constants are determined by the system analysis group. But this group cannot make load-flow and stability studies until conductor size and bundling arrangement are determined by the conductor specification group. Thus, the circle of needed information is complete, and the need for cut-and-try solutions with close coordination is obvious. Therefore, working arrangements were established to insure rapid interchange of key data.

Electrical Design Study Results

Since this project marks the first use of the systems approach to design and construction of a major portion of an electric utility system, the methods used in problem definition, problem solving, and decision-making are of particular interest. An article of this scope cannot describe comprehensively the technical considerations behind each important decision. However, a review of the decisions reached in each study group will illustrate the system approach.

System Analysis

The system analysis group established the following design and operational parameters: size and location of shunt reactors, transformer size with tap range and desirable taps, generator power factor limitations, normal and abnormal system dynamic voltages, normal and abnormal power and reactive flow, transient stability characteristics, and system equivalents for use in related studies.

To obtain this information, the study group developed a comprehensive schedule of digital computer load-flow and transient-stability studies. The VEPCo system and some interconnected systems were represented in detail so that complete system behavior could be observed. Four basic system configurations were considered: peak load and peak generation for the 1965 and 1966 systems, zero generation at Mt. Storm for the 1966 system, and light loads and light generation for the 1966 system. Over 200 separate load flows based on these configurations were examined, and appropriate transient stability runs were made from selected load flows.

Before load-flow and stability runs could be made, conductor size, spacing, and bundling arrangement was needed from the conductor specification and line insulation groups. The system analysis group aided in determining these quantities by making studies of losses and shunt reactor requirements for various bundling arrangements.

Results: Various shunt reactor ratings were studied with different transformer taps, and for many system conditions. Normal and abnormal system voltage levels were within acceptable limits with no shunt reactor compensation for system conditions experienced in 1965 and 1966.

Although certain switching procedures are required to energize the 500-kv system, this creates no operating hardship. Since shunt reactors are not required, a major reason for autotransformer tertiary windings was eliminated. Studies of grounding requirements and harmonic suppression also showed that tertiary windings are not required.

Some economies can be realized if transformer tap change is restricted; however, a new voltage level is being established with anticipated high-capacity interconnections at 500 kv. Therefore, a 10 percent tap range was recommended for all autotransformers. Final tap settings were selected as a compromise to give: (1) Acceptable low-side bus voltages while exporting power from Mt. Storm with line-out conditions; and (2) acceptable low-side and high-side voltages with Mt. Storm out of service but with the 500-kv system in service. Generator transformers will also have a tap range of 10 percent.

System stability studies showed the 1966 system to be stable for double-line-to-ground faults without reclosing. The system is also stable upon reclosing on faults on the Mt. Storm-Dooms line. Faults on the Mt. Storm-Loudoun line can be handled by reclosing the end remote from the power station at high speed, and reclosing the Mt. Storm end on hot line only.

Conductor Specification

Conductor specifications were based on (1) radio influence and corona and (2) economic evaluation. The economic evaluation related RI and corona, conductor costs, loss evaluation, and tower and stringing costs. The RI and corona team continually revised its calculations as new phase spacing, conductor sizes, and other requirements were developed by the other participants.

Radio influence investigations included gradient calculations, measurements of radio station field strengths, and laboratory radio influence voltage tests. Gradient calculations were done by computer for single-, two-, three-,

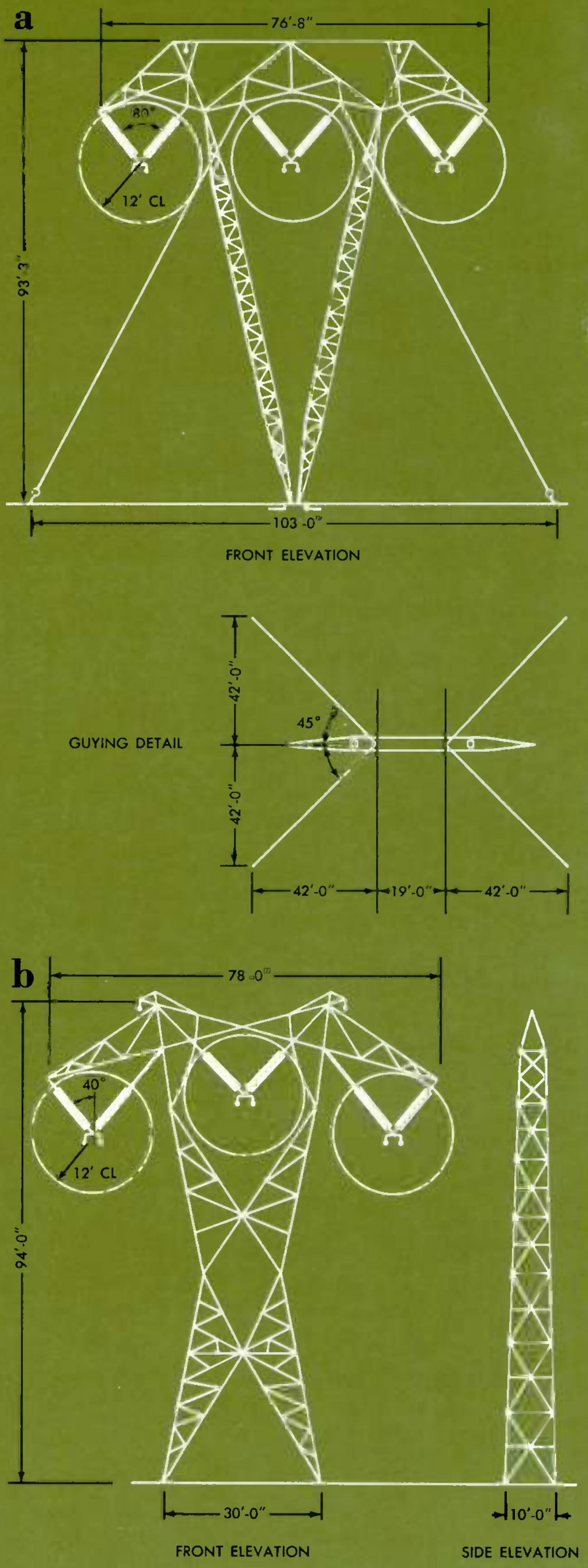


Fig. 1—Lateral elevation views of the (a) guyed-vee and (b) self-supporting tower designs which will be used on the VEPCo 500-kv system.

and four-conductor bundles at 30-, 25-, and 40-foot spacings. Lateral field and RI generation were calculated at the same time. Preliminary tower designs were proposed by Stone & Webster and VEPCo, and lateral field strengths were estimated for various distances from the center line of the right of way for these designs.

As another part of the initial tests, radio station signal levels were measured along the proposed rights of way. Analysis of this data with population information indicated the degree of protection required along the line.

Laboratory tests then were made on single conductors and two-conductor bundles of various sizes. Wet tests indicated the corona-start voltage and the level of radio noise for various configurations and conductor sizes. These tests were correlated with the field data from the test projects, and RI was estimated for all individual conductor sizes considered in the economic evaluation.

Results: The system analysis and preliminary RI calculations showed that a two-conductor bundle with 18-inch spacing should be used. Results of the tower design work indicated a minimum phase spacing of 30 feet to maintain 11 feet from conductors to steel. Measurements on existing EHV lines suggested that RI level should be about 30 db above 1 microvolt per meter at 200 feet from the center of the right of way. Radio noise calculations and tests showed that conductor diameter should be from 1.6 to 1.65 inches for a two-conductor bundle with 30-foot phase spacing.

Two types of conductors were considered: Aluminum cable steel reinforced (ACSR) and 5005 aluminum alloy with no steel core. The 5005 alloy has the strength and sag characteristics required, is easier to splice, is harder than aluminum used in ACSR and is less susceptible to nicks and scratches. A 1.65-inch diameter, 61-strand, 5005 conductor has been developed with approximately the same resistance as a 1.6 ACSR conductor, so that the loss evaluation is favorable. The 5005 conductor will be used for both line and bus so that fittings can be standardized.

Tests conducted to date at Apple Grove on a 1.6-inch bundle with 18-inch spacing operating at 500 to 525-kv have verified the analytical work.

Line Insulation

The line insulation level is based on results from the groups studying switching surges and lightning performance. Both groups used surge test data obtained on insulator strings at the Ohio Brass Company laboratory.

Switching surges are transient overvoltages that appear on a system during circuit energizing and high-speed reenergizing. The switching surge study group first conducted an analog computer study of the proposed 500-kv system. This gave the upper limit on switching surge overvoltages and suggested wave shapes. Since computer results are conservative, these studies were modified by experience obtained in two years of field testing of switching surges by Westinghouse on commercial transmission circuits. These modified results were used to determine wave shapes for testing the insulator strings.

The switching surge computer study also investigated the use of circuit breaker resistors on reclosing to limit switching surge overvoltages. Thermal energy discharge requirements of the lightning arresters and the effect of transformer tertiary windings and line compensation on switching surge overvoltages were also determined.

The second part of the line insulation problem is lightning protection. The lightning protection study group first recommended an adequate shielding angle to prevent direct strokes from terminating on phase conductors. Then, with adequate shielding and ground resistance provided, the number of line insulators was specified to insure less than one outage per 100 miles per year.

The group developed a new method for estimating lightning performance, since previously available methods have failed to accurately predict the number of outages on EHV lines above 230 kv. This new method is based on recent fundamental work of Wagner and Hileman. A new geometrical model of the shielding failure characteristic relates exposure of phase conductors to the magnitude of stroke current. A digital computer program calculates the number of shielding failures using data on the probability of stroke current magnitude. From this a shielding angle is determined.

Once adequate shielding is assured, the number of outages that will occur for strokes to the ground wires must be calculated. The basic approach is similar to the AIEE Estimating Method, in which an analog computer study determines the volts-per-ampere of stroke current and time-to-crest of voltages resulting from a stroke to the ground wire on a line of variable footing resistance. Coupling factors between ground wire and phase conductor are calculated, and the probability of flashover is determined for various numbers of insulators.

For the VEPCo project, a more realistic tower representation was used in the analog computer study. Also various rates of rise of the lightning current were considered, rather than a single average value as has been previous practice. Finally, strokes to quarter span and mid span were assumed to cause tower flashovers as well as strokes to the tower. All of these new factors were included in the probability approach.

Results: Switching surge investigations showed that insertion of a resistor in the breaker closing sequence could control switching surge voltages on the system to an acceptable level. This eliminated switching surges as a consideration in line insulation level, so that lightning became the governing factor. Lightning shielding studies indicated that the VEPCo line needed a 22-degree shielding angle to prevent direct strokes to the phase conductors. Formerly, a 30-degree angle was considered adequate for most transmission lines. The 500-kv system will have satisfactory outage performance (one outage per 100 miles per year) if 24 insulators in a Vee string are applied in a 24-foot window, and if the footing resistance does not exceed 22 ohms. Twenty-five insulators will be used at elevations above 1500 feet. The 22-ohm tower footing resistance requirement places a severe restriction on line design in mountainous terrain. Therefore, additional data was obtained to permit calculations of counterpoise design.

Equipment Insulation

The objective of the equipment insulation group was to select the lowest and most economical basic insulation level (BIL) consistent with good engineering practice. The BIL of substation equipment is generally determined by the maximum lightning and switching surges impressed on equipment terminals. Exact BIL depends on the protective characteristics of the lightning arresters used, and their number and location. The desired BIL provides the optimum economic balance between equipment and arrester costs. The limitation of 60-cycle voltage insulation strength also must be factored in before the final level is selected.

The general practice in selecting BIL level is to apply lightning arresters at the transformer terminals, so that transformer BIL is determined by arrester characteristics and the desired margin of protection. If circuit breakers and other equipment are not properly protected by these transformer arresters, additional arresters must be judiciously placed in the substation.

Results: The system analysis group determined the maximum 60-cycle voltages that might occur at arrester locations for various system fault conditions. Results showed that a 70-percent arrester rated 368 kv can be used at the generator step-up transformers. Seventy-five percent arresters rated 394 kv can be applied at all other locations. The switching surge studies indicated that switching surges that would spark over arresters would impose duty well within the thermal rating of the arresters.

The transformer BIL chosen for these arresters is 1300 kv. This affords adequate switching surge and impulse margins of approximately 20 percent.

For the circuit breakers and disconnect switches, studies of two basic substation designs, based on analog computer results, balanced the economies of additional arresters against reductions in BIL. It was found that a severe economic penalty would result for BIL's above 1550 kv. Below 1550 kv, the economic incentive was not as great, and after factoring in such considerations as contamination, a 1550-kv BIL was chosen for circuit breakers and disconnect switches.

Relaying, Metering, Communications

This study group was assigned the task of establishing any special requirements that might accompany the new 500-kv system voltage level. The absence of shunt and series compensation made their task much easier, since no special relaying schemes are required.

Results: Conventional four-zone directional comparison carrier relaying using KD relays and 10-watt TC carrier is being used. Transfer-trip relaying with frequency-shift carrier will clear faults in the 500-kv station service transformer. The same scheme will be used for the Loudoun and Dooms transformers until their 500-kv breakers are installed. Relaying carrier will be conventionally coupled line-to-ground on the phase conductor. The insulated ground wires will be used for communication carrier only. Field tests are investigating possible adverse effects of RI on these channels.

Potential transformers for metering are not presently required, and all potential measurements will be made with coupling capacitor potential devices. Additional studies are being made on devices for billing metering.

Equipment Innovations for 500 Kv

The design of structures and equipment has been closely correlated with the electrical investigations described

Fig. 2—Developmental prototype of a single-column, two-interrupter unit for the 500-kv SF_6 circuit breaker; three of these units form one pole of the breaker.

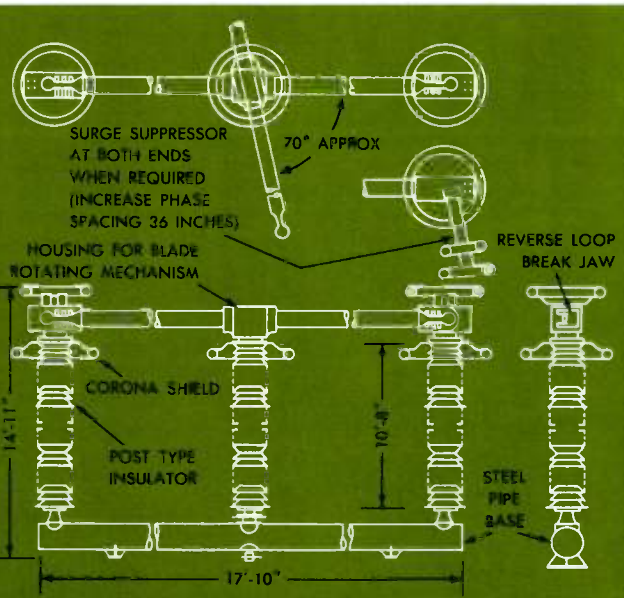


Fig. 3—Line drawing of the new horizontal-break 500-kv disconnect switch (for 1550 BIL).

above. New ideas for structures and new designs of electrical equipment have been developed. A project of this magnitude, as an industry first, justified the investigation of many different approaches in equipment design. Three major developments will be summarized here: structure design, breaker design, and disconnect switch design.

Tower and Substation Structure Design

Several tower materials were considered by the study group, including aluminum. The material finally selected was Cor-Ten steel. Selection of this corrosion-resistant material was based on: high strength, reducing tower weight; corrosion resistance, requiring no painting; a dark brown appearance, blending well with the landscape; better resistance to surface damage than galvanized steel; ability to be drilled and welded in the field with no bolt loosening.

Two basic tower designs will be used: A guyed-Vee design (Fig. 1) will be used in the mountains to reduce foundation problems; a rectangular base self-supporting tower will be used elsewhere to avoid the inconvenience of guys to property owners. Static wires will be suspended from two-foot links to reduce tower tensions due to unbalance from ice unloading. This saves considerable tower weight.

Special steel shapes will be employed, such as 60-degree angles for triangular members rather than 90-degree angles for square members. This configuration further reduces structure weight.

High-strength, heat-treated, corrosion-resistant rods assembled in long links are being studied for guys. These rods should reduce vibration problems with long guys and will require less field labor to install. At present, however, the rods are not economically competitive with the conventional guy strand. Present plans, therefore, are to make an experimental installation of the rods on one line section with the remainder of the line using high-strength Alumoweld guys.

Substation structures will use steel similar to the line towers, except it will be Mayari-R steel. Special shapes will also give new design freedom here.

500-Kv Circuit Breakers

Successful experience with sulfur-hexafluoride power circuit breakers at 230 kv and below led breaker designers to select this concept for the 500-kv breakers. A modular design with live tanks mounted on porcelain columns has been chosen.

While SF_6 as an interrupting medium is not new, the use of modular live tanks is an advance in design. This design was selected as the logical next step in breaker development for 500 and 700 kv for several reasons: A three-pole dead tank breaker could not be shipped completely assembled at 500 kv; each different BIL used for 500 and 700 kv would require costly new development of a suitable dead tank and bushing, whereas the live-tank approach permits use of duplicate units for increasing voltage ratings up to 700 kv; and finally, the new design incorporates a new mechanical arrangement of interrupters that allows interrupting times approaching two cycles.

Each pole of the 500-kv, 35 000-mva breaker contains a total of six interrupter units housed in three live tanks, each mounted atop a porcelain column. A single-column, two-interrupter prototype on test is shown in Fig. 2. Three of these units form one pole of the breaker and have a single high-pressure SF_6 reservoir at their base.

Each pole has a separate pneumatic operating mechanism, and all six breaks of each pole are mechanically interconnected to assure simultaneous operation. The three poles are synchronized electrically and pneumatically to assure opening and closing of individual phases within one half cycle of each other.

Resistors are not needed in the SF_6 breaker either to control the rate of rise of recovery voltage or to help interrupt line-charging current. However, resistors can be applied in the closing operation to hold switching surges to less than twice normal line-to-ground voltage. Inclusion of these resistors permits system insulation to be reduced to the level required by lightning.

500-Kv Disconnect Switches

There is also innovation in the design of two new 500-kv disconnect switches. For years, the single vertical-break switch has been the dependable industry standard. This same reliable design has been extended to 500 kv. However, at 500 kv the vertical-break pole unit is 18 feet long, 15 feet high when closed, and 28 feet high when opened. Because of the increased size of the 500-kv vertical-break disconnect switch, overhead substation structures must be much taller, which increases structure costs. To minimize structure heights and associated costs, a more compact horizontal switch was developed.

Both switches have a 16-inch diameter galvanized steel tube base. The tube is the foundation for stacking the tall insulators, and it assures reliable control of the large current-carrying members. Also, it eliminates steel in the supporting structure. Station post insulators used in stacking limit deflection to about 50 percent of the deflection obtained with stacks of cap and pin units.

An important new feature common to both switch designs is the surge suppression resistor assembly, which overcomes the problem of switching surges caused by opening or closing the switch on energized buses. Switching surges of sufficient magnitude can impose severe duty on lightning arresters. The resistor, composed of three 500-ohm resistors in series, has demonstrated its ability to control switching surge voltages. The switch design is such that the resistor can be added in the field if system parameters change to require this protection.

Conclusions

From its earliest conception, the VEPCo 500-kv project has been recognized as an opportunity to pioneer advanced EHV technology. A single contract for engineering and equipment for the entire EHV system has resulted in maximum coordination of system design and equipment, complete with application warranty. Relationships have been established between the participants to permit maximum use of existing technical knowledge throughout the industry. This knowledge has resulted in an optimum system design. The results of the VEPCo project have been most satisfactory to date and should contribute substantially to advancement of EHV technology in this country.

Modern Galvanizing

*G. J. Hay, Project Engineer, Metals Province, Industrial Systems,
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.*

Electrical, mechanical, and chemical technology are integrated in today's high-production galvanizing lines.

American industry is using an ever-increasing quantity of galvanized steel in its fight against corrosion. One of the reasons is the low cost of zinc, lowest of all the common metals used for protective coating. Another is that the bond between the steel base and the protective zinc coating is so strong that end products can be fabricated by normal manufacturing procedures. Perhaps the most important advantage of zinc as a protective coating is its anodic relationship to iron and steel; this relationship extends the corrosion protection of the zinc even to sheared edges and small damaged areas.

Galvanized steel sheet is used in roofing and siding panels, guard rails, culverts, and many other construction products. The household appliance and automotive markets also help create a continually growing demand; for example, the American Zinc Institute estimates that the amount of galvanized steel used per automobile by American auto makers has nearly doubled since the 1960 model year.

Zinc coatings are commonly applied by dipping the article to be coated in molten zinc. This operation is called hot-dip galvanizing to distinguish it from the less common zinc electroplating processes.

Hot-dip galvanizing was once performed on individual sheets cut to the desired length. The sheets were transported in succession through operations in which they were cleaned with acid solutions, coated with flux, dipped in molten zinc, and cooled.

Development in the 1930's of the first of several continuous hot-dip processes revolutionized the production of galvanized steel. These processes treat a continuous strip of steel charged to the line in coil form. The ends of succeeding coils are welded together to form the continuous strip. The industry conversion to the continuous processes has greatly accelerated since the second World War.

Continuous Processes

The simplest continuous process in use today passes the steel strip through a pickling bath of muriatic (hydrochloric) acid, then through a flux bath, and then into the spelter (zinc bath). The coated strip is cooled and sheared to cut length, and the sheets are then inspected and wrapped for shipment. The incoming coils may be unannealed, or they may be annealed and temper rolled. (Temper rolling reduces the strip cross section slightly to cold work the strip and thereby achieve the hardness and flatness required in the end product.)

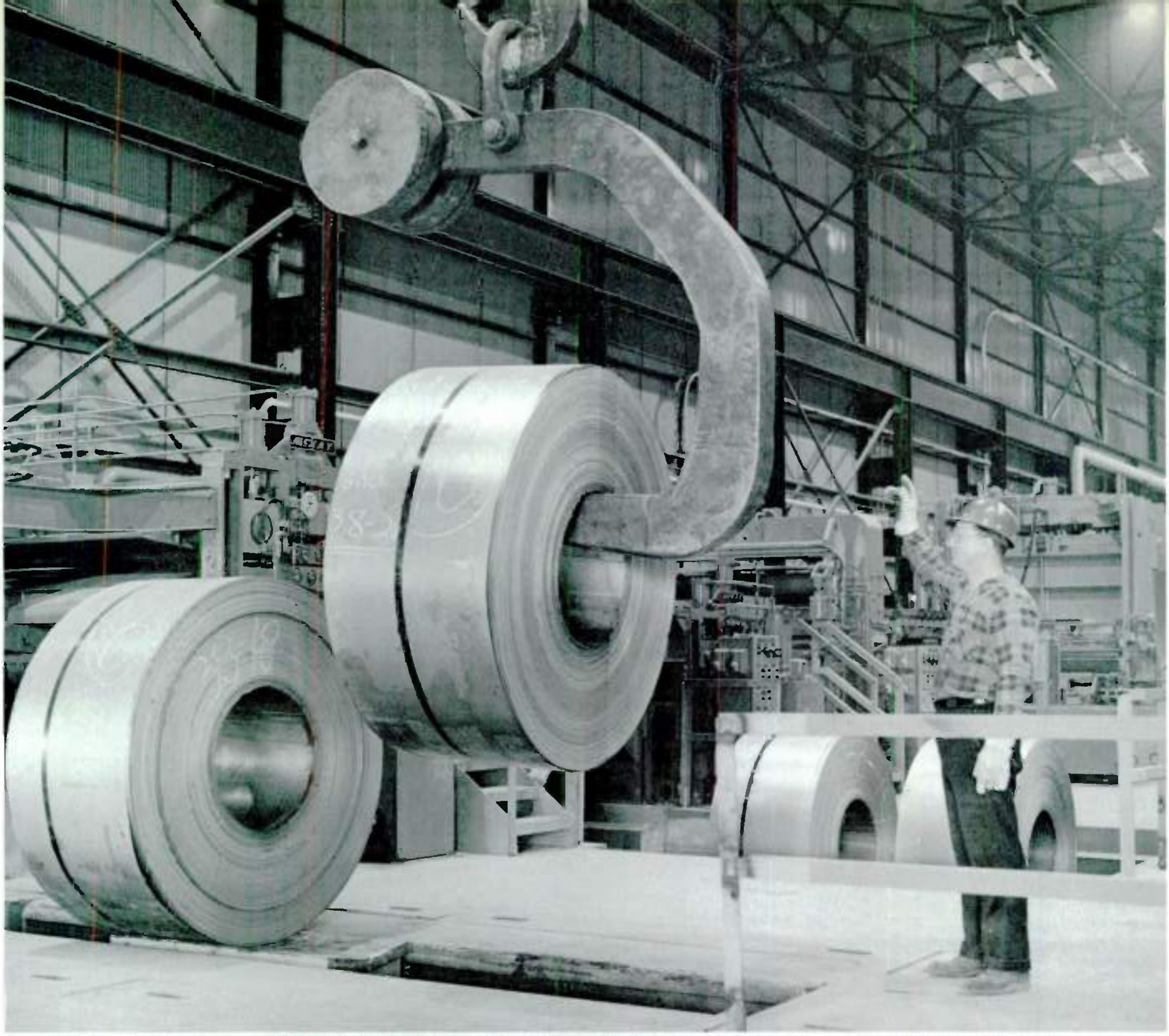
Another process employs a furnace in the line to continuously anneal the strip in a protective atmosphere that prevents oxidation. The strip is cooled after annealing and passed through a muriatic-acid pickling bath, and it then enters the molten zinc through a flux box. Asbestos wipers control the thickness of the zinc coat. Their use limits the strip speed to approximately 150 feet per minute (fpm), but the process produces extremely adherent zinc coatings.

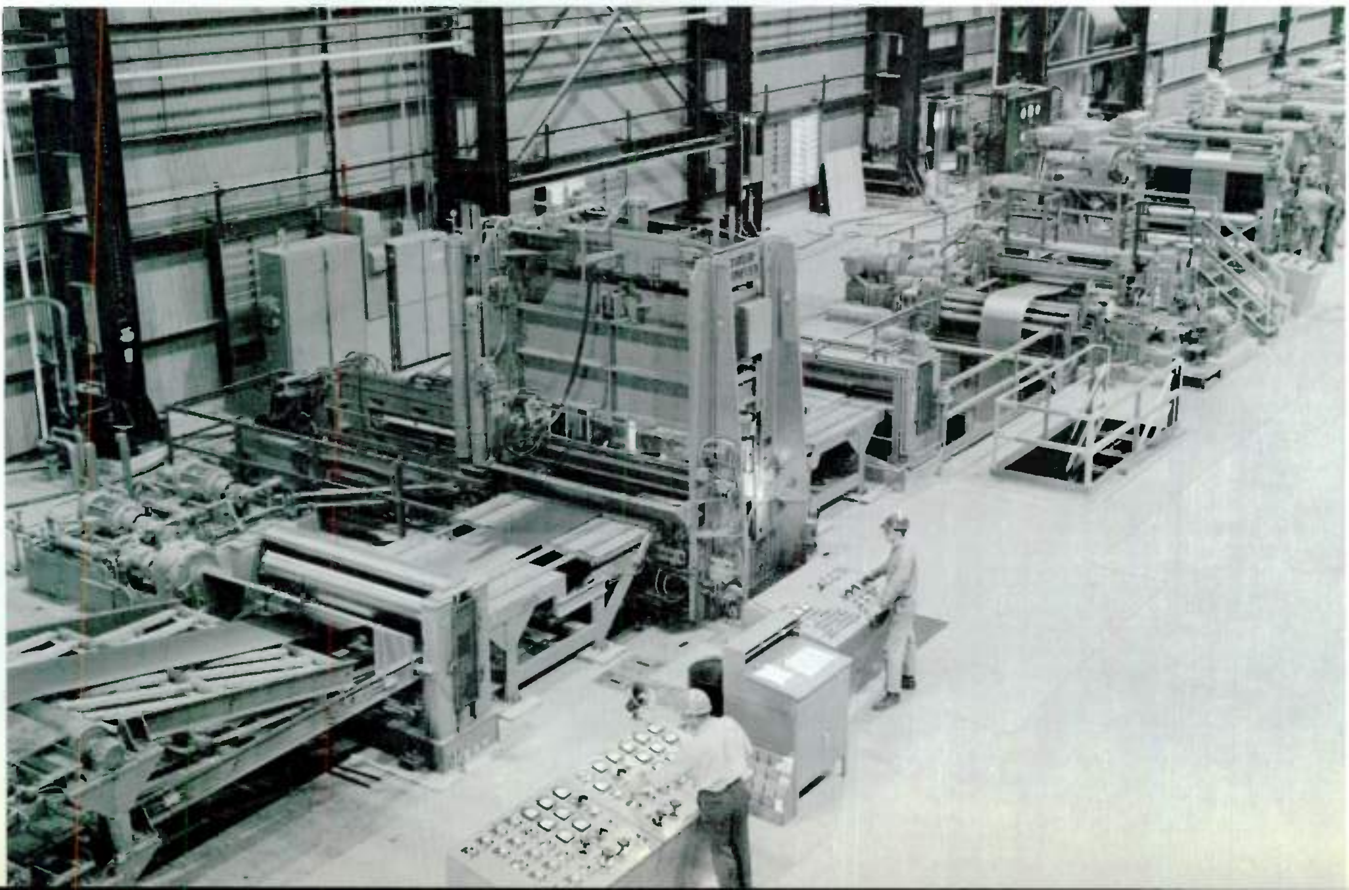
The Sendzimir process was the first continuous hot-dip process to operate at a relatively high production rate, and most modern galvanizing lines are of this general type. In the conventional Sendzimir process, the strip first passes through an open-flame oxidizing and degreasing furnace and then into a second furnace. There it is annealed or "normalized," and the oxide formed in the first furnace is partly reduced in an atmosphere of dissociated ammonia. The degree of oxidation must be closely controlled to obtain a uniform oxide film. Cooling zones of the reducing furnace lower the strip temperature to approximately that of the coating bath. The strip then enters the spelter through a conduit extending below the surface of the bath so that the oxide film will not be changed by exposure to air. Aluminum added to the molten zinc suppresses formation of a zinc-iron alloy layer at the interface of the zinc and the steel, and thereby increases the adherence of the coating. Facilities for production of both coils and strip are usually included in the line arrangement. Many modifications of the basic Sendzimir continuous process have been introduced.

Top—A Cook-Norteman hot-dip galvanizing line is shown in this sequence of photographs and the accompanying diagram. Coils weighing up to 70 000 pounds are charged to the line here at the entry end. A resistance-type seam welder (right background) joins each new coil to the one preceding to form a continuous ribbon.

Right—Acceleration of the entry section of the line follows completion of the welding. Tension-free loops before and after the side trimmer assure good tracking while the strip is trimmed to width. Out of the second loop, the strip enters the No. 1 bridle (right background).

All photographs courtesy of Bethlehem Steel Company.

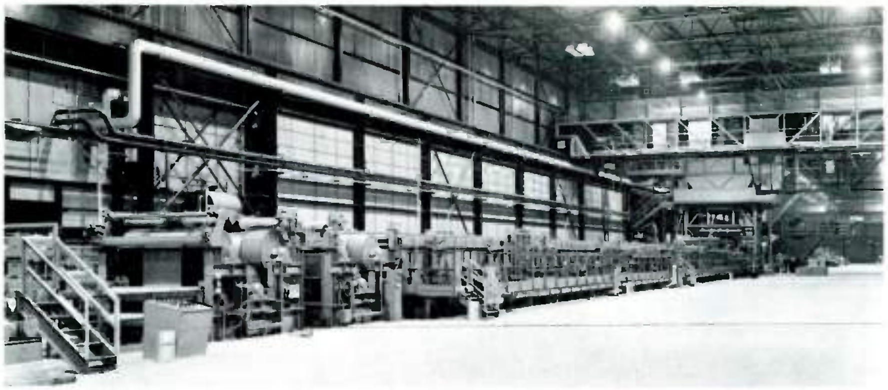


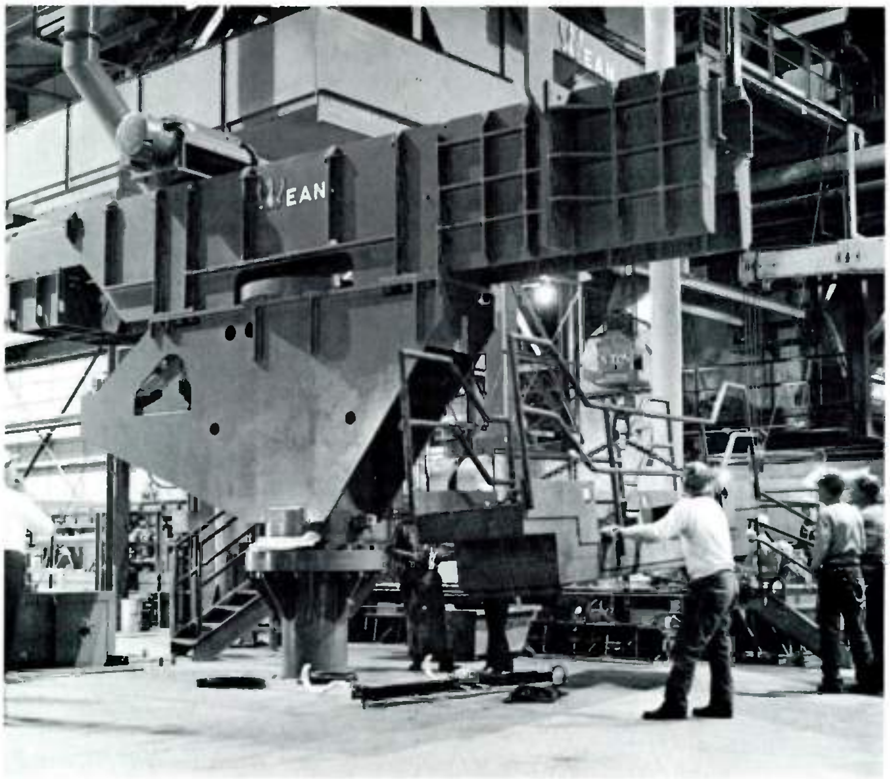


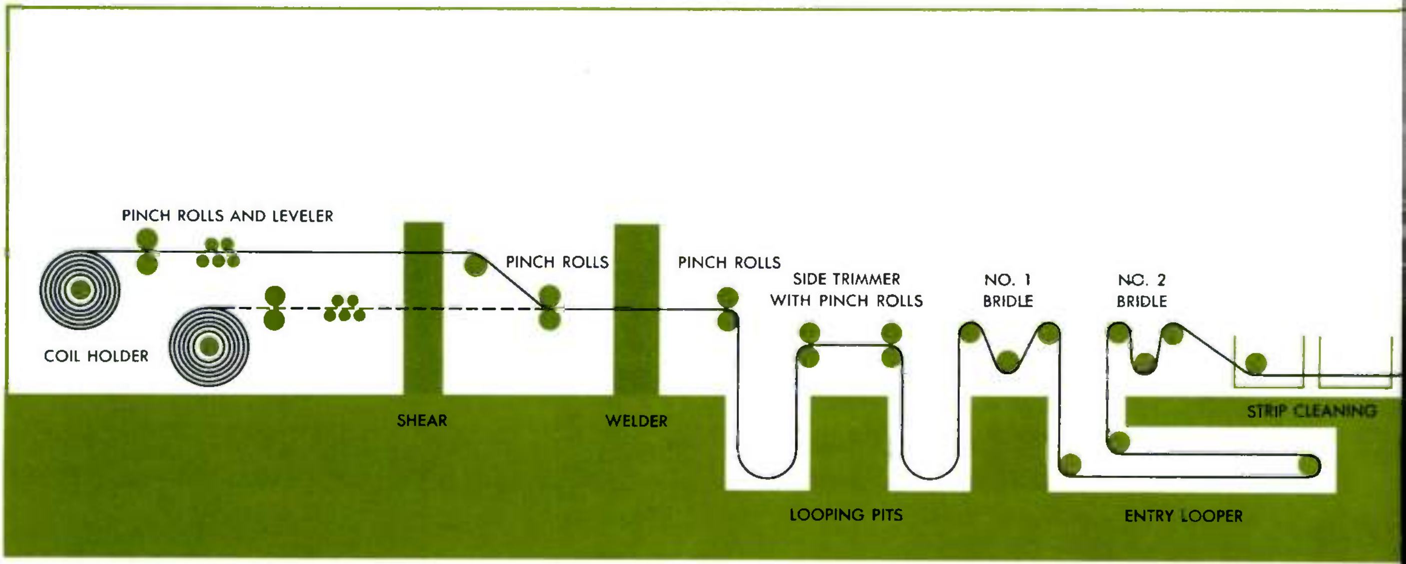
The latest continuous process development is the Cook-Norteman, or Wheeling, process. Several basic steel producers have installed Cook-Norteman lines under license from Wheeling Steel Corporation. The drive and control equipment for all of these lines that are presently installed and operating (as well as for many of those with in-line annealing) has been supplied by Westinghouse. A recent galvanizing-line installation employing the Cook-Norteman continuous hot-dip galvanizing process is illustrated in the accompanying diagram and also in the sequence of photographs on these pages.

Cook-Norteman Process

The strip is cleaned by passing successively through an acid tank, an alkali tank, an electrolytic tank, and another acid tank. A multiple-brush mechanical scrubber follows each tank. The strip then enters a liquid flux bath. As it leaves this bath, the uniformity of the flux film thickness is maintained, at varying strip speeds, by a system of rolls and brushes. Two vertical ovens dry the flux and preheat the strip before it enters the aluminum-bearing spelter. As the strip leaves the zinc bath, the coating thickness is determined by the spacing, speed, and surface configuration of the coating rolls. The strip is cooled and, depending on the intended end product, it may be leveled (flattened by flexing alternately in opposite directions). It is then chemically treated





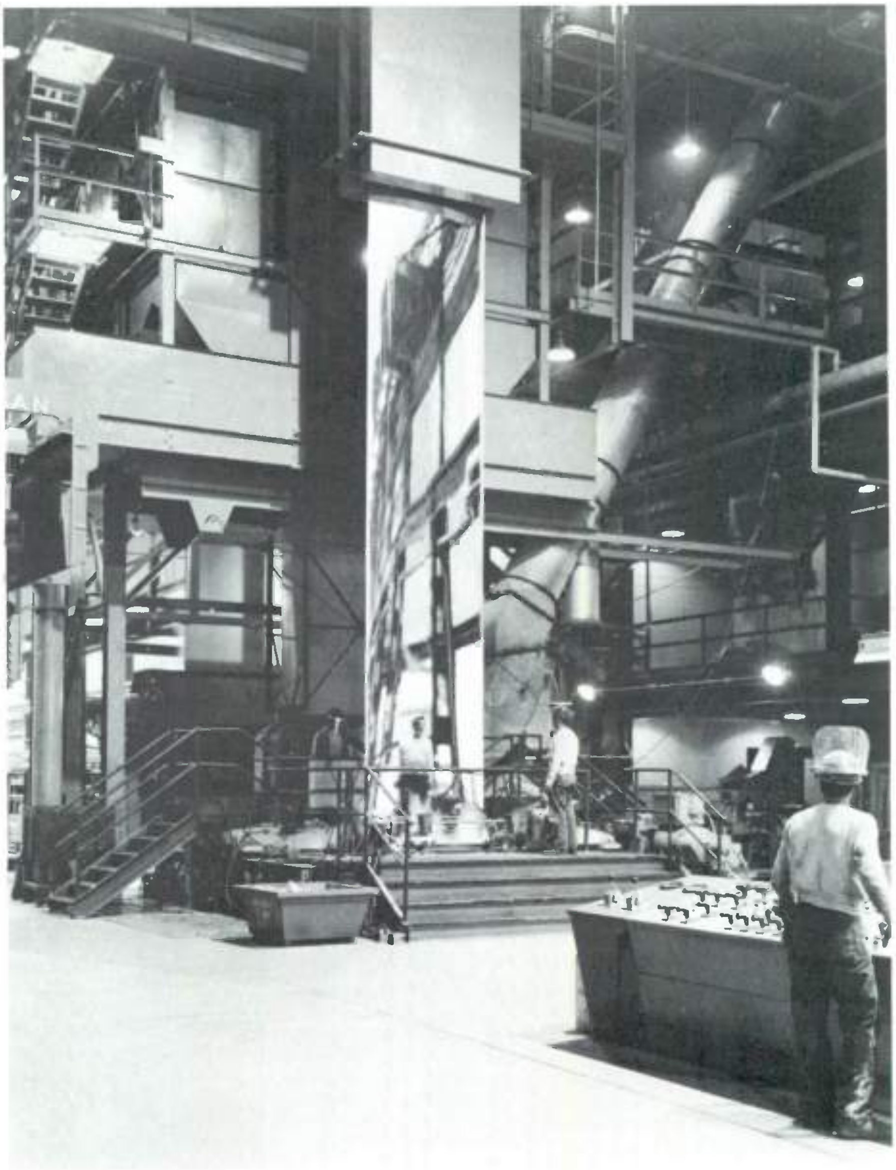


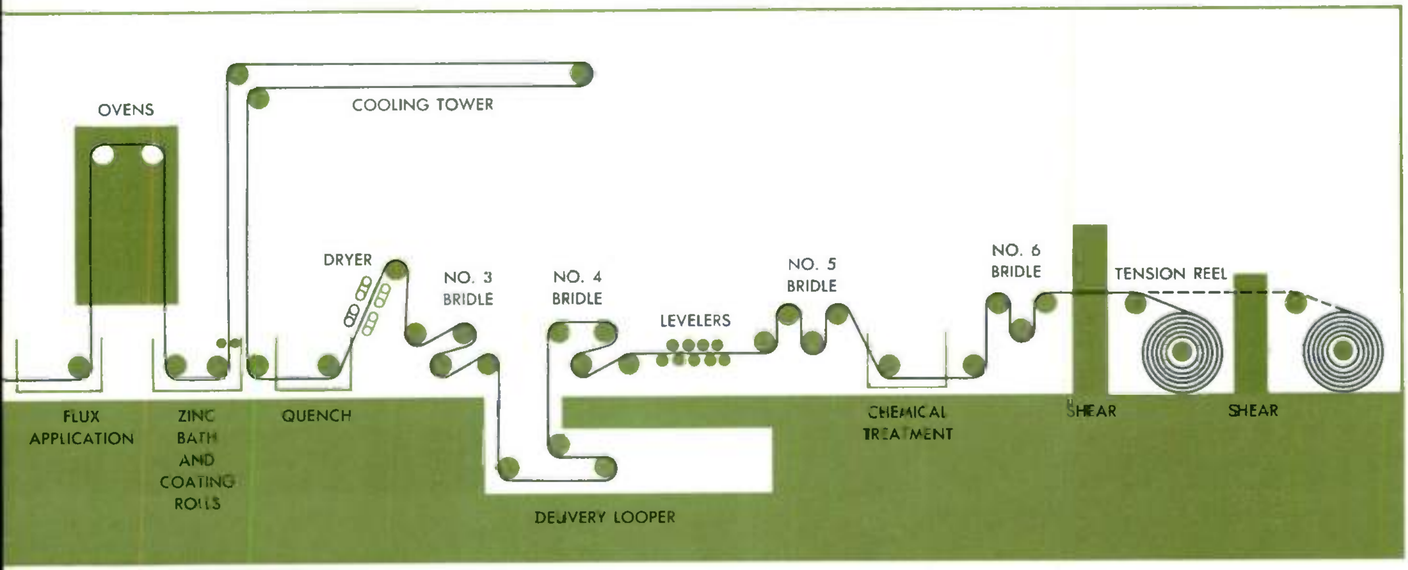
Top Left—Between the No. 1 and No. 2 bridles (two large rolls in the foreground), the strip passes down to a looper, where a two-strand loop car travels horizontally under the cleaning and flux-application tanks. The looper provides strip storage to permit constant processing speed in the center section when coils are being added in the section. The flux is dried, and the strip is preheated, in the large structure rising over the tanks.

Lower Left—A jib crane with 15-ton capacity and a 7- to 24-foot boom length provides crane service in the zinc-bath area, where the flux-drying and preheat ovens restrict conventional crane service. Workmen, after completing a mechanical modification, are replacing a portable crosswalk. This walk is normally located over the zinc bath primarily to give access to the top coating roll for maintenance of the proper surface conditions on that roll.

Right—As the strip rises to the cooling tower from between the coating rolls, molten zinc mirrors an operator watching this critical point of the process. Also visible are two sections of strip in the up and down passes of the flux-drying and preheat ovens. Ducts exhaust fumes from the area where strip enters the molten metal.

Diagram—The essential elements of a Cook-Norteman hot-dip galvanizing line are diagrammed here. Steel strip is fed in from coils at the left; as one coil is exhausted, its end is welded to the start of a fresh coil to form a continuous strip. Powered pinch rolls and bridles keep the strip moving under precisely controlled speeds and tensions. After cleaning and flux application, the strip is coated by immersion in molten zinc. Details of the line are shown in the accompanying sequence of photographs.





to preserve the brightness of the zinc coating in storage. Finally, the treated strip is either recoiled or sheared to cut length.

The electric drive and control system for a Cook-Norteman galvanizing line is essentially the same as that found on other large continuous processing lines. However, the development of the process was a marked departure from the previous processes because of significant new design and operational features in several important process areas.

First, there are no furnaces or other facilities for in-line annealing of the strip. Coils of steel strip that have been cold reduced, box annealed, and temper rolled can be charged to the line, or hot-rolled pickled coils can be used to produce heavier gauge material. This feature permits the production of galvanized steels having a wider range of tempers and suitable, therefore, for use in a greater variety of end products.

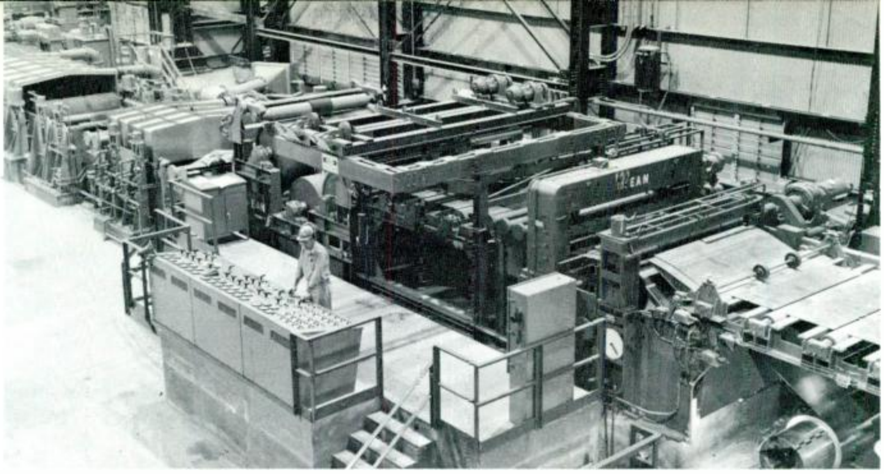
Another important engineering feature is the fluxing system. As was previously mentioned, an aluminum-bearing spelter is used. Common chloride fluxes floating on the surface of the spelter would rapidly remove the aluminum from the bath as aluminum chloride, which is highly volatile at galvanizing temperatures. Consequently, a film of flux is applied to the strip by passing it through a bath containing an aqueous solution of zinc ammonium chloride. The flux is baked on the strip before it enters the molten zinc. This fluxing method makes an appreciable contribution to the controlled production of tight coatings.

The coating bath temperature is maintained at approximately 850 degrees F by low-voltage 60-cycle induction coils. These inductors perform a second important function, keeping the zinc and the aluminum addition thoroughly mixed by thermal circulation. Because of the differences in melting temperature and specific gravity of the two metals, the aluminum tends to separate out and rise to the surface of the bath. The constant mixing action insures that the zinc-iron alloy layer is satisfactorily inhibited, thus contributing further to the quality of the galvanized steel.

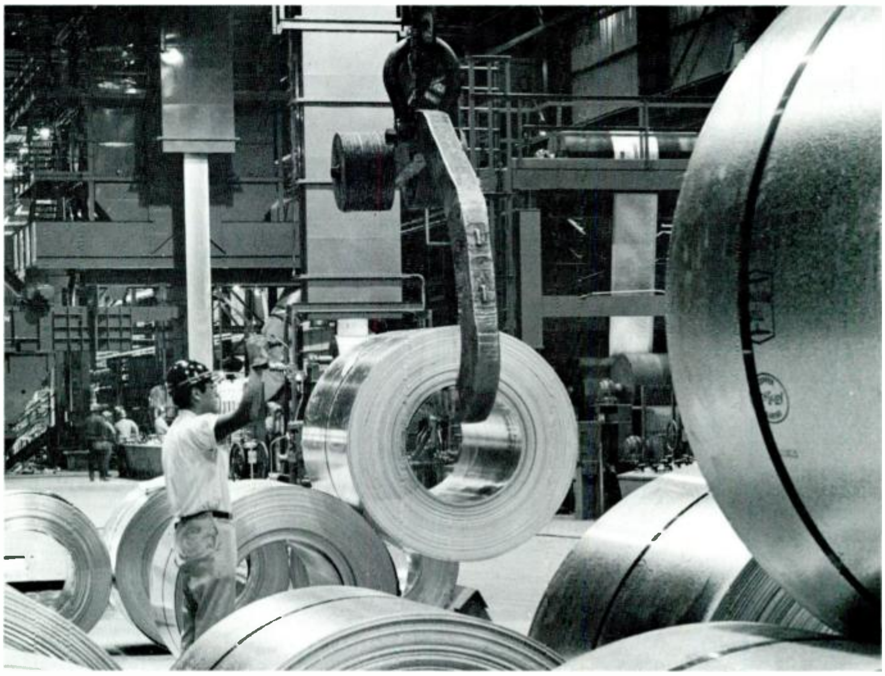
Routine production interruptions are easily accomplished, mainly because there is no in-line annealing facility requiring complex shutdown procedures even for short out-of-operation periods. The line proper is shut down simply by lifting the strip (with built-in air valves) above the solution level in the tanks, removing the coating rig, and shutting off the gas flow to the flux-drying and strip-preheating ovens. (The coating rig is built in two sections so it can be removed without

Left—The main operator's station is the heart of the line. Many process variables are monitored and controlled here, and direction is given to the line drive control. An x-ray gauge measures coating thickness as the strip completes more than 400 feet of horizontal travel above the roof trusses, where it is cooled by air blast. Still at an elevated temperature, the strip next passes through a water quench. After drying, it enters the No. 3 bridle, which sets the strip speed in the line center section. Between the No. 3 and No. 4 bridles, a second loop car accumulates strip during delivery-section coil removal and reel transfer. Levelers between the No. 4 and No. 5 bridles insure flatness, which is especially important for products destined for two of the largest galvanized-steel markets—the appliance and automotive industries.

Top Right—From the chemical treatment tanks (left), the strip enters the No. 6 bridle (the large rolls seen behind the operator). After identification marking, the strip is recoiled on one of two tension reels (right). The reel control indexes the reels automatically for overwind operation (clockwise rotation) or underwind operation (counterclockwise rotation). This line can also produce sheared sheets, up to 16 feet long, instead of coiled strip.



Lower Right—Completed coils of galvanized steel frame the main process area of the line. The galvanized steel is now ready for fabrication into various products.



parting the strip.) The molten zinc can be pumped from the main pot to gas-fired pre-melt or holding pots during extended shutdown periods. Electrically, only shutdown of the motor-generator sets and removal of auxiliary ac power are required.

These procedures are reversed to resume operation. The electrical controls are interlocked to insure that the correct startup sequence is followed.

The Cook-Norteman line illustrated in this article is designed to process steel strip varying in width from 18 inches to 72 inches, and in thickness from 0.0135 inch to 0.175 inch. Line speeds range from 50 to 300 fpm. Coils weighing up to 70 000 pounds are charged to the line, and coated strip is produced in coils weighing up to 70 000 pounds or in sheets up to 16 feet long. The line is approximately 1000 feet long.

Some idea of the size and complexity of this line can be conveyed by a few approximate figures on the electrical equipment. The dc motors, for example, supply 2100 horsepower to motivate the wind and unwind reels, the pinch rolls and bridles that move the strip through the line, the helper drives that prevent excessive strip tension build-up from deflector- and submerging-roll frictions, and special drives such as levelers and shears.

Seven motor-generator sets supply 1700 kilowatts of adjustable-voltage power from main and auxiliary dc generators. Twenty-five regulator systems control the variables of speed, voltage, current, counter emf, and position. Thirty main and auxiliary operator's stations are located along the line. There are 75 dc adjustable- and constant-voltage control panels, varying in width from 20 inches to 36 inches. Low-voltage ac fan, pump, and adjustment drive motors total 2000 horsepower in ratings from 1/4 to 200 horsepower. The five ac control centers are each more than 30 feet long.

Installation and startup of this line proceeded extremely well. Threading of the line was accomplished during September 1962; when zinc was transferred to the main pot on October 8, the line produced quality galvanized steel.

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ENGINEER
Sept. 1963

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Transistorized Power-Line Carrier for Protective Relaying

H. W. Lensner, Relay-Instrument Division, Westinghouse Electric Corporation, Newark, New Jersey.

This new ten-watt transistorized carrier set and a phase-comparison carrier control unit that uses solid-state logic elements provide a fast, secure protective relaying system.

The designer of power-line carrier must resolve conflicting requirements: narrow receiver bandwidth is desirable because it makes possible close spacing between channels, and hence more channels; but the narrower the bandwidth, the slower the operating speed must be (since the speed of response of any communication channel is proportional to its bandwidth). Therefore, when the first transistorized carrier equipment (Type KR[1]) was introduced by Westinghouse, it was designed as the best compromise between these two requirements—a relatively narrow bandwidth to provide sufficient channel capacity, but adequate operating speed to handle power-line carrier relaying.

The KR set was designed for one-watt power output, based on known field requirements and the capabilities of transistors available when it was developed. Although power levels of 25 and even 100 watts had been used in various earlier tube type designs, experience indicated that a sharply tuned one-watt unit would provide more than adequate service at a great saving in space and battery drain. Until recently, this power level has been adequate.

Recent applications of carrier to EHV lines and to high-attenuation circuits have presented a signal-to-noise problem not usually encountered. Therefore, to satisfy those applications where excessive noise or attenuation or both prohibit the use of KR carrier, a new 10-watt transistorized carrier set, called Type TC, has been developed.

The basic operational characteristics of the new TC carrier set are compared with the KR carrier set in the table. In addition to higher power output, the new TC carrier has faster operating speed, obtained at the expense of greater bandwidth. This compromise was made to increase the relaying capability of TC over KR equipment for relay systems requiring faster receiver response. The voice communication on TC carrier is limited to a maintenance channel, as on the KR set. TC carrier can also be used for telemetering and supervisory control, but with instant priority given to the relaying function.

TC Carrier Set

The emphasis on relaying capability for the new 10-watt transistorized carrier equipment led to the following design objectives:

1) Full ten watts transmitter output with 48, 125, or 250-volt dc supply.
2) Suitable for either directional or phase-comparison relaying.
3) Fast channel response time.
4) High adjacent-channel attenuation to permit maximum use of carrier spectrum.
5) Low stand-by battery drain.
6) Adequate surge protection from power-line or dc supply surges.
7) Ambient temperatures of −20 to +60 degrees C.

In addition to these specific objectives, the general requirements of reliability, a minimum of adjustments, and ease of maintenance were factors in the development of TC power-line carrier.

The carrier transmitter is crystal-controlled, with the crystal operating at the output frequency. The transmitter delivers 10 watts of output power over a frequency range of 30 to 200 kc, with all harmonics at least 55 db below 10 watts. A series-resonant output filter serves the dual function of reducing harmonic output and limiting surges that enter the set from the power line. The only adjustment normally required on the transmitter is the output control, located between the oscillator and the following amplifier stage, shown in the transmitter block diagram (Fig. 1).

The superheterodyne receiver has an essentially constant bandwidth over the 30–200 kc range. The receiver has a pass-band 1500 cycles wide, with attenuation increasing to over 80 db at 2 kc on either side of resonance when used for directional-comparison relaying. For phase-comparison relaying, the 80-db points are at 3 kc on either side of resonance. This difference in response is the result of a broader i-f filter required for the square-wave blocking signal used in phase-comparison relaying. The build-up and decay times for the receiver are both 2 milliseconds, so that there is no distortion of *on* and *off* intervals in relaying. A block diagram indicating the major sections of the receiver is shown in Fig. 2.

Although the primary function of the TC carrier set is to provide a blocking signal for carrier relaying, a channel for voice communication between the terminals of a line section is also desirable during periods of adjustment and maintenance. To provide this feature, a Voice Adapter can be used. It is intended only to provide communication between the carrier sets (or telephone jacks on the switchboard), and cannot be used as a regular communication channel, or converted into a two-wire extension for a PBX board, for example. The Voice Adapter is a separate assembly, which can be permanently mounted on the TC panel.

Power Supply

Transistors are relatively low-voltage, high-current devices, so that station battery voltage must be reduced to 45 volts for the TC set. To obtain a low stand-by current

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[1] "Modernizing Power-Line Carrier with Transistors," E. E. Scheneman, *Westinghouse ENGINEER*, July 1958, pp. 98–101.

Operational Characteristics of KR and TC Carrier

	Type KR	Type TC	
Application	Directional-Comparison Relaying, Telemetering, Supervisory Control, Maintenance Communication.	Directional-Comparison Relaying, Telemetering, Supervisory Control, Maintenance Communication, Phase-Comparison Relaying.	
Frequency Range	30 to 200 kilocycles		
Frequency Stability (rated conditions)	±20 cycles		
Operating Range	40 db maximum		
Signal-to-Noise Ratio	12 db minimum		
Power Output	1 watt	10 watts	
Receiver Output	20 ma into 2000 ohms	200 ma into 30 ohms (relay) 20 ma into 2000 ohms (aux)	
Response Time		Directional Comparison	Phase Comparison
Pickup	5–6 milliseconds	3 milliseconds	2 milliseconds
Dropout	7 milliseconds	3–4 milliseconds	2 milliseconds
Pulse Rate (per second)	15	60	
Bandwidth (db down)	3 at 500 cycles 45 at ±1 kc	3 at 1500 cycles 80 at ±2 kc for directional comparison use 80 at ±3 kc for phase comparison use	

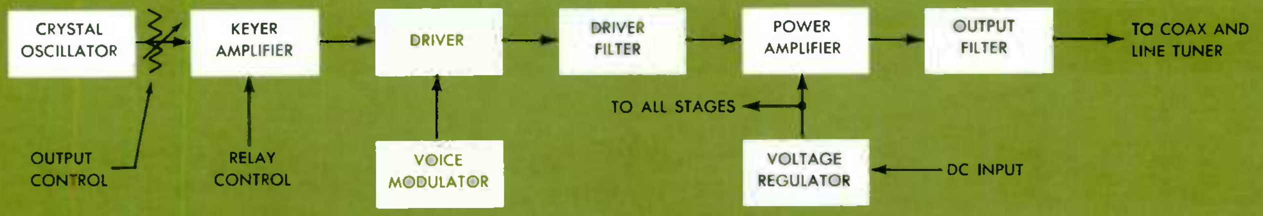


Fig. 1—Block diagram of Type TC carrier transmitter.

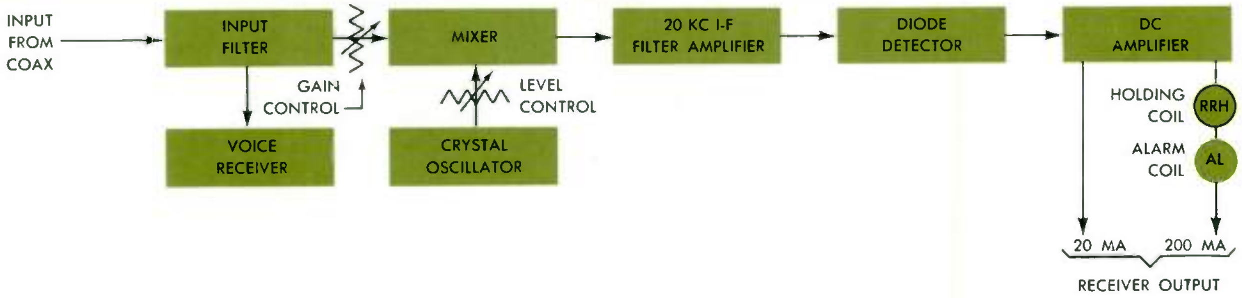


Fig. 2—Block diagram of Type TC carrier receiver.

Fig. 3—Front and rear view of Type TC power line carrier set. The transmitter, receiver, and power supply are mounted on this single 19 by 17½ inch panel.

drain, a Zener-controlled series type of regulator is used, with a silicon power transistor as the series regulating circuit element. With this arrangement, the stand-by current drain for a 125-volt supply is only 0.25 amperes; current increases to 1.1 amperes when carrier is transmitted.

For a 48-volt supply, the Zener regulating diode is closer to its breakdown voltage, so it is operated at a somewhat higher current to assure good regulation. This results in a stand-by current of 0.5 ampere with a 48-volt supply.

The regulator circuit used for 48- and 125-volt supplies is impractical for 250-volt operation, and a more elementary type of regulator is used, which results in a higher stand-by current of 1.5 amperes.

Surge Protection—Adequate surge protection is essential in any transistorized apparatus connected to a power system station battery. Surges originating not only from

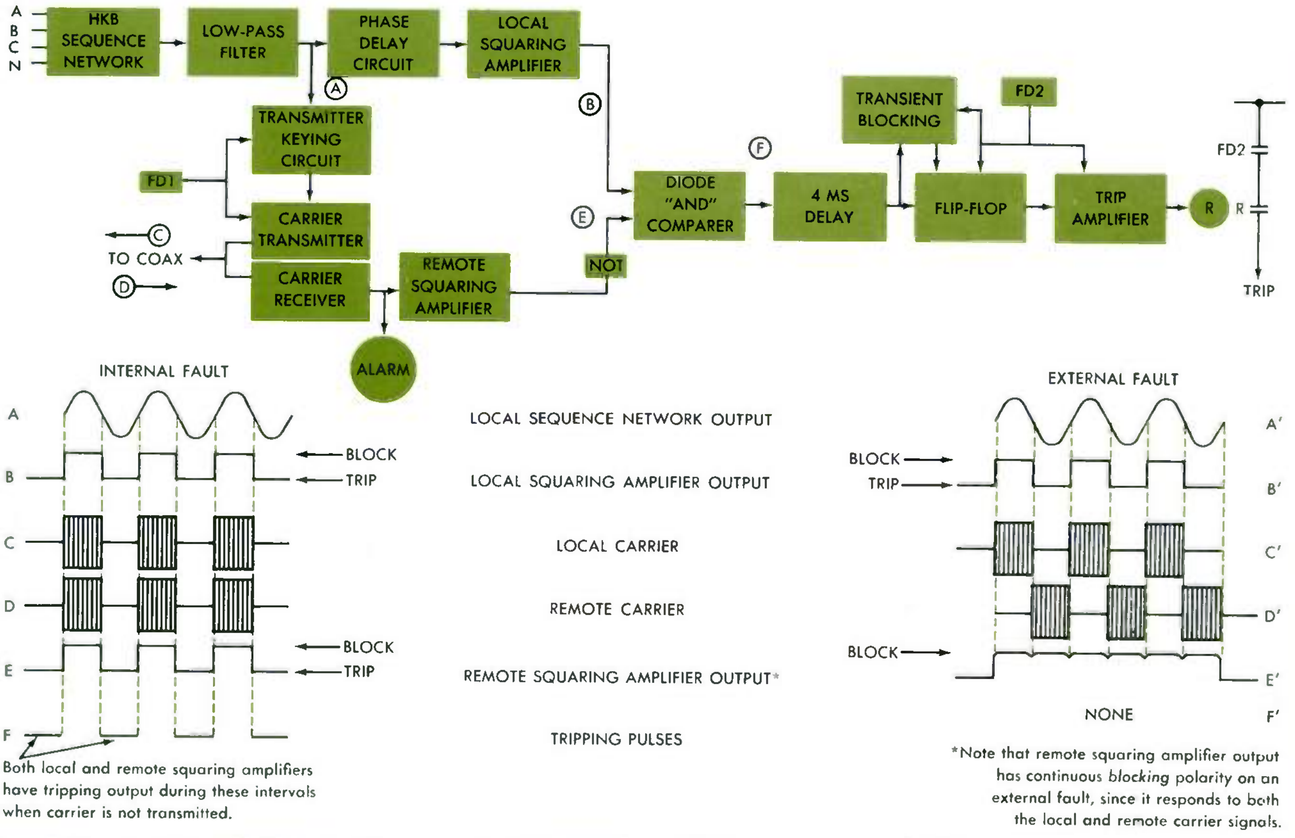
Fig. 4—Phase-Comparison Relaying System Logic

Output from the sequence network passes through a low-pass filter and provides a 60-cycle voltage A. This voltage energizes the transmitter keying circuit, which in turn controls the transmission of half-cycle pulses (at 60 cycles) of carrier C if the fault detector ($FD1$) also operates.

Voltage A is also an input to the phase-delay network and local squaring amplifier. The local signal is delayed by an amount equal to the overall carrier channel delay, and thus brings the local tripping and remote blocking signals into phase with one another during an external fault. Thus, output B is the local quantity to be compared with a similar voltage E received from the remote terminal D through the carrier receiver and remote squaring amplifier. Since tripping can take place only on the half cycles that carrier is not received from either the local or the remote terminal, this is indicated by the NOT block.

The quantities B and E energize the diode AND circuit, where they are compared as to relative phase position. If they are of the correct phase position for an internal fault, after a four-millisecond delay during the half cycle in which carrier is not transmitted, tripping is initiated through operation of the flip-flop and trip amplifier circuits. Current transformer connections to the sequence networks at the two terminals are such that carrier is transmitted on the same half cycles from both terminals during an internal fault (Compare C and D for an internal fault), thus allowing tripping F during the half cycles that carrier is not transmitted. However, if the fault is external to the protected line section, carrier is transmitted on alternate half cycles from opposite terminals, as shown at C' and D'. Thus, each terminal blocks the opposite terminal during the half cycles when it is attempting to trip. The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals, relay coordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

For any fault, if tripping does not occur in less than two cycles after the fault detector ($FD2$) operates, the flip-flop is desensitized so that a transient pulse cannot operate it. This will still allow the relay to trip for an internal fault, but will prevent the possibility of tripping at the clearing of an external fault. However, if an internal fault should develop before the external fault is cleared, the change in phase position of the local and remote carrier pulses will cancel the transient blocking after approximately two cycles to allow a slightly delayed tripping.



Both local and remote squaring amplifiers have tripping output during these intervals when carrier is not transmitted.

*Note that remote squaring amplifier output has continuous *blocking* polarity on an external fault, since it responds to both the local and remote carrier signals.

lightning, but from line switching, breaker tripping, or operation of any dc coil device in the station can destroy transistorized equipment that is not properly protected.

To provide surge protection, Zener diodes are used both as power-supply regulators and as peak clippers. The dc supply voltage is heavily by-passed to ground, and the static components in the voltage-regulator and power-amplifier circuits are also protected by Zener diodes.

Mechanical Design

The TC transmitter-receiver and power supply are mounted on a single panel 19 inches wide and 17½ inches high. The assembly can be mounted on a swinging rack in an indoor or outdoor cabinet, or can be supplied for rack mounting. The receiver gain control, on-off and test switches, fuses, pilot light, and test jacks are front mounted. Front and rear views of the TC set are shown in Fig. 3.

The carrier set contains three removable printed circuit boards: (1) receiver, (2) transmitter oscillator, keyer amplifier and driver stages, and (3) small components of the power-amplifier. These circuits have test points to facilitate checking dc and signal quantities and, being removable, are easily serviced. The power-amplifier transistors and power supply components are mounted at the top of the assembly so that heat is dissipated away from other components.

Phase-Comparison Relaying with TC Carrier

Two basic systems are used in carrier relaying—*directional comparison* and *phase comparison*. The phase-comparison system differs functionally from the directional comparison system in that the relative current directions at the two ends of a protected line section are compared rather than the power directions. Both carrier systems operate on the principle of quickly tripping breakers at both ends of the protected section if current or power flows into the section from both directions, indicating an internal fault. However, the operating requirements for carrier equipment used for phase-comparison relaying are more severe than for directional comparison relaying. Carrier is turned on and off sixty times a second with essentially square waveform, and the receiver must follow this pulsing with short build-up and decay times (or turn-on and turn-off times) to maintain proper phase relationship.

The original KR transistorized carrier was suitable only for directional comparison relaying; the new TC carrier can be used for both. Since each system has advantages in certain applications, the new TC carrier provides additional flexibility in relaying applications.

Transistorized Phase-Comparison Equipment

Phase-comparison relaying has been well established in nearly 20 years' experience with tube-type carrier and control circuitry. Hence, with transistorized carrier now generally accepted, redesign of the phase-comparison carrier control unit for transistor operation is a logical step toward a completely static carrier relaying system. Although the basic principle of operation is the same as with tube-type equipment, solid-state logic elements from the computer field have been introduced, and have resulted in a faster and more secure relaying system.

Static Control Unit

A block diagram of the complete phase-comparison system is shown in Fig. 4. The blocks in this illustration include complete functional units such as the TC carrier transmitter and receiver, the control unit logic-circuit elements, and the sequence network, which converts the three-phase line currents into a proportional single-phase voltage.

Operation of the phase-comparison relaying system is described in Fig. 4, which also shows wave diagrams for internal and external faults. Briefly, when a fault occurs, alternate half-cycle pulses (at 60 cycles) are provided to the carrier transmitter for transmission to the remote terminal; similar tripping pulses are developed for use at the local terminal on the half cycles that carrier is not transmitted. The local logic circuitry is such that tripping can occur only on a half cycle when a signal is not received from either the local or the remote terminal. Therefore, if the phase conditions are such that a fault external to the carrier terminal is indicated, each terminal blocks the opposite terminal during the half cycle that it would otherwise trip.

Since the sequence network and the low-pass filter contain reactive circuit elements, discharge of their stored energy at the clearing of an external fault might cause an incorrect relay operation. To avoid the possibility of such a condition, a *transient blocking circuit* (Fig. 4) is included which desensitizes the flip-flop circuit after allowing sufficient time for tripping of bona fide internal faults.

Fault Detectors

Fault detectors supervise the operation of the blocking and tripping functions. A low-set fault detector *FD*1 controls transmission of the carrier blocking signal. Operation of *FD*1 instantly starts carrier at full output, and also activates the transmitter keying circuit, which turns carrier off during alternate half cycles. The high-set fault detector *FD*2 supervises operation of the local flip-flop and trip amplifier; thus it must pick up for tripping to take place. Fault detector *FD*2 is calibrated to operate at 125 percent of the *FD*1 setting for a two-terminal line. This margin insures that carrier will be started at both terminals before *FD*2 operates for a remote external fault. For internal faults, the total relay operating time is about two cycles, or 33 milliseconds.

Application

This relaying system is used for high-speed protection of transmission lines. Its application depends on the relative values of minimum fault current and maximum load current, since overcurrent fault detectors are used. For some applications where an unsatisfactory ratio exists between these two quantities, it is possible to use distance-type fault detectors such as the Westinghouse K-Dar relays[2] in a combined scheme providing directional-comparison relaying for three-phase faults and normal phase-comparison relaying for all other types of faults. Such a combination extends the field of application for phase-comparison relaying to transmission lines (particularly multiterminal lines) where overcurrent fault detectors could not be used.

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[2] "K-DAR Compensator Relaying," H. W. Lensner, *Westinghouse ENGINEER*, July 1959, pp. 114–118.

RESEARCH AND DEVELOPMENT

Columbium Alloys . . . A new family of structural alloys meets the challenges of modern technology's higher temperatures.

Technology has been moving steadily into areas of higher temperatures and more exacting conditions than structural metals have hitherto been called on to endure. This is true in industrial operations as well as in the more spectacular applications such as space-vehicle structures and new power sources.

In chemical processes, for example, high temperatures are necessary for some reactions, and they make others proceed more rapidly and efficiently. Heat engines of all kinds are being pressed for greater power and efficiency, usually by increasing inlet temperature. Nuclear reactor components are subjected to severe heating and sometimes to corrosive liquids and gases. Altogether new power sources loom on the horizon, and some of them, such as thermionic and magnetohydrodynamic generators, are inherently high-temperature devices. Space vehicles that are to re-enter the earth's atmosphere must maintain structural strength in spite of aerodynamic heating that may range up to 4500 degrees F.

To meet many of these high-temperature structural needs, a family of alloys based on columbium (niobium) has been developed by Westinghouse engineers and metallurgists. The new alloys can be used at temperatures in the range of 2000 to 3000 degrees F for many applications where nickel- and cobalt-based alloys cannot be used because of corrosion limitations or strength and melting-point limitations (Fig. 1). Their densities are about equal to that of stainless steel. This makes them light metals by comparison with tungsten and tantalum, two other refractory metals being considered for high-temperature structural use.

Physical Properties of Columbium Alloys

Property	Alloy B-33	Alloy B-66
Density	0.306 lb/in³	0.305 lb/in³
Melting Point	4310°F	4300°F
Young's Modulus	15.8×10^6 psi	15.3×10^6 psi
Resistivity		
78°F	21.8 micro-ohm cm	24.9 micro-ohm cm
—320°F	6.64 micro-ohm cm	10.9 micro-ohm cm

High-temperature strength is achieved in the alloys without drastic losses in pure columbium's attractive properties of workability and low-temperature ductility. Without workability, fabrication would be difficult and costly; without low-temperature ductility, the intense cold of outer space would make a structure brittle and unsafe.

The new alloys appear to have some of the best-balanced combinations of properties yet achieved with columbium. Two of them are in commercial production, and such items as tubing, wire, foil, sheet, and honeycomb panels have been made from them.

The first to be produced was a columbium-vanadium alloy called B-33. It has moderate strength and is intended for applications where excellent fabricability is the prime requirement. The alloy is easily welded and resists corrosion by liquid metals. The latter characteristic has qualified it for consideration for use in the pressure vessels, piping, heat exchangers, and fuel-element cladding needed for the nuclear reactors that will produce power in space.

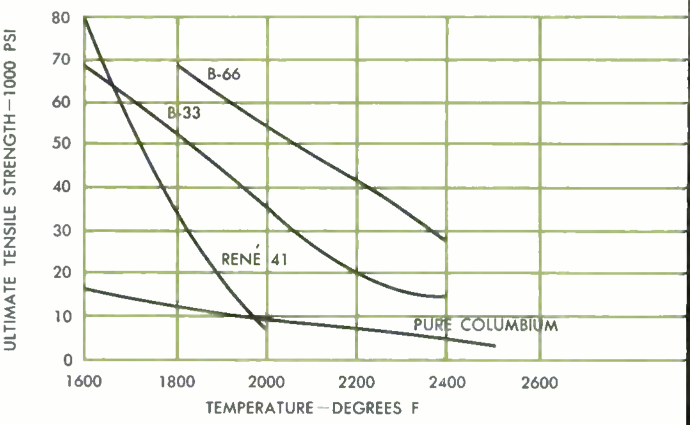
B-33 is a single-phase solid-solution alloy containing about five percent vanadium. Its physical properties are shown in the table.

This alloy can be sheared and formed at room temperature without cracking. Sound ductile welds can be made by inert-gas arc welding. The alloy's oxidation resistance is somewhat better than that of unalloyed columbium, although, like most refractory metals, it requires a protective coating for extended use at elevated temperatures in an oxidizing environment.

Fig. 1 (Right)—Effect of temperature on the ultimate tensile strengths of the columbium alloys B-33 and B-66. The characteristics of pure columbium and of René 41, one of the strongest high-temperature nickel alloys known, are shown for comparison. The latter's strength decreases rapidly in this high temperature range.

Fig. 2 (Center)—In levitation melting, magnetic fields float the specimen while induced current melts it. The technique permits preparation of alloy specimens without contamination from contact with a crucible.

Fig. 3 (Far Right)—Rolling a columbium alloy in pilot-plant production. The new family of alloys combines the properties of high-temperature strength and workability. Conventional fabricating methods are employed to produce sheet, tubing, honeycomb panels, and other structural elements that withstand high temperatures.



The other alloy in commercial production is B-66, which contains five percent vanadium, five percent molybdenum, and one percent zirconium. B-66 has considerably better high-temperature properties than B-33, but it, too, can be worked by conventional methods.

The new alloys are relatively easy to process, in contrast to the difficulties encountered with other high-strength refractory metals such as some experimental columbium alloys, tungsten, and molybdenum. The latter materials usually have to be processed at high temperatures and either in an inert atmosphere or within the protective cladding of a less active metal. The new alloys require such protection only during melting and ingot breakdown; after that, conventional processing methods are used.

Development

Columbium is chemically active, which makes it difficult to separate from its ores. This, and the fact that it was considered a scarce element until recently, limited its application for years to such uses as a "getter" in electron tubes and a constituent of some welding electrodes and alloy steels. Then discovery of extensive ore deposits, coupled with the increasing need for better high-temperature structural materials, led to serious consideration of ways to take advantage of its properties—high melting point, high-temperature strength, low-temperature ductility, low neutron-absorption cross section, and resistance to corrosion by some gases and liquid metals.

The Westinghouse research and development program aimed at developing strong alloys began about seven years ago. It has been performed, in part, under contract with the U.S. Air Force Directorate of Materials and Processes, Aeronautical Systems Division, Dayton, Ohio.

The first step was to study the properties of columbium metal to acquire the background information needed for systematic investigation of alloys. Specimens of commercially pure columbium were studied to determine low-temperature flow and fracture characteristics, creep-rupture properties, recrystallization behavior, oxidation kinetics, and other physical qualities. The results were encouraging, and simple alloys were prepared for phase-diagram and oxidation studies. Here the investigators used the previously developed technique of levitation melting in an inert atmosphere to keep from contaminating specimens by contact with a crucible or the atmosphere (Fig. 2).

These experiments showed that the commercial-quality columbium was not pure enough for accurate phase-diagram studies, so much of the early effort was devoted to purifying the metal by cage zone refining. With pure metal to work with, the effects of controlled metallic and nonmetallic additions on the chemical and mechanical properties of columbium were studied. Dispersed-phase strengthening effects were discovered, and this knowledge formed the basis for successful development of the family of useful structural alloys.

Applications

Columbium alloys are expensive and will be until they are produced in greater volume. For that reason, many of their initial applications will be in the structures and power plants of space vehicles and high-performance aircraft. Their relatively light weight will simplify launchings and increase payloads. High-temperature strength will permit use of smaller, more efficient engines operating at higher temperatures and also will permit vehicles to return safely to earth in spite of aerodynamic heating.

The alloys also should find use in nuclear reactor structures, fuel elements, and heat exchangers, especially for reactors that operate at unusually high temperatures and those that are cooled by liquid metals. For the fuel elements, columbium can be used either as alloy cladding or in fuel alloys with uranium. Its low neutron-absorption cross section makes it attractive for all nuclear applications.

Commercial uses should include equipment for handling molten zinc and other corrosive materials. Reaction vessels and piping for chemical processes are other good possibilities; so are blades, combustion chambers, and other components of high-temperature gas and steam turbines. Farther away, probably, but still definite application possibilities, are thermionic and magnetohydrodynamic generators.

Paradoxically, another family of columbium alloys for use at the opposite end of the temperature spectrum may be fully as important as the high-temperature family. This is the group of superconducting alloys that lose their electrical resistance at very low temperatures.

Both properties—superconductivity and high-temperature strength—open so many possibilities that columbium alloys are certain to have far-reaching effects in many areas of technology.

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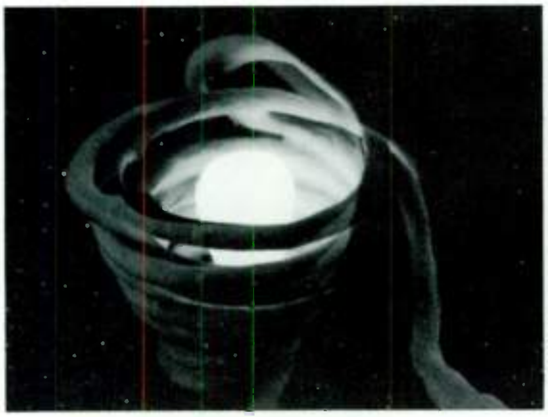

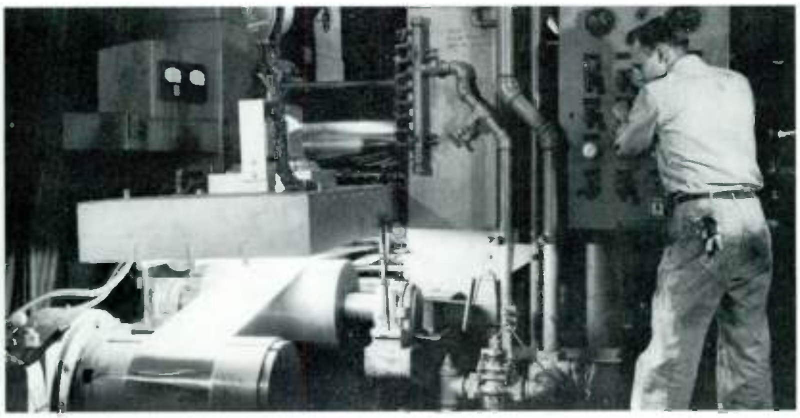

A Distribution Transformer With Zero-Percent Impedance

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Westinghouse Electric Corporation, Sharon, Pennsylvania.*
*R. J. Radus, Research Laboratories, Magnetic Department,
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania.*

The voltage drop in a distribution transformer is eliminated in this new design, by building in capacitance to cancel transformer inductance.

Of all the limits imposed on the design and operation of electrical distribution systems, voltage regulation is one of the most important.

From the first customer located at the distribution substation to the last customer at the end of the line, the utilization voltage must be held within close limits. For, if the user's voltage level were not held with a reasonable tolerance, either his appliances and lighting would have a shortened life or his equipment would not perform satisfactorily. For this reason most distribution system loading practices are dictated by voltage regulation rather than by thermal loading.

In a typical distribution feeder system at peak load, about 30 percent of the total voltage drop is in the distribution transformer itself, the remainder being contributed by the primary feeder, the secondary line, and the secondary drop (Fig. 1).

A new distribution transformer, designed for zero-percent impedance, eliminates this voltage drop. This unit therefore allows more flexibility in the design of new distribution systems; moreover, it makes possible the extension of distribution systems to new areas without creating voltage problems, or can be used as a replace-

ment for conventional transformers to correct for load-density problems in existing systems.

The zero-percent impedance transformer (see photo below) is constructed with sufficient *internal* series capacitance in the coil to cancel transformer inductance. The result is that there is no voltage drop through the transformer at a typical load power factor. Also, the integral series capacitance overcomes problems of lamp flicker caused by sudden load changes, such as motor starting.

Transformer Voltage Regulation

The difference between the transformer input voltage and the output voltage is the impedance voltage drop, which is composed of two components: First, the IX drop due to transformer reactance; and second, the IR drop due to the resistance of the transformer windings (Fig. 2a).

By adding the correct amount of capacitance in series with the transformer either in the primary or secondary circuit, the IX_L voltage drop could be cancelled out and the IR drop compensated for, eliminating the transformer voltage drop (Fig. 2b).

In the past, this has not been a practical solution because of two problems. The use of a capacitor in series with the distribution circuit creates several operating problems, such as ferroresonance and subsynchronous motor starting. Also, the combination of a series capacitor and a capacitor overvoltage protector has not been economical until now.

Therefore, to use this technique of eliminating the transformer voltage drop, two problems had to be solved: (1) development of an inexpensive series capacitor; and (2) design of a device to eliminate the undesirable effects of the series capacitor, which would also provide overvoltage protection for the capacitor.

Zero-Percent Impedance Transformer

A new transformer winding technique has been developed in which it is possible to obtain a predetermined amount of series capacitance in the high-voltage winding. This new transformer design uses foil windings to combine the functions of a capacitor and a transformer in the same basic assembly.

Aluminum foil is strip wound throughout in the high- and low-voltage windings, and creates about five percent series capacitance compensation.

The high-voltage winding is split into two parts: a main winding and an auxiliary winding (Fig. 3). Each winding is connected to one side of the input primary circuit, and the two windings are not connected metallically to each other. They are electrically coupled by the capacitance between them, as both winding conductors are aluminum foil with a large surface area and are spaced closely together. Sufficient distributed capacitance is thus available to overcome the impedance voltage drop of the resultant transformer.

Since the total turns of the main high-voltage winding are not increased, but only the second foil and some additional insulation between the two foils are added to the coil design, the series capacitance can be obtained economically.

The magnetic core is of standard construction. The low-voltage winding is aluminum foil or strip made by a new foil-winding technique (see photo, next page). The transformer is oil filled and the mechanical parts are of standard Westinghouse construction.

Left—Zero regulation transformer rated 25 kva, 7200 volts. A pre-engineered package of series capacitance, CSP distribution transformer, and automatic capacitor protector.

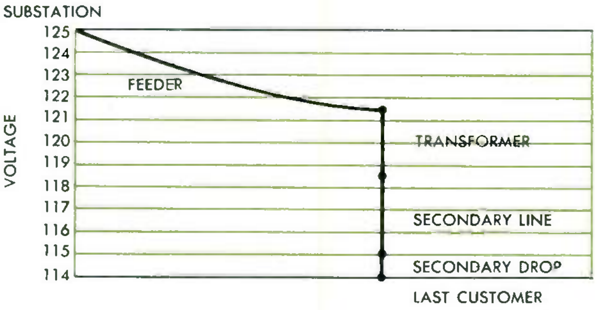

Fig. 1—Peak load voltage profile of a typical feeder system at its peak load condition. This shows a drop of eleven volts from the substation to the last user.

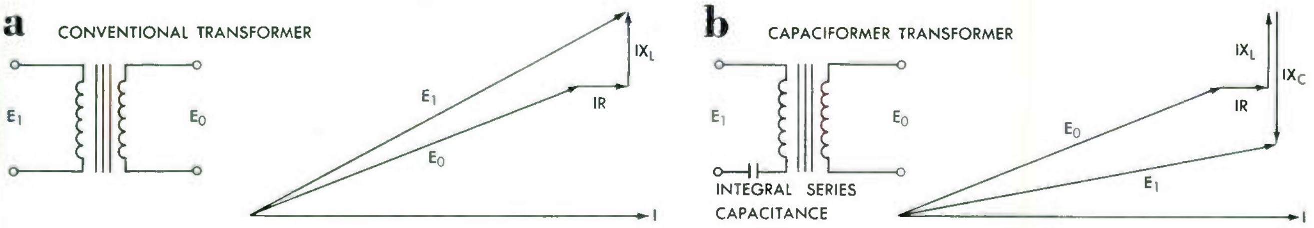

Fig. 2.—(a) The voltage drop through a standard distribution transformer is composed of the IX_L drop due to transformer reactance and the IR drop due to winding resistance. (b) The integral series capacitance of the Capaciformer cancels out the IX_L reactance voltage drop and compensates for the IR winding drop, providing zero voltage regulation.

The transformer has to provide zero voltage drop at a typical system power factor. The voltage regulation characteristics with varying power factors up to 400 percent rated load are shown in Fig. 4. The rising voltage characteristics at power factors lower than 80 percent are very desirable because these are motor-starting power factors, and a rising voltage through the transformer offsets the voltage drop in the other system components caused by the high motor-starting currents—eliminating light flicker.

Current-Limiting Action

Although it might appear that the new transformer, with its zero voltage drop, would allow very high short-circuit currents to flow, actually, the converse is true. This transformer is made with a coil design that has an impedance of 4 to 5 percent if it operates without the series capacitance. The impedance limits short-circuit currents from 20 to 25 times rated current, or less than half the short-circuit of today's standard distribution transformer.

This problem is solved by automatically eliminating the capacitor at currents greater than normal loading practices. This is accomplished by the spark gap protector, as described later. The new design has zero-percent impedance from no-load to 400 percent rated load; above 400 percent rated load, the impedance is increased to about 5 percent at a full short circuit (Fig. 5).

The impedance change with load thus allows the full benefit of the zero impedance up to 400 percent of the nameplate rating, and yet limits fault currents to safer levels, reducing the magnetic forces on cables, insulators, and all system equipment by a factor greater than 5 to 1.

Coil Insulation

The inclusion of capacitance and the change to foil winding in the transformer coil necessitated the development of a better insulation system, because the voltage stresses are higher than in most transformer designs.

During the development, several of the new, electrical-grade plastic films were evaluated for use as a coil insulation. To economically test all of the various combinations of materials and processing cycles, scale-model foil coils were wound with an insulating film and aluminum foil, processed, and impregnated with transformer oil in a steel container. These "foilettes" were thermally aged both at 150 and at 180 degrees C with test samples of the film taken periodically. As the containers held samples of all the various transformer materials, the test results showed both the thermal degradation rate of the film and whether any adverse reaction between the film and other material took place.

The material selected, an electrical-grade polyester film, possessed the desirable characteristics needed for this application, and this film proved to be thermally stable and compatible with the transformer materials used, and the thermal aging rate compared favorably with Insuldur insulation on both short-time and long-time test periods.

The selection of an insulating material with these characteristics permits the design of a zero-percent impedance transformer with the same thermal overload capability as the Westinghouse standard 65 degrees C rise transformer.

The complete core-and-coil assembly for the Capaciformer. The core is a conventional Wescor design.

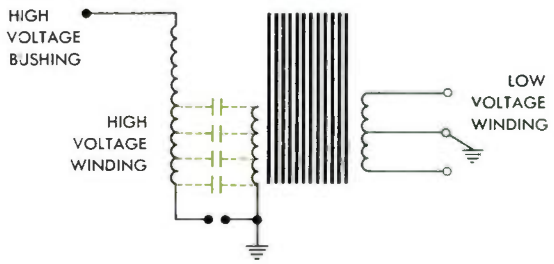

Fig. 3—The series capacitor section is formed by the main and auxiliary winding wound closely together like plates of a capacitor. As the total turns of the main high-voltage winding are not increased, but only the second foil and additional insulation are added to the coil design, the series capacitor can be added at an economical cost.

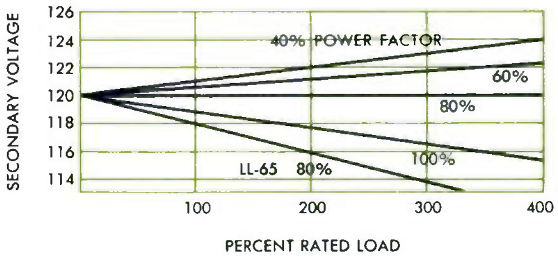

Fig. 4—Transformer voltage regulation curve with varying power factors up to 400 percent load.

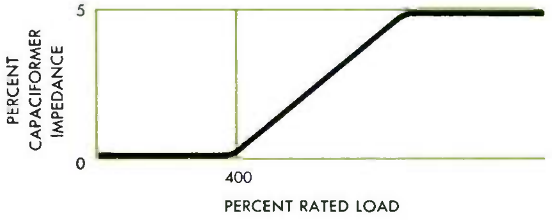

Fig. 5—The Capaciformer, when operated above 400 percent nameplate rating, increases its impedance to limit short-circuit currents.

Zero-Percent Impedance Transformer Protector

The series-capacitor section of the zero-percent impedance transformer requires a voltage-limiting device to protect the capacitor from overvoltage caused by high overloads, and also to provide a method of damping out unstable circuit conditions, such as ferroresonance and subsynchronous motor starting.

The protective device developed (see photo below) is a simple spark gap formed by two metal electrodes that break down at a voltage level corresponding to the capacitor voltage drop at 400 percent rated transformer load. This protector, along with a bleeder resistor, is connected across the series capacitor section.

Two permanent magnets form a magnetic field around the spark gap, at right angles to any arc that may form across this gap. The purpose of the magnetic field is to drive the arc at high speed, so that it extinguishes itself after the capacitor discharge, and does not permit power follow or 60-cycle current to flow in the gap.

The characteristics of the spark gap during ferroresonance caused by transformer excitation is such that the gap fires whenever the capacitor voltage reaches the breakdown level; the arc conducts during the capacitor discharge period of about 50 microseconds, and then is extinguished. This mode of operation successfully damps out the ferroresonant condition in a few cycles. In fact, the transformer inrush period is very short compared to the usual transformer inrush transient.

For transformer overloads above 400 percent nameplate rating, the protector sparks over each half-cycle to prevent overvoltages from damaging the capacitor dielectric. This also effectively shorts out the capacitor section to increase the transformer impedance as the overload increases.

If the overload approaches a short-circuit condition, the rate of rise of capacitor charging voltage becomes high enough so that multiple breakdowns occur during each half-cycle. When the short-circuit load is dropped, the protector gap recovers in a few cycles to the nonfiring mode. The short time that the arc is present in the gap each half-cycle (less than one percent of the time) eliminates the thermal problem that plagues the conventional spark gap.

From all the tests made, the magnetically biased spark gap is the only device that meets the capacitor section protection requirements economically and eliminates all the operating problems caused by series capacitors.

Field Tests

In August, 1962, a 25-kva, 7200-volt zero-percent impedance transformer was installed on the Pennsylvania Power Company system at Sharon, Pennsylvania, as a joint experiment between Westinghouse and the electric utility company. This unit has been serving a load of 22 homes continuously since installation with no adjustment or repair.

The daily peak loads on this transformer have been as much as 180 percent of rating, with the average daily peaks about 140 percent rating. The ambient temperature at this installation has varied from minus 26 degrees F to plus 80 degrees F, with no effect on voltage regulation. The test installation showed equal input and output voltages for all loads.

Conclusion

The new zero-percent impedance transformer—called the Capaciformer—is presently made in 25-kva, 7200, 7620, and 8000 high-voltage ratings, and low-voltage ratings of 240/120 for residential use. Applied on distribution systems it will eliminate about 30 percent of the system voltage drop and, therefore, help solve many problems of increasing load density.

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The protective device—a voltage-limiting device to protect the capacitor from overvoltage caused by high leads, and also to provide a way of damping out unstable circuit conditions such as ferroresonance and subsynchronous motor starting. The protector is connected in parallel, along with a bleed resistor, across the series capacitor section.

Induction Heating for Strip Annealing

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Adding induction heating sections to conventional continuous-strip heating furnaces provides economic and metallurgic advantages.

Development trends in strip-process industries are toward higher and higher speeds in continuous lines. Higher speeds increase production in a given line, with consequent lowering of capital investment and operating cost per ton of product. A modern processing line is the equivalent in capacity of two to three lines of a decade ago, and the trend is still upward.

High-speed continuous processing lines in the steel and nonferrous metals industries usually include furnace sections for heating the strip. A number of these lines are in successful operation for continuous annealing of carbon steels, stainless steels, silicon steels, and nonferrous metals; for annealing and heat treating aluminum and its alloys; and for heating steel strip for galvanizing. Complicating the trend toward higher line speed is a trend toward production of thinner products, such as thin steel strip.

Further speed increases, along with better process control, can now be attained by adding induction heating sections to conventional furnaces. Induction heating is, therefore, an important method to consider for the high-speed processing lines of today and tomorrow.

Heating rates with induction heating are extremely fast because much higher power densities can be applied to the strip than are possible with furnace heating. Thus, the heating zone in a processing line can be shortened. Changes in strip surface condition do not affect heating. The amount of heat energy imparted to the strip can be increased or decreased in an instant, and this provides a fast method of following process changes. It also permits close process control for optimum metallurgic properties. No high temperature gradients between furnace temperature and desired strip temperature are required. Finally, induction heating facilitates strip handling.

Induction Heating of Strip

The most common method of induction heating employs helical current-carrying coils around the piece to be heated (Fig. 1a). The magnetic flux produced is parallel to the longitudinal axis of the workpiece, and induced current flows around the surface of the workpiece at generally 90 degrees to the direction of the magnetic flux. This type of coil is called a *longitudinal-flux* induction-heating coil. It can be efficiently applied to magnetic metal strip because the high permeability of magnetic material concentrates flux in the strip. However, it is not practical for nonmagnetic strip because the small cross section of the strip intercepts only a small part of the coil's flux.

This limitation has been overcome with the development of a quite different type of induction coil (Fig. 1b). It is called a *transverse-flux* induction-heating coil because the magnetic flux is perpendicular to the surface of the

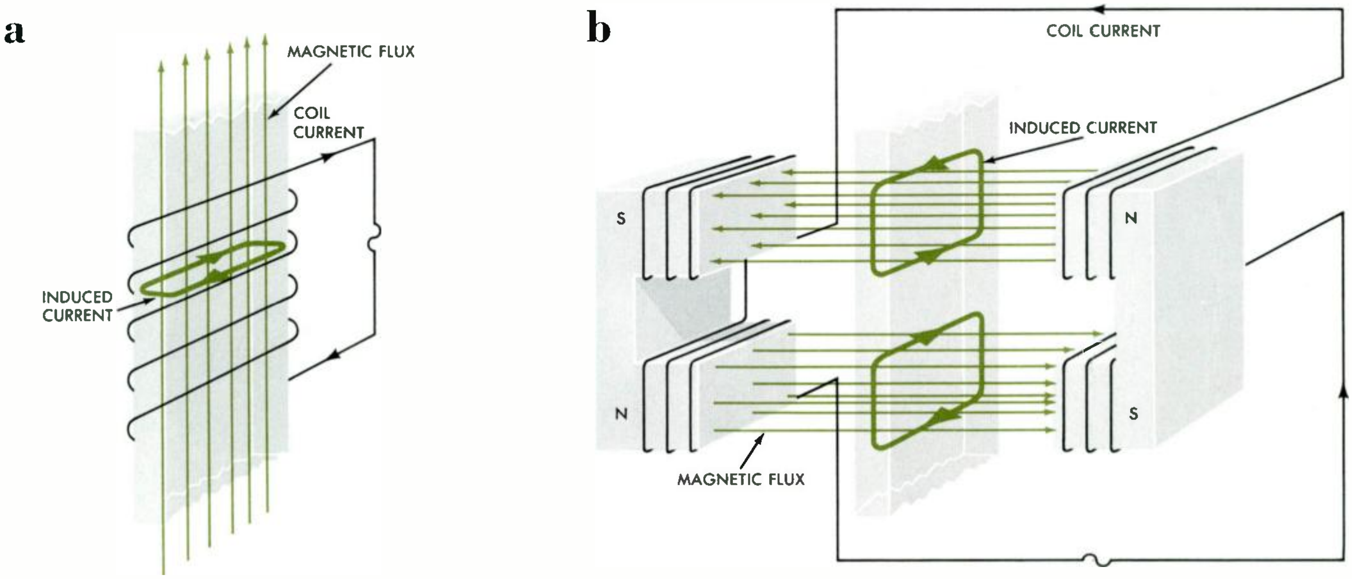

Fig. 1—(a) Longitudinal-flux induction heating is performed with a coil that surrounds the moving strip. It is best suited for magnetic metals because these materials concentrate flux in the strip. (b) Transverse-flux induction heating employs coils on each side of the strip. The coils pass magnetic flux through the strip, so they are effective with nonmagnetic metals.

strip and passes through the strip instead of along its length.[1] The induced current flow is across the width of the strip and at 90 degrees to the flux lines. Since the flux passes through the strip from north to south magnetic poles, the current is induced in bands and the strip must be kept in motion to obtain uniform heating.

Very high power densities can be induced in the strip by both methods, so the amount of power required to raise strip temperature any desired amount can be supplied by a relatively short coil. In production installations, control-system interlocks disconnect the heating coils if the strip stops moving and thus prevent overheating.

In general, the longitudinal-flux coils (which are simpler in construction) are applied for ferromagnetic steel strip to be heated up to the critical or Curie point. For low-carbon steels, this is in the range of 1330 to 1340 degrees F. All nonferrous metals are more efficiently heated by transverse flux. Both types and their related equipment have been applied in high-speed heating of strip in production installations.

Longitudinal-flux coils are used for reflowing tin on tin plate in high-speed tinning lines. Frequencies range from 95 000 to 110 000 cycles per second (cps). The equipment has been thoroughly proven with regard to reliability and low maintenance. Aluminum and its alloys are being annealed and heat treated in large continuous lines with transverse flux at frequencies as low as 60 cps. Ratings range from 300 to 4000 kva.

Characteristics of Induction and Furnace Heating Methods

Heating Rates and Power Densities—Induction heating coils are relatively short for large changes in temperature, so their use can considerably shorten the heat-up section of a line (Table I). If very high temperature gradients are used in furnaces, heating times can begin to approach those made possible by the induction method. However, high temperature gradients can be difficult to apply when heating thin strip because of related problems in strip handling. Also, high heat storage in the heating unit prevents quick temperature change when speed is changed.

More moderate temperature gradients are employed in conventional furnaces, so the furnaces are quite long because of the relatively long heat-up times. In general, radiation and combined radiation-convection methods with reasonably high temperature gradients are much slower in heating rates and available power densities than induction heating methods. This suggests the possibility of combining the advantages of induction methods with those of furnace methods. Case studies on large multiple-strand continuous furnaces support the feasibility of this approach. These studies will be discussed later.

Product quality, also, can be improved by fast controlled heating. The quality of a final strip product can vary due to changes in such operating factors as surface condition of the strip, changes in speed, accuracy of control of final strip temperature, temperature difference between furnace and strip, and strip-handling problems related to variations in temperature and tension. Application of induction heating as a supplement to furnace heating can minimize or eliminate variations in these operating factors and thereby reduce variations in product quality.

Effects of Surface Condition—When strip is furnace heated to 1100 degrees F and higher, most of the heat is transferred to the strip by radiation. This transfer is affected by strip emissivity. Surface condition determines the emissivity factor, which is a measure of the rate at which heat can be absorbed by the strip.

For example, consider an annealing furnace heating 0.010-inch by 30-inch strip operated at 1600 degrees F

Table I—Strip Heating Rates With Various Heating Methods (0.010-inch steel heated to 1250 degrees F)

Method	Approximate Heating Time (sec)	Power Density in Strip (kw/sq ft of strip)	Power Density in Strip (Btu/sq ft of strip)	Furnace Length Required for Speed of 1000 Feet/Minute (feet)
High-Frequency Induction	1.0	71	243 000	16
Radiation With Furnace at 2300° F	4.5	15.7	54 000	72
1600° F	18	3.93	13 500	287
1350° F	25	2.83	9750	400
High-Velocity Convection Plus Radiation at 1350° F	12.1	5.65	20 000	194

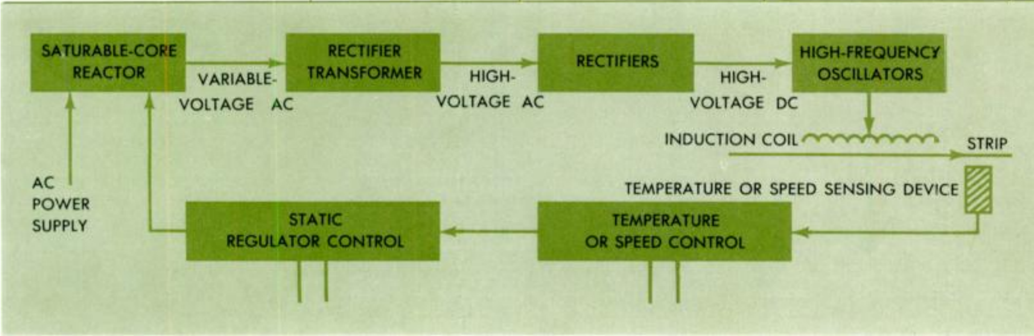

Fig. 2—The main components of an induction-heating control system are diagrammed here. Control response is fast enough to provide constant strip temperature regardless of changes in operating conditions.

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[1] "Transverse Flux Induction Heating," Robert M. Baker, *AIEE Transactions*, 1950, Vol. 69, Part 2, pp. 711–719.

Table II—Approximate Energy Costs/Ton With Various Heating Methods
(0.010-inch steel heated to 1250 degrees F)

Method	Energy/Ton (Btu)	Energy/Ton (kwhr)	Energy Cost/Ton ($)
High-Frequency Induction		195	1.95
Electric Resistor Furnace at 1700° F		113	1.13
Direct Gas-Fired; 2300° F Furnace, 300° F Preheat	1 270 000		0.64
Gas-Fired Radiant Tube With Recuperative Tubes at 1700° F	710 000		0.36

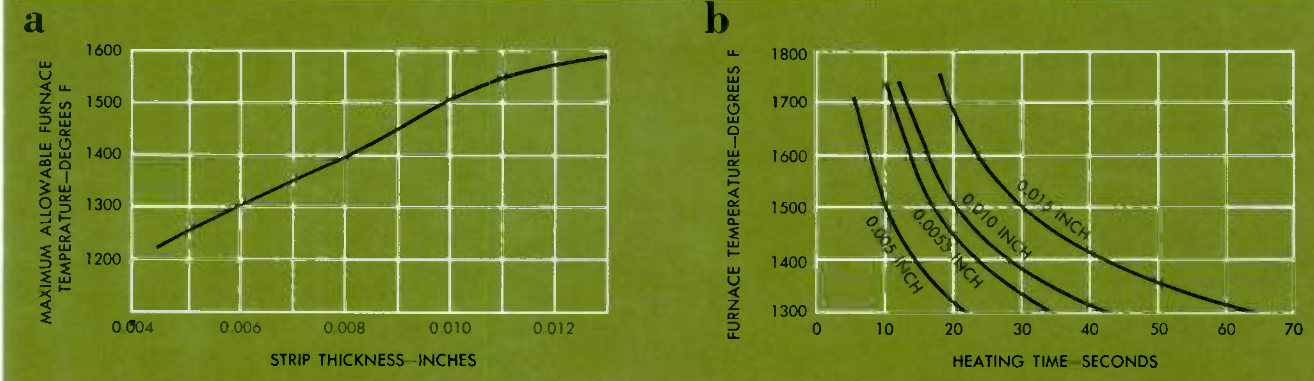
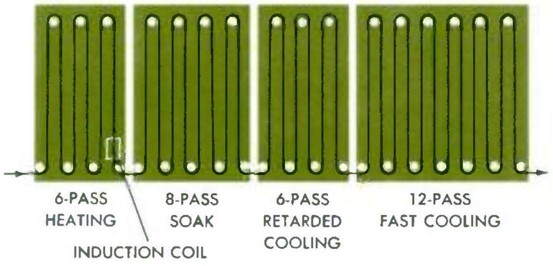


Fig. 3—These are typical furnace operating conditions used as the base for comparison studies of annealing systems employing furnace heating only and those employing furnace heating plus induction heating. (a) Maximum furnace temperatures that can be used with various steel strip thicknesses. (b) Time required to heat steel strip to 1250 degrees F with various furnace temperatures. An average strip emissivity of 0.3 is assumed.



Strip Size (in.)	Furnace Temperature (°F)	Furnace Heating Only		Furnace Plus Induction Heating	
		Strip Speed (ft/min)	Production (tons/hr)	Strip Speed (ft/min)	Production (tons/hr)
0.013 × 32	1600	1000	41.7	1220	51.5
0.010 × 32	1500	1000	32.0	1380	45.3
0.005 × 32	1250	885	14.5	1650	27.0

Fig. 4—A typical annealing system might have 32 passes, as shown here, with each pass requiring about 55 feet. The production of such a system, with furnace heating only and the operating conditions presented in Fig. 3, is tabulated for several strip thicknesses. For comparison, the higher production of the same system with 600 kw of induction heating added to the heating section is tabulated also.

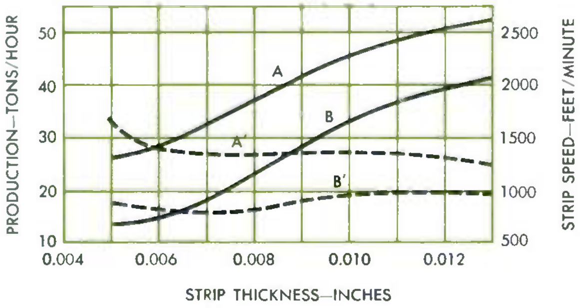


Fig. 5—Production (A) and strip speed (A′) made possible by adding 600 kw of induction heating, shown as functions of strip thickness. Production (B) and strip speed (B′) with furnace only are shown for comparison. The curves are based on Fig. 4 data, with 32-inch strip. The furnace is assumed to have looper storage and to be operated at maximum temperature.

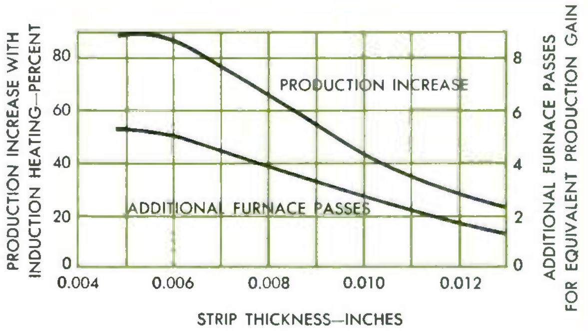


Fig. 6—Production increases (Figs. 4 and 5) are shown as percentages by the upper curve. The lower curve shows the number of furnace passes (each 55 feet long) that would have to be added to give the same production gain as that added by 600 kw of induction heating. The induction coil would be about seven feet long.

and at a strip speed of 1000 feet per minute (fpm). Radiation heats the strip to 1250 degrees F in approximately 16.5 seconds when the overall strip emissivity is 0.3. The final strip temperature would be only about 1140 degrees F, at the same speed and furnace temperature, if the strip emissivity decreased to 0.25.

Of course, small variations in final temperature are corrected by the "soak" section of the furnace (temperature-equalizing section following the heat-up section). However, since it is not a heating section and the strip is moving at relatively high speed, it cannot correct any great error due to emissivity variation. Even if a temperature sensor could follow the changes, the furnace, because of its size and heat storage, cannot instantly regulate the amount of heat to match these changes; its response time is in minutes, whereas the strip passes through in seconds.

If the final heating is done by an induction coil, there is no temperature variation due to emissivity changes. Induction heating generates heat within the strip and is not affected by surface emissivity.

Effects of Speed Changes—The continuous annealing process often is slowed for coil changes. Strip temperature can then increase rapidly over the desired level if the furnace is operating at considerably higher temperature.

For example, if normal operating conditions are 1000-fpm speed with the furnace at 1600 degrees F and the strip being heated to 1250 degrees F, a speed reduction of 500 fpm could permit strip temperature to increase to 1500 degrees F in approximately 10 seconds. With normal tension and thinner gauges, this temperature may be excessive for the strength of the strip. "Heat buckle" and strip breakage may then result. (Heat buckle is defined as a rather severely buckled region of limited width running down the center of the strip. The cause is too much tension for the operating temperature being used, or excessive temperature for the tension that must be used to insure proper tracking of the strip.) If heat buckle is allowed to develop to any extent, it causes strip breakage and sometimes damages rolls in the temper mill following the annealing operation. Furnace temperatures are usually set lower for thinner gauges to prevent heat buckle, but furnace capacity then is not used fully.

If induction heating is used for the final stage of heating, the induction power can be instantly turned down to follow a speed reduction. The line can even be completely stopped without danger of overheating the strip.

Strip-Handling Problems—The strength of any metal decreases rapidly in the annealing range. (Steel at 1400 degrees F is only about 30 percent as strong as it is at 1200 degrees F.) Therefore, a rather delicate balance must be maintained between excessive tension and excessive temperature to prevent heat buckle and breaking. The balance becomes more critical as the strip being handled becomes thinner.

Many of the present strip-handling problems are related to the practice of operating the furnace at temperatures considerably higher than final desired strip temperature to keep production rates up and furnace size down. The use of induction heat in the final annealing stage would eliminate the necessity for operation on a temperature gradient and thus minimize or eliminate the factors that cause heat buckle and strip breakage.

Control Accuracy and Speed—The amount of induction heat applied to a strip can be increased or decreased in fractions of a second. Thus, it can respond immediately to changes in speed, desired final temperature, or any other controlled variable. Such response speed is not possible in a furnace because of high heat storage in the brickwork. In addition, the furnace usually operates at higher temperatures than the final desired temperature of the strip, so control of final temperature is difficult if speed and emissivity are changing.

Also, true strip temperature can be measured more accurately in an induction-heating section since the sighting device is not subject to the effects of surrounding and hotter furnace walls nor to variations in the temperature of electric heating elements or gas-fired radiant tubes. Recent advances in pyrometry have produced devices that can measure temperatures practically independently of variations in emissivity. Thus, suitable sensing devices are available to work with the fast-response regulators used with induction systems.

A control system for high-frequency strip heating is diagrammed in Fig. 2. This system provides direct control of the amount of heat required at a fast enough rate to hold strip temperature constant despite changes in process conditions. Also, operating conditions can be preset with assurance that the desired process results can be obtained and reproduced.

Applying Induction Heating

The relative energy costs of various heating methods are shown in Table II. Induction heating is more expensive than furnace heating, so the most economic way to apply it in high-speed high-tonnage lines is to combine heating methods. The less expensive fuel energy is used for preheating, and induction for final heating. The advantages of induction heating are then realized at reasonable overall energy costs. To show how this could be done, an engineering evaluation has been made on a typical high-speed continuous annealing line used primarily for thin strip.

The furnace operating conditions taken as a base for the study are summarized in Fig. 3. An example will illustrate how the curves were used in the evaluation. Fig. 3a shows the maximum furnace temperature that can be used when annealing various gauges. The heavier the gauge, the higher the allowable furnace temperature. Suppose 0.010-inch strip is to be annealed to approximately 1250 degrees F. Fig. 3a indicates that furnace operating temperature can be approximately 1500 degrees F. From Fig. 3b, the heating time is approximately 20 seconds.

With heating time now determined, the strip speed can be calculated from the effective length of the heating chamber. If, for example, the heating chamber is 330 feet long, the speed would be about 1000 fpm. Production rate for strip 32 inches wide would be 32 tons an hour.

This method was used to determine production rates for various gauges at various furnace operating temperatures. Results of one such study are shown in Fig. 4, with the increases in production made possible by adding 600 kw of induction heat to the heating section.

More complete results of the analysis illustrated in Fig. 4 are summarized in Figs. 5 and 6. Fig. 5 compares the production level possible with induction combined with the furnace and that with the furnace only. Fig. 6 shows the production gains as percentages and clearly indicates that the percentage gains achieved by adding induction heat increase as the gauge decreases. This is because, without induction heating, the furnace temperatures have to be lower to handle the thinner gauges. Fig. 6 also shows the number of additional furnace passes that would be required to give the same production gain that the addition of induction heat gives. The addition of more heating passes would not be desirable because the furnace heating section is already quite long, and strip-handling problems increase with furnace length.

This method can be used to analyze the operation of any size line under any operating conditions. The amount of supplementary induction heating can be greater or less than the 600 kw shown in this example. The analysis can demonstrate the best balance between furnace and induction heat to meet a certain specified range of production requirements with a reasonable economic balance between furnace preheat and induction final heating. The principles apply to both ferrous and nonferrous metals.

Metallurgic Advantages With Thin Steel Strip

A series of tests was performed with 0.010-inch and 0.005-inch steel strip of low-carbon type similar to that used in tin plate. The samples were heated by high-frequency induction to annealing temperatures ranging from 1100 to about 1350 degrees F. After six days of aging at room temperature, they were bent flat on themselves in a direction parallel to rolling and examined for cracks. Although these tests were limited in scope, the general results point to interesting possibilities in production annealing of thin steel strip.

In a typical test, the induction-heating time from 1100 degrees F to 1250 degrees and back down to 1100 degrees was approximately 2½ to 3 seconds. The short cycle time resulted in hardness values of 73 to 75 Rockwell 30-T. By comparison, the time in a radiation-type continuous anneal is 9 to 12 seconds, and these longer cycles (with about the same top temperatures) result in hardness of approximately 63 to 64 Rockwell 30-T. Hardness, of course, is not a complete measure of the manner in which the strip can be applied; high strength and ductility are required in the thin gauges, and the bend tests demonstrated that the induction-annealed strip had these properties.

The most significant part of the cycle probably is in the temperature range starting at 1100 degrees F and the time interval above 1100 and back again to 1100. This is because recrystallization starts at a rapid rate in the region of 1100 degrees F for thin-gauge low-carbon steel that has been highly cold worked, such as that used for tin plate. The relative strength and ductility are related to the total time above 1100 degrees F.

The fast heating rates afforded by induction heating in the range where recrystallization takes place, and the ability to adjust the amounts of heat almost instantly, make possible production of strip in the high strength and ductility required by container forming operations. Such production is not readily achieved with heat transfer by radiation from a continuous furnace.

Very fast heating in the recrystallization range probably minimizes the solubility of carbides throughout the mass so that aging tendencies due to carbide precipitation are not a problem.

An example of a continuous annealing system particularly suited for thin strip is shown in Fig. 7. This system would allow production of high tonnages in the thinner gauges without excessively large furnaces. It also would provide the short cycles that give the stiffer steels required for thin-gauge applications. The advantages of induction heat would be combined with the economy of gas preheat. This example only indicates the possibilities. Other combinations using the same approach can be worked out to meet specific requirements.

Summary

Induction heating is a singularly flexible final heating method because it applies power directly to the strip for fast heating and high response speed. The flow of heat energy is readily adjusted to maintain constant conditions such as final temperature. Thus, it permits design of high-speed lines without excessive furnace lengths. It also provides fast cycle heating to improve metallurgic properties in thin steel strip.

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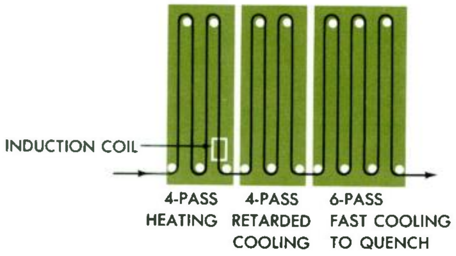


Strip Size (in.)	Furnace Temperature (°F)	Strip Speed (ft/min)	Production (tons/hr)
0.013 × 32	1350	775	32
0.010 × 32	1300	1000	32
0.005 × 32	1300	2000	32

Fig. 7—This proposed continuous annealing system is engineered especially for thin steel strip (though suitable also for thicker strip). It is designed for high production with few passes and a short annealing cycle. The heating section employs gas preheating, with a combination of high-temperature infrared heating and 600 kw of induction heating to bring the strip to final temperature. The line can be stopped without overheating the strip because the furnace temperatures do not exceed annealing temperatures.

New Electrical System Boosts Tin-Plate Production

A modern drive system and high-frequency reflow equipment will soon increase production of tin plate at Weirton Steel Company. The new electrical system is being installed on the No. 2 halogen electrolytic tin line at the company's Weirton, West Virginia, plant. The modernization program is expected to be completed late this year.

In operation, successive coils of steel strip will be welded together in the entry section of the three-section line to form a continuous strip. Plating will take place in the center section, and the finished product will be recoiled on tension reels in the third section.

The redesigned line will have a nominal strip plating speed of 1450 feet per minute with 240 volts applied to the dc driving motors. Each section will run independently, isolated from the others by separate motor-generator sets that total 1650 horsepower. The line will process steel strip ranging in thickness from 0.003 to 0.015 inch and in width from 20 to 40 inches.

After the strip leaves the plating tanks, radio-frequency induction heating coils will fuse the plating into a smooth tight film on the base metal. The coils are energized by an rf generator powered by a three-phase mercury-vapor rectifier system. The rectifier is supplied from a 6900/13 000-volt transformer.

Twelve silicon rectifier banks with integral transformers and saturable reactors connected into full-wave, three-phase, balanced bridge circuits will furnish dc power to 12 plating cells in the two plating tanks. Full-load efficiency is 86 percent.

One synchronous and four induction motor-generator sets, with a total of 21 dc generators, will supply drive power for the line and auxiliary equipment. The synchronous-motor unit with three generators will serve the entry, center, and delivery sections of the line. The induction-motor units will supply the auxiliary drive motors, excitation for the saturable reactors in the rectifiers, and the control circuits.

Trinistor regulators will control the three adjustable-voltage generators supplying the line-drive motors. The fields of all drive motors will be excited from a constant-voltage dc bus so that their speeds can be regulated by controlling armature voltage. ■ ■ ■

230-Kv SF_6 Circuit Breaker Proves Itself at Grand Coulee

A sulfur hexafluoride (SF_6) circuit breaker rated 20 000 mva and 230 kv has been subjected to customer field tests conducted by Bonneville Power Administration and the United States Bureau of Reclamation at Grand Coulee Dam. The tests confirmed the rating of the breaker, established by the Westinghouse High Power Laboratory, and other field tests made on this type of breaker in France and in this country. The breaker was designed and built for Public Utility District No. 2 of Grant County, Washington, for installation in its Wanapum Switchyard.

The tests included line dropping of four different lengths of line, ranging from 72.4 to 351 miles; bus fault interruptions including a high-speed reclosing operation; and several kilometric fault tests with the point of fault located to produce maximum severity of rate of rise of recovery voltage across the breaker contacts.

Two bus fault interrupting tests were made with 17 of the 18 Grand Coulee generators connected to the bus. A current of 46 000 amperes was interrupted in 2.65 cycles. The same current timed to produce maximum duty on the breaker was interrupted in 2.75 cycles on the first opening of an instantaneous reclosing operation. The close-open portion of this operation involved the interruption of 28 200 amperes in 2.5 cycles. The maximum fault duty calculated for the bus faults was 19 000 mva.

The performance of the breaker when interrupting the kilometric faults, which measured between 22 400 and 24 000 amperes and were located less than a mile from the breaker, indicated no sensitivity to rate of rise of recovery voltage. This was true even without use of the capacitance connected to the line side of the breaker for comparison purposes in two of the tests. ■ ■ ■

Inspection Data Collected and Summarized by Computer

Manufacturing inspection reports used for quality and reliability improvement are commonly prepared by collecting and summarizing large amounts of data. The logical tool for such collecting and summarizing is the electronic computer. Unfortunately, many data-processing computer systems for quality-control use have been limited in value because of the bulk of the data presented and the necessity for understanding the code system in which it was presented. The significant facts were there, but they were hard to find and had to be decoded when found.

A new data-processing system designed expressly for inspection data employs a computer *to weed out non-essential information* as well as to collect and summarize information. This limits the size of the final summary report to two report pages for each reporting unit. (A reporting unit can be one inspection station, one department, or an entire plant.) Moreover, the computer prints out the report in numbers and ordinary words, with no coding.

The system was developed and is used at the Westinghouse Aerospace Electrical Division. Most of the products of this division are devices for generating and applying electric power in aircraft and space vehicles, so high quality

Top Left—This tiny radio receiver was developed to demonstrate the feasibility of a high-performance subminiature receiver with all of its major circuits in the form of molecular-electronic functional blocks. The unit is powered by a six-volt battery contained in the box with the on-off switch. It operates in the citizen's band at frequencies from 25 to 30 megacycles, and it has a range of about one mile when operated with a standard "walkie-talkie" transmitter.

The functional blocks used in the receiver are a radio-frequency amplifier, a mixer oscillator, an intermediate-frequency amplifier, and an audio detector amplifier. The receiver was built with Westinghouse funds as an outgrowth of molecular-electronic development work under contract to the Electronic and Manufacturing Technology Laboratories, Aeronautical Systems Division, U. S. Air Force, Wright-Patterson Air Force Base, Ohio.

Lower Left—One of the largest steel-mill stripping cranes ever built has gone into service at the Coatesville, Pennsylvania, electric melt shop of Lukens Steel Company. The 400-ton screw-type crane has a lifting capacity of 150 tons and a rated stripping force of 400 tons. It was built by Alliance Machine Company.

The crane is now being used to strip "big-end-down" ingots. The ingot is held down by a ram, and the mold is broken loose by screw-operated stripping tongs. The mold is then raised by the main hoist, as shown here.

Extractor jaws for stripping "big-end-up" ingots can be added to this crane in the future, if desired. The mold for such an ingot would be held down by the stripping tongs, and the ingot would be gripped and pulled out by screw-operated extractor tongs. When the ingot broke loose from the mold, it would be raised by the main hoist.

The new crane differs from conventional stripper-extractor cranes by being mounted on a 360-degree revolving column and by having hydraulically actuated stripper tongs. It can handle ingots and molds weighing from 10 to 75 tons, and it is capable of lifting simultaneously a 75-ton mold and a 75-ton ingot.

Right—A lower level added recently to the George Washington Bridge by the Port of New York Authority increases the traffic capacity of the structure by 75 percent. Mercury-vapor lighting, consisting of about 500 luminaires, provides the illumination level needed for safe night driving on the new level. The luminaires have 250-watt clear lamps and are attached to the overhead girders in a pattern that prevents glare and shadows. Ballasts are located in remote cabinets at intervals along the bridge.

Two of the upper-level lanes are reversible, and lower-level lanes are opened and closed to adjust the bridge's capacity to the changing traffic conditions at various times of the day. This type of operation is made possible by 131 fluorescent illuminated directional signs controlled from the bridge administration building in New Jersey.

New Literature

THERMOELECTRIC HEAT PUMP APPLICATION DATA, SERIES 54–760, is a collection of data on heat pumps with matching power supplies. The 14 pages of information cover unit selection, construction, application examples, dimensions, characteristic curves, and schematic diagrams. There is also a section on the principle of cooling by the Peltier effect. *Westinghouse Semiconductor Division, Youngwood, Pa.*

DH-P PORCEL-LINE METAL CLAD SWITCHGEAR is an illustrated booklet describing the new line of switchgear in which high-strength porcelain insulates all live parts from ground. Essential parts of the switchgear are color coded and explained in detail. In addition, the booklet presents results of complete unit tests that simulated actual operating conditions. A four-page application data supplement is inserted in the booklet. *Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pa.*

and reliability are of great importance. The summary reports give the division management compact readable material that shows where action is needed to improve quality and reliability and to reduce scrap and rework.

Inspectors and testers prepare a daily report, at each inspection station, showing part numbers, the number of parts inspected, the number rejected, and the reasons for rejection. A quality engineer reviews this data each day to detect potential problems early and also to correct any errors in the reports before they get to the computer.

The data is then punched into cards for the computer, which prepares a list showing the parts inspected and the types of defect found at each station during the time period covered by the listing. The listing is checked for errors by a quality engineer, and a copy is retained for detailed reference material.

The corrected listing is then returned to the computer, which prints out the final summary report. This report does not contain all of the data collected; it is greatly simplified by lumping all of the parts that had few defects into a "miscellaneous" category. Thus, the reader immediately sees the significant facts without having to wade through a mass of data.

Copies of the summary reports are sent to the persons responsible for manufacture, engineering, and quality control of the product line covered by the report. Each copy is accompanied by the quality engineer's written comments on problem areas, recommendations for corrective action, and comments on the progress of programs for improving quality and reliability. The result of the program is systematic elimination of quality problems. ■ ■ ■

Deep-Sea Test Facility Simulates Ocean Pressures

As man ventures farther into alien environments, his requirements for environmental test facilities become increasingly stringent. An example is the new equipment for simulating deep-sea pressures being built at the Westinghouse Defense Center, Baltimore, Maryland. The equipment will be used to test oceanographic research devices and Navy torpedoes.

The new facility includes two steel tanks in which it will be possible to duplicate pressures found at ocean depths of approximately 11 000 feet and 16 000 feet. These pressures are about 5000 and 7000 pounds per square inch (psi), respectively. The tanks will supplement existing facilities capable of simulating pressure at a depth of 2000 feet below the ocean's surface.

The 7000-psi tank is seven inches in diameter and twelve feet long. The 5000-psi tank is two feet in diameter and six and one-half feet long. Both will be mounted vertically in a pit surrounded by reinforced concrete. ■ ■ ■

Products for Industry

VELOCITY-DEVIATION INSTRUMENT permits precise measurement of velocity deviation in any application where the deviation can be converted to low-level sine-wave signals. Typical applications include precise measurement of gear noise, flutter and wow in tape and disc recorders, cyclic frequency variations in pulse generators and oscillators, and disturbances in rotating machinery. The instrument measures either linear or angular velocity deviation with a sensitivity of 0.001 percent through the frequency range of 900 cycles to 50 kilocycles. *Westinghouse Scientific Equipment Department, P.O. Box 868, Pittsburgh 30, Pa.*

COMBINATION SYNCHRONOUS MOTOR STARTER AND STATIC EXCITATION SYSTEM provides magnetic full-voltage starting and also overload and out-of-step protection. The system includes an Ampgard 2500 ac motor starter and a silicon-diode rectifier that eliminates the need for a separate exciter. Motor synchronizing is done automatically by a static Slipsyn control. This unit performs the complex operations of applying motor field excitation at the proper machine speed and the proper rotor and stator angular relationship, detecting out-of-step condition and removing field current, and protecting the rotor damper winding against overheating when operating below synchronous speed. *Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pa.*

PACKAGED HEAT PUMPS AND AIR CONDITIONERS designed expressly for high-rise construction are slender and upright to reduce the amount of floor space required and to facilitate access to components from either side of cabinet. Cooling capacities of the two heat pumps and air conditioners in the new line are 18 000 Btuh and 21 000 Btuh at 95 degrees F outdoor temperature; heating capacities of the two heat pumps are 32 000 and 41 000 Btuh at 20 degrees F outdoor temperature. Cabinet dimensions are 20 inches deep by 31 inches wide by 81 inches high. *Westinghouse Air Conditioning Division, P.O. Box 510, Staunton, Va.*

DISTRIBUTION TRANSFORMER PROTECTION KIT provides conventional distribution transformers with low-cost lightning and overload protection when the more accurate and complete protection of a CSP transformer is not economically justified. The Protecto-Combo kit consists of a lightning arrester (valve or expulsion type) and a dual-element high-voltage fuse. It is bolted externally to any 5- to 50-kva, 7200- or 7620-volt transformer. *Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pa.*

PORTABLE INDUSTRIAL X-RAY UNITS can be used for inspecting light or heavy parts. The Baltograph 200B is rated at 200 kv at 5 ma; the Baltospot 140B (photograph) is rated at 140 kv at 5 ma. Both units consist of an X-ray head and a control panel. Both are made weather resistant for outdoor use. *Westinghouse X-Ray Division, 2519 Wilkens Avenue, Baltimore 3, Md.*

100-KVAR CAPACITORS (Series 13) have the same mounting dimensions as the NEMA standard for a 50-kvar capacitor. The new units are 13½ inches wide and supplement the 20-inch (Series 20) 100-kvar design. Users can now increase the capacity of installations made with 50-kvar capacitors by changing to 100-kvar capacitors. Also, mounting equipment can be designed to take either 50- or 100-kvar units. *Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pa.*

250-AMPERE SILICON CONTROLLED RECTIFIER LINE has forward blocking voltage and peak reverse voltage up to 700 volts. The rms forward current is 400 amperes, and one-cycle surge rating is 5000 amperes peak. This is the highest-power silicon controlled rectifier commercially available. The type 221 was designed for high-power inverters where fast switching is needed. Other uses are motor control, plating supplies, and ignitron replacement. *Westinghouse Semiconductor Division, Youngwood, Pa.*

TYPE FX-372 TAUT-BAND-SUSPENSION INDICATING INSTRUMENTS hold their reading. A solenoid-actuated device moves a steel wire in front of the pointer backward to pin the pointer gently to the dial. The pointer remains there until the solenoid is de-energized, when spring action returns the wire to a neutral position. This makes it possible to read several instruments at once. *Westinghouse Electric Corporation, P.O. Box 868, Pittsburgh 30, Pa.*

About the Authors

R. J. Radus has spent his career developing magnetic devices for a variety of purposes. After earning his BSEE from the University of Pittsburgh in 1951, he spent several months on the Graduate Student Course, then joined the materials engineering department. Here he worked on magnetic amplifiers, and developed a line of transductors for use as instrument transformers in high-voltage dc systems. Later, he joined the director systems department, where he worked on industrial and shipboard reactor control.

In 1956, he rejoined the materials engineering department, and was one of a trio that discovered a unique combination of a permanent magnet and soft magnetic pole pieces and keepers that has a "memory." Later, he discovered a means of controlling this memory electrically, and subsequently helped develop several applications for the controllable permanent magnet.

His contribution to the Capaciformer transformer was the development of the spark-gap protector. While this seems far removed from his usual field of magnetics, as Radus says, "Toward the end of the development, we managed to find a way to make a permanent magnet a necessary part of the system." Thus his career in magnetics was kept intact.

J. J. Astleford last appeared in these columns in 1960, as the author of an article about the then new Unoreg regulator. This time he writes on a different solution to voltage regulation —the zero impedance transformer.

Astleford is a graduate of the University of Alabama, where he earned his BSME in 1956. After attending the Graduate Student Course, he was selected for the Advanced Design Course in early 1957. After completion of this course, he joined the Transformer Division. He is now a design engineer in the Distribution Transformer Division, where he has participated in the design of a variety of distribution transformers and their associated elements. Among these are the subjects of his two articles, and the ER breaker for large CSP distribution transformers.

When **H. W. Lensner** previously appeared in the ENGINEER ("K-Dar Compensator Relaying," July 1959), we mentioned on this page that he was working on a new transistorized carrier relaying scheme. He describes some of the results of this work in this issue.

Lensner joined Westinghouse in 1939, after obtaining his BSEE and MSEE from Case Institute of Technology. His first assignment on the Graduate Student Course was with relay engineering. He liked the work and stayed on with the relay department.

In 1951, Lensner was made a Senior Design Engineer responsible for high-speed relays for transmission-line protection, and for all pilot-channel relaying using wire, power-line carrier, or microwave channels. When power-line carrier equipment was transferred from East Pittsburgh to Newark in 1961, Lensner was given full design responsibility for transistorized carrier equipment and associated apparatus.

G. J. Hay writes about metal processing systems from an extensive background of application engineering experience in that fast-evolving field. He joined Westinghouse on the graduate student course in 1950 and went on to the metal working section of the industrial engineering department (now Metals Province Engineering, Industrial Systems). He is a project engineer, responsible for the application of systems engineering to the design of advanced electrical drives and controls for processing lines used in the steel and nonferrous metals industries.

Hay served in the U.S. Army Air Forces from 1942 to 1946 as a radar and radar-trainer technician and operator. After the war, he attended the University of Wisconsin and earned his BSEE there in 1950.

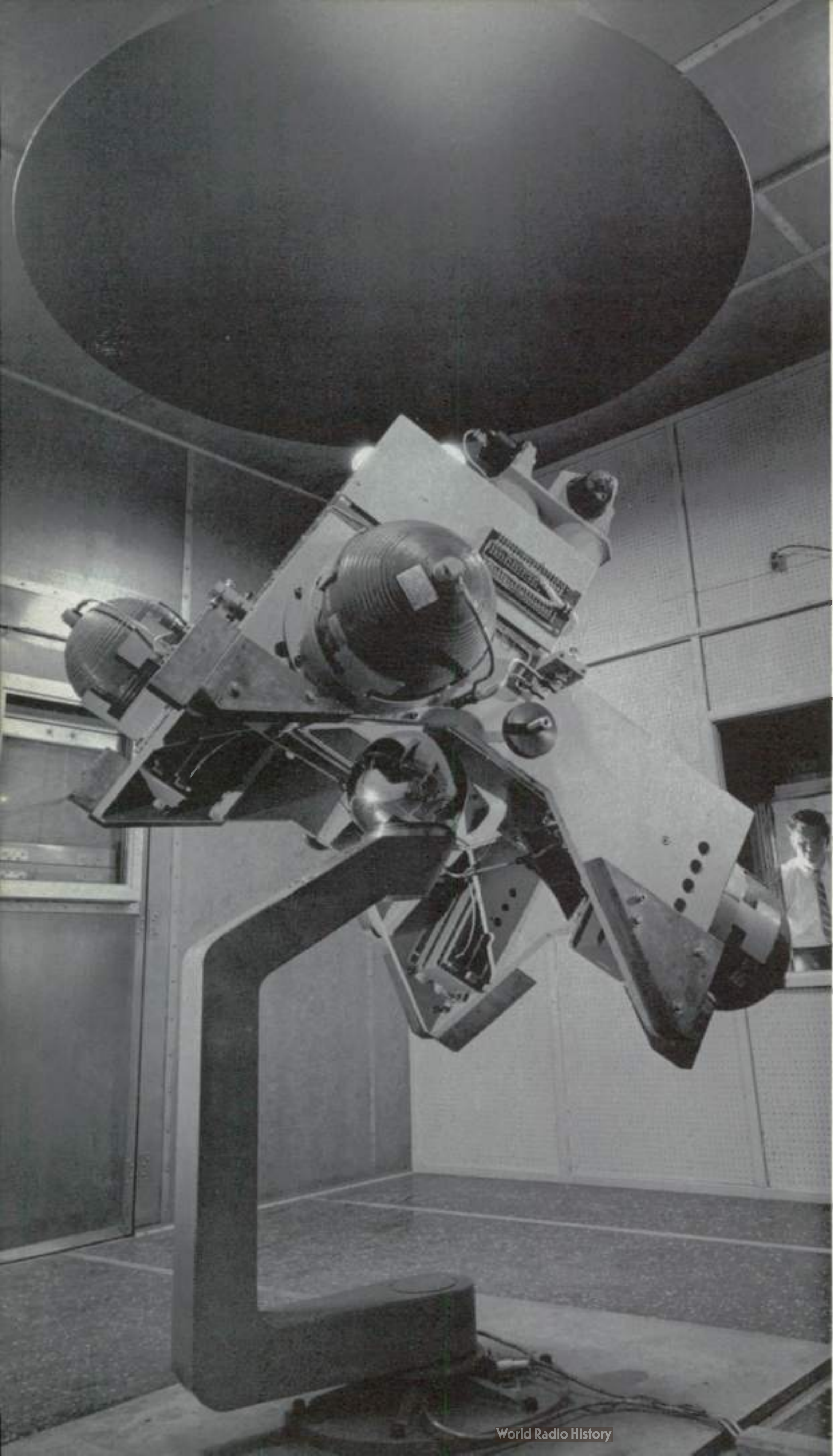
C. E. Peck earned his BS and ME degrees in mechanical engineering at Carnegie Institute of Technology in 1927 and 1931, respectively, and his MS in mechanical engineering at the University of Pittsburgh in 1932. He joined Westinghouse in 1928 and went through the mechanical design school. He then performed development work on large rotating apparatus, especially in heat flow, ventilation, and hydrogen cooling. He became a section engineer in the industrial heating department in 1935 and engineering manager of the department in 1946. When this department became a division in 1955, he continued as an advisory engineer.

Peck moved in 1958 to the metal working section of the industrial engineering department (now Metals Province Engineering, Industrial Systems). He has contributed to development and application of heating processes for the metal-working industries, including continuous processes such as the strip annealing systems that he describes in this issue. He received the Trinks Industrial Heating Award, sponsored by the publication *Industrial Heating*, in 1958 for his contributions in this field.

James A. Rawls, Manager of Engineering and Construction for the Virginia Electric Power Company, joins **J. K. Dillard,** a frequent contributor to these pages, to describe the 500-kv VEPCo system. Dillard also discussed 500-kv, from an economic standpoint, in his last article in the ENGINEER (March 1963).

Rawls is a graduate of the Virginia Polytechnic Institute with a BS in Electrical Engineering (1926). He has been a Registered Professional Engineer in Virginia since 1936. Rawls' activity in electric transmission is evident from his participation in various professional groups: He is a Fellow Member of IEEE, and Vice Chairman of the Transmission and Distribution Committee, and a member of the Standards Committee for this group; he is a Member of CIGRE (International Conference on Large Electric Systems) and U. S. Representative on two of its main committees; and since April 1963, he has been a member of the Federal Power Commission's Transmission and Interconnection Special Technical Committee working on the Federal Power Survey.

Dillard, Manager of the Electric Utility Engineering Department, is an EE graduate of Georgia Tech and has an MS degree from MIT.



Stationary Orbits

New satellite attitude control systems are put in orbit on this satellite motion simulator at the Westinghouse Air Arm Division. The aluminum dish overhead simulates the earth, about which the test table is "orbiting." When the dish is heated to 150 degrees F, satellite control devices are made to believe they are seeing the earth from an altitude of 500 to 1000 miles. The test table is supported by a 12-inch stainless-steel ball bearing, which floats on a cushion of air. Attitude of the table is controlled with brief bursts from small air jets that act like miniature rockets.