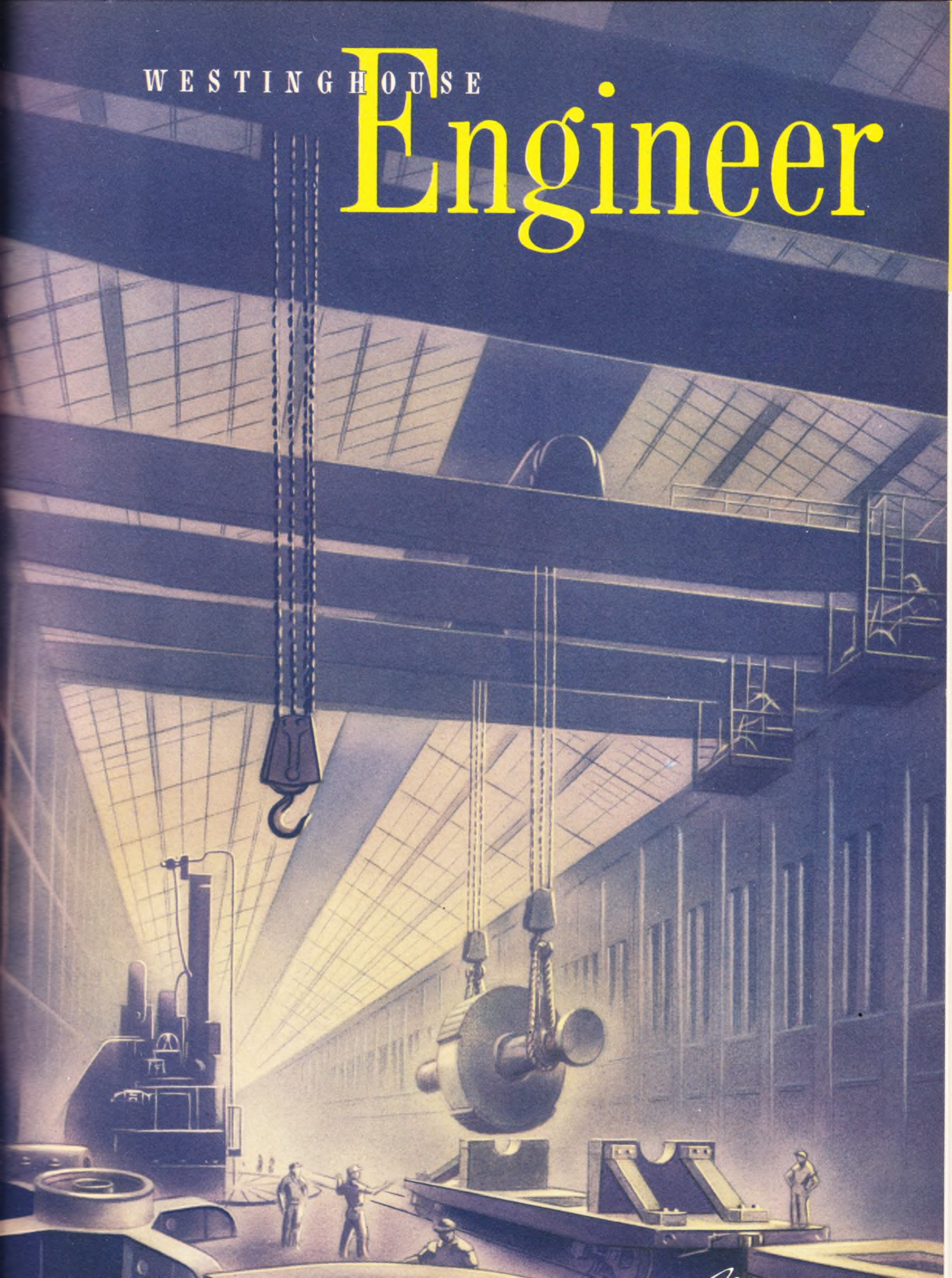
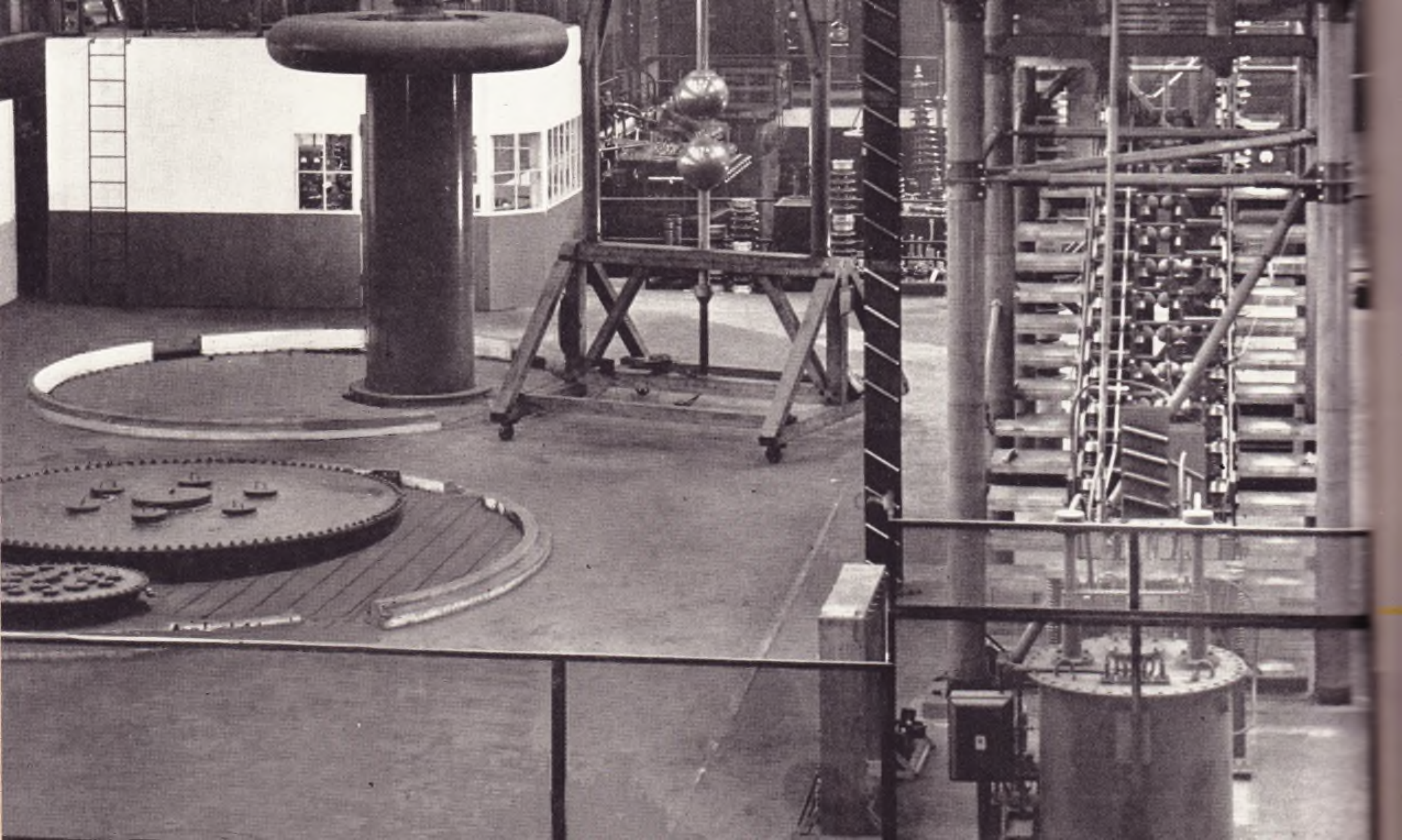
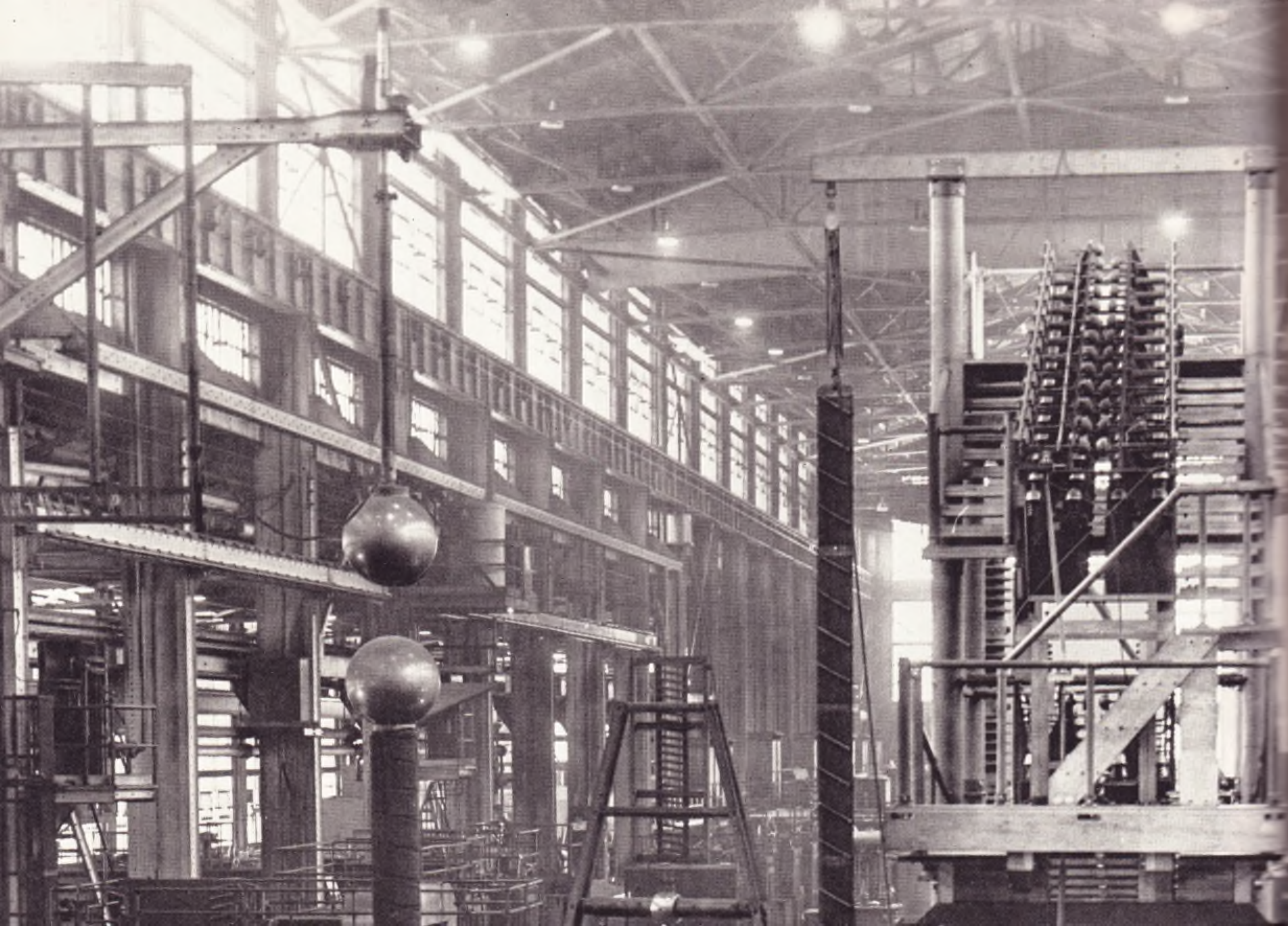
WESTINGHOUSE Engineer







Impulse Testing, a Power-Transformer Routine

The laboratory test of yesterday becomes the routine test of today. Such has been the course of the electrical industry, and one of its great strengths. Although less than 20 years ago the nature of lightning was unknown, the few cautious attempts in the early thirties made to test specimens of high-voltage equipment with relatively feeble man-made surges were followed by more severe impulse tests. Now Westinghouse power transformers receive, as routine, impulses that are equivalent to direct strokes of lightning. Impulse testing of transformers is more than just a means of proving impulse adequacy to designer and user. It is also an instrument of quality control. Mark up another important milestone in transformer history.

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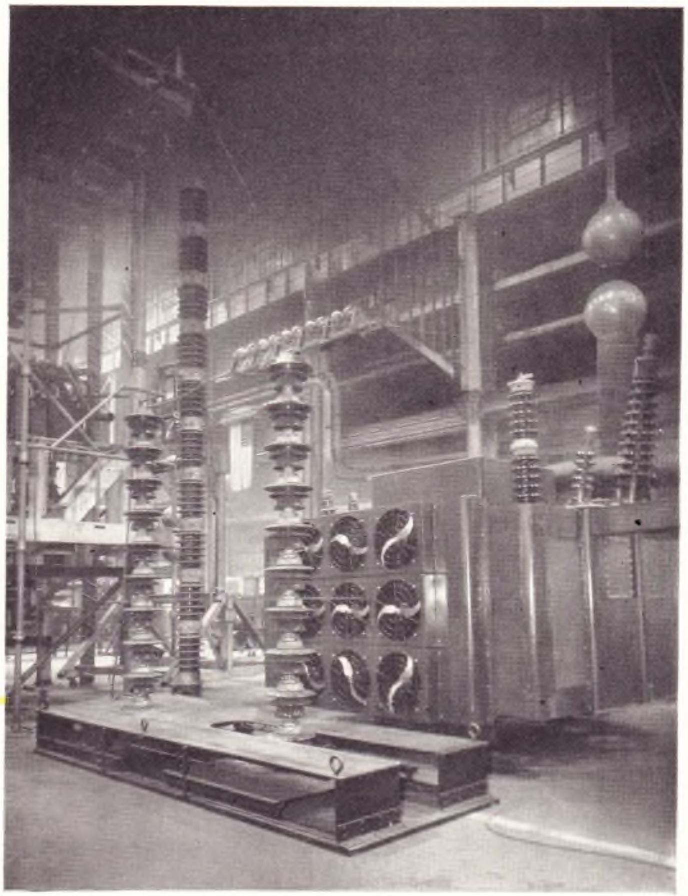
POWER transformers built by Westinghouse now receive an impulse test as a matter of production routine for quality control. This procedure was initiated experimentally on June 1, 1944 and in the first eight months has been applied to a total of 350 000 kva of power transformers. A 3 600 000-volt impulse-generator station has been installed in the production aisle so that power transformers following assembly can be given impulse tests that prove the adequacy of their design and workmanship and determine the ability of the transformers to withstand lightning surges. Because the surge-generator test station is located as part of the assembly floor it is unnecessary to move the transformers to the high-voltage laboratory as heretofore. This greatly shortens the time required to make an impulse test, and permits testing each transformer under cover so that all conditions can be carefully observed. The impulse-generator, built especially for routine impulse testing of power transformers, is designed for rapid operation, with the flexibility required to subject transformers of the various ratings to the impulses appropriate for their voltage classes.

With this procedure applied to power transformers, impulse testing becomes a quality control instead of just a means of satisfying the designer or the user as to impulse strength in the case of selected units. The particular tests prescribed as routine are considered fully as rigorous as any test now applied to power transformers and hence often make unnecessary the special impulse testing sometimes required by purchasers

The quality-control test for power transformers consists of applying to each unit two front-of-wave (i.e., steep-front) impulses followed by two full-wave impulses with normal excitation at power voltage. The steep-front wave used rises at the rate of 1000 kv per microsecond. For a particular transformer under test this wave is allowed to reach the peak voltage specified by the tentative NEMA standard for a unit of that voltage rating. The full-wave impulses correspond, within practical limits, to the crest-voltage levels and 40-microsecond duration set as standard by ASA.

The front-of-wave impulses provide a check of the insulation at the line end of the transformer and in adjacent parts. These steeply rising waves correspond to the effect of direct or almost direct lightning strokes that highly stress the turns nearest the incoming line. These waves, however, do not penetrate throughout the transformer windings. The full wave gives an overall test to the entire winding, inasmuch as the long duration of the wave permits it to check the adequacy of the insulation deep in all parts of the winding. In combination with power excitation the full waves provide an effective method for detecting faults throughout the winding. This combination of impulses adopted as a quality-control test differs from the ASA impulse test in that two steep-front waves of 140 percent of chopped-wave crest value are substituted for two chopped waves of 115 percent of full-wave crest value, and two full-wave impulses are used instead of one.

The front-of-wave and full-wave impulses for power trans-



Something has been added to the power-transformer assembly aisle. It is a three and a half million-volt impulse generator for quality-control testing. The three-stair surge generator is at the right, the control room behind the large spheres, while the transformers on test are usually in the [illegible] beyond. In the view at the right (Fig. 1) is a 42 500-kva transformer being given a quality-control impulse test of its 115-kv insulation.

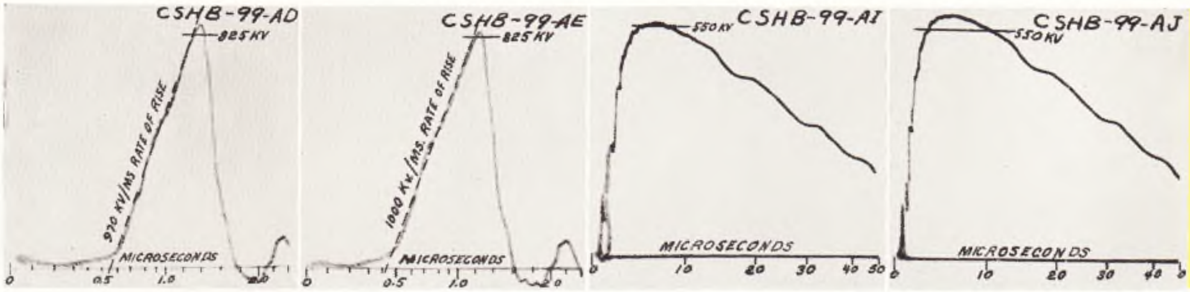


Fig. 2—These oscillograms show the two steep-front and two full-wave impulses applied to the 115-kv transformer shown in Fig. 1, the photo on p. 67.

formers have been chosen on the basis of a large volume of impulse-testing experience. Since 1931 power transformers totaling six million kva have been impulse tested by the Westinghouse Company. Of the power transformers impulse tested from 1939 to 1944, about 80 percent received the ASA test (two chopped waves and one full wave). About 20 percent received, in addition, a front-of-wave test. Of all the faults listed in table I, 19 percent were developed by the front-of-wave test. Sixty-five percent of the faults resulted from the application of the full waves. The remaining 16 percent first appeared on the chopped wave, in part, because the chopped impulses precede the full wave in the ASA test. Had the full-wave test preceded the chopped-wave test, a number of these faults would have developed on the full wave. Furthermore, if the transformers that received the ASA test had in addition the front-of-wave test, experience shows that all the faults would have been accounted for by the front-of-wave and full-wave tests alone. This led to the conclusion that the front-of-wave and full-wave impulses are the two all-important impulses to combine in a quality-control test. The chopped wave adds little or nothing to the adequacy of testing covered by the combination of front-of-wave and full-wave impulses because the steep-front and full waves reveal any fault that the chopped wave alone indicates.

The possibility that impulse testing might itself introduce insulation weakness was considered in the early days of impulse testing. Some believed that impulse testing might constitute more of a hazard than serve a useful purpose, this in spite of the unquestioned acceptance of the long-standard low-frequency dielectric-strength test. Such fears have proved to be groundless. Many transformers have been life tested by subjecting them to groups of about a hundred steep-wave and full-wave tests, each group being followed successively by another of higher voltage. At intervals the transformers were dismantled for examination. In no case did a careful examination of the disassembled transformer disclose a weakness if the many applications of impulses had indicated none. On the other hand, with few exceptions, when failure was indicated by test, the faults were located on disassembly of the transformer. In the few exceptions the faults were minor. In almost all cases where faults were detected by the impulse test, the transformers passed the low-frequency AIEE tests. The life tests have also disclosed that if failure occurs at all it takes place within the first few tests at a given voltage level. Continued impulse testing at that voltage level does not produce failure.

The manner of detecting faults is important in impulse testing. Of the faults referred to in table I, fully 50 percent were indicated on cathode-ray oscillograms. Smoke and bubbles were observed in 90 percent of all faults. The association of smoke and bubbles with faults is likely to be even greater with the new set-up, because these tests were made on transformers outdoors where weather conditions at times did not permit inspection. Records were also taken with the

Fig. 3—This lead-to-lead fault developed on the full-wave impulse. Fusion of the copper resulted from power follow.

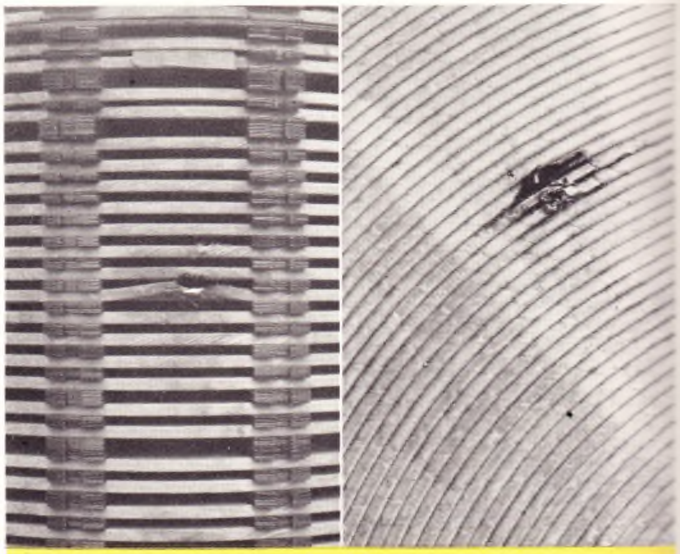


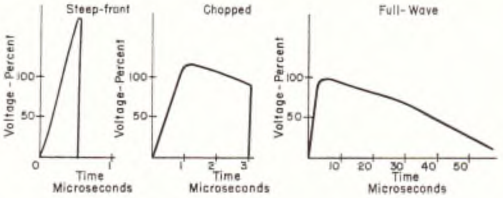
Fig. 4—A coil duct (left) had been damaged when winding and core assembly was lowered into the tank. Fault was detected on full-wave impulse, and also by the disturbance produced from power-follow current. This turn-to-turn insulation failure (right) developed on front-of-wave impulses. Subsequent full-wave tests and power follow developed fault more fully. Failure was detected by smoke and bubbles.

Shapes of Impulse Waves

No single wave shape reproduces all the conditions of surge to which high-voltage apparatus are exposed. If the lightning-produced surge travels some distance along the line before it reaches the transformer, its voltage-time shape may be represented as the full wave in which the voltage builds up to a crest in one or two microseconds and declines gradually, reaching half value in forty or fifty microseconds. Such a wave is defined by the times in microseconds to reach crest value and to decline to one half crest value. Thus a 1.5/40 wave is one reaching crest in 1.5 microseconds and half-crest value in 40 microseconds.

If a severe lightning stroke hits the terminal directly or very close to it electrically, the surge voltage continues to rise steeply until it is relieved by the flashover of an insulator or the discharge of a lightning arrester, causing a sudden, very steep collapse in voltage. This condition is represented by the steep-front wave. The rapid rise and sudden collapse of the surge voltage places a more severe stress on the turns of the winding and insulation at the line end of the transformer than does a full wave.

The chopped wave can be looked upon as the voltage appearing on the line when a full wave is reduced in length by flashing over an insulator once the crest of the wave has been reached. Because of its shorter length it has less penetrating effect than the full wave and therefore develops less stress on the insulation near the center of the winding. It produces less stress on the insulation at the end of the winding than the steep-front wave because of its lower magnitude.



magnetic oscillograph but disclosed so few faults not shown by the cathode-ray oscillograph and by visual inspection that this extra complication is not considered justified in the quality-control test setup. All impulses in the quality-control tests are recorded on cathode-ray oscillograms.

The location of the impulse generator in the shop for quality-control testing received special attention. From the tank assembly and fitting, the transformers are moved to the test floor where each unit receives the ratio, resistance, impedance, iron loss, and temperature tests required. Low-frequency dielectric tests follow the quality-control impulse testing. Thus, the manufacture of power transformers moves uniformly from the beginning of the assembly aisle to the shipping floor.

In designing the impulse generator the aim throughout has been to facilitate production and expedite testing, all in keeping with good practices in testing and safety. To this end, operations of the impulse generator and in the testing have been mechanized wherever feasible. For example, the setting of the series gaps is done automatically through a motor-driven gear mechanism and adjustments are rapidly made from the operating room by suitable remote-control indicator. In this manner the operator can adjust the generated voltage automatically in a few seconds, in fact, during the charging of the generator from one test to the next. The charging equipment is liberally built to charge the generator to full voltage in 15 seconds if required. The discharge operation of the generator is all-automatic. It is synchronized with the cathode-ray oscillograph and is provided with features that insure positive discharge operation. A relay in the operating room enables repetitive applications of impulse voltage in case such be required for life testing.

Considering that power transformers for the larger part are tailormade, one of the problems in the design of the generator proper has been to provide the necessary flexibility suitable for the multiplicity of load and voltage ratings encountered. From experience with the surge-generator at the high-voltage laboratory built for testing of power transform-

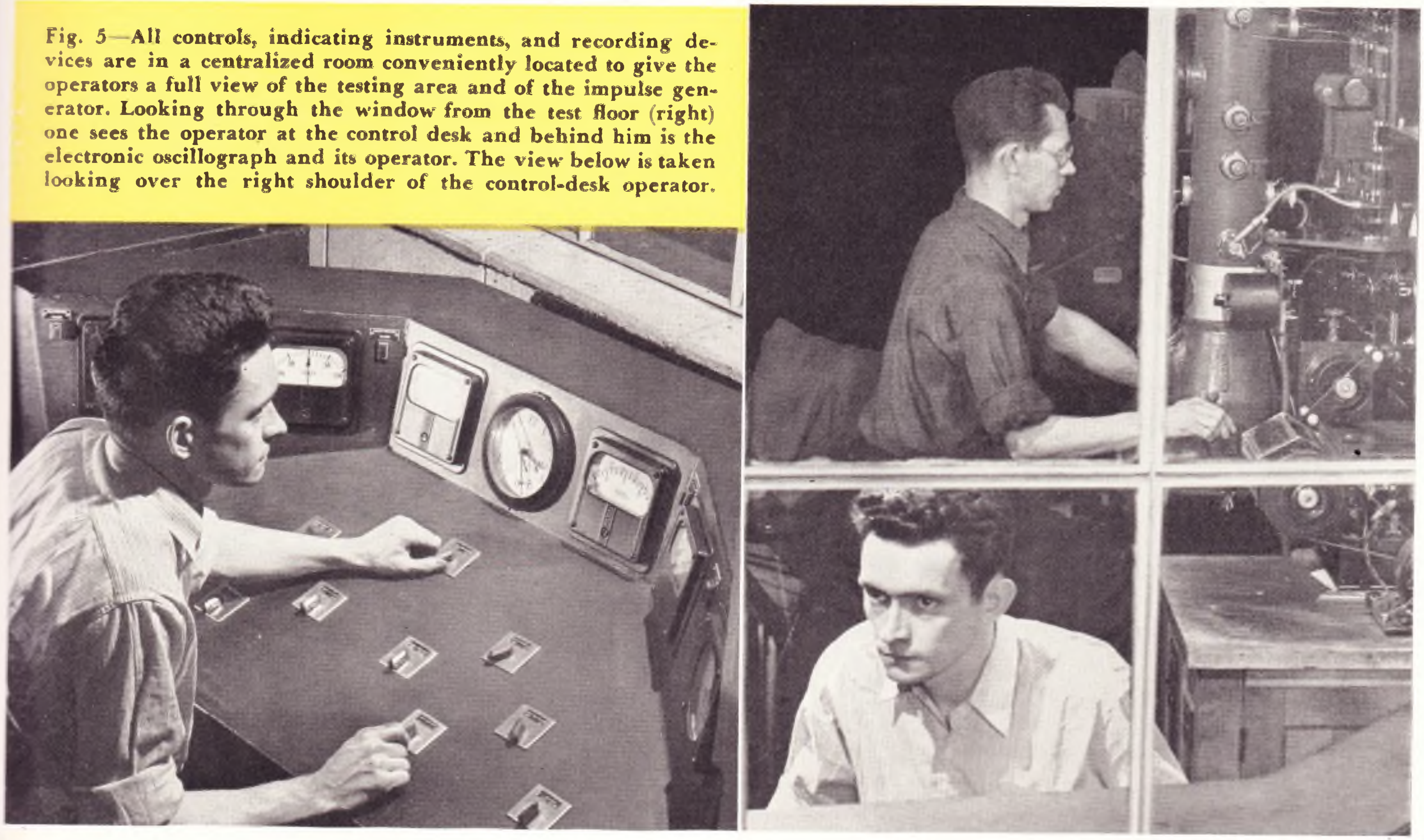
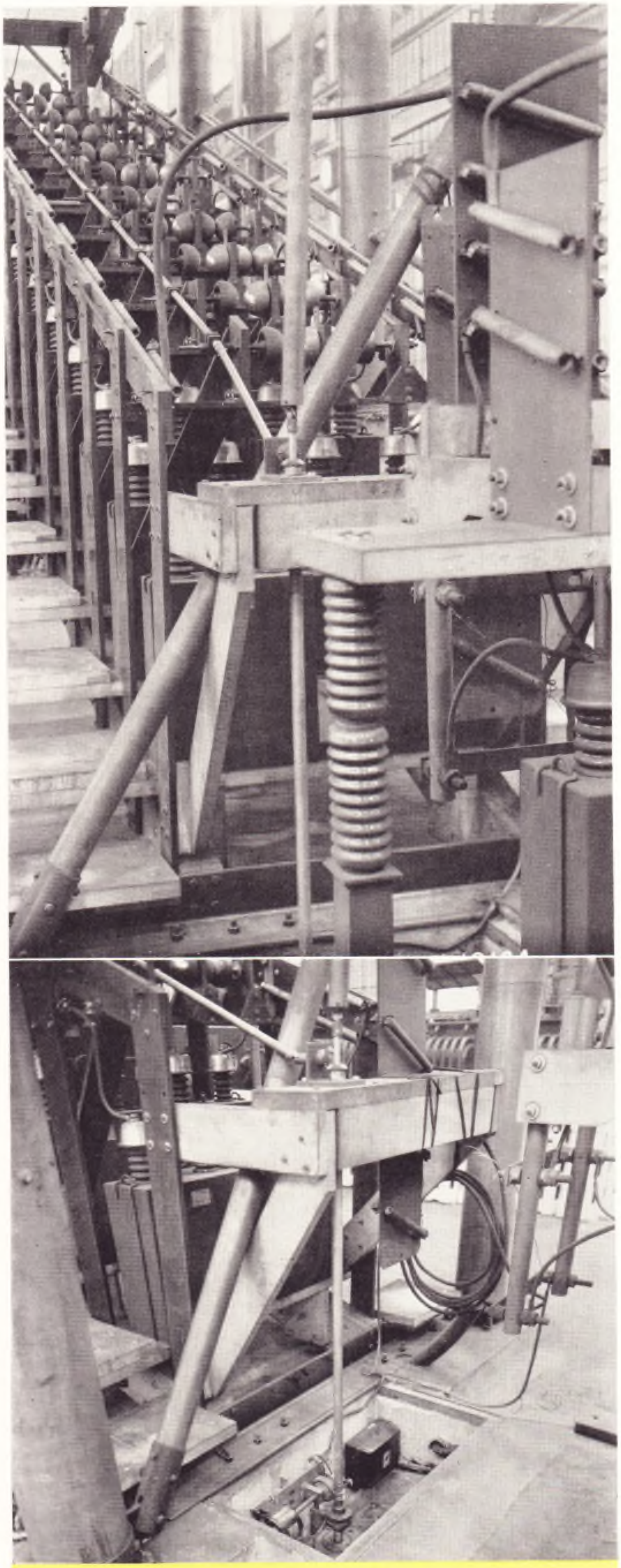


Fig. 5—All controls, indicating instruments, and recording devices are in a centralized room conveniently located to give the operators a full view of the testing area and of the impulse generator. Looking through the window from the test floor (right) one sees the operator at the control desk and behind him is the electronic oscillograph and its operator. The view below is taken looking over the right shoulder of the control-desk operator.



The operator in the control room can adjust the series gaps of the impulse generator by a remote-control handle on his desk. The series gaps of one stair of the three-stair generator and a part of the linkage are shown in the upper view (Fig. 6). The remote-controlled, motor-driven gear for gap setting is at the base of the impulse generator (Fig. 7).

TABLE I—ANALYSIS OF FAILURES IN POWER TRANSFORMERS ON IMPULSE TESTS, 1939 TO 1944

Insulation Failure	Due to Material, Workmanship, Manufacturing or Processing (Percent of Total Failures)	Design Deficiencies (Percent of Total Failures)
Major insulation	3.5	3.5
Leads and bushing terminals	26.4	10.5
Terminal board	1.8	3.5
Static plate	12.3	—
Coil duct	21.1	3.5
Turn-to-turn	—	8.3
Other parts	5.6	—
Total percentage	70.7	29.3

TABLE II—TYPICAL FAULTS IN POWER TRANSFORMERS DETECTED BY IMPULSE TESTING

Insulation Failure	Cause	Insulation Class-Kv	Part of Winding Across Fault—Percent	Reference
Major insulation	Materials	115	100	—
Tap leads	Workmanship	5	25	See Fig. 3
Lead-to-coil	Assembly	15	12.8	—
Static plate	Workmanship	46	100	—
Coil duct	Mechanical damage	69	4	See Fig. 4
Coil duct	Foreign object	115	10.6	—
Turn-to-turn	Design	15	0.87	See Fig. 4

ers, a three-stair design using 12 steps per stair was selected. Each step consists of two ¼-microfarad, 100-kva capacitors. All the steps in series give a generator rating of 3 600 000 volts and a capacitance of 0.0139 microfarad.

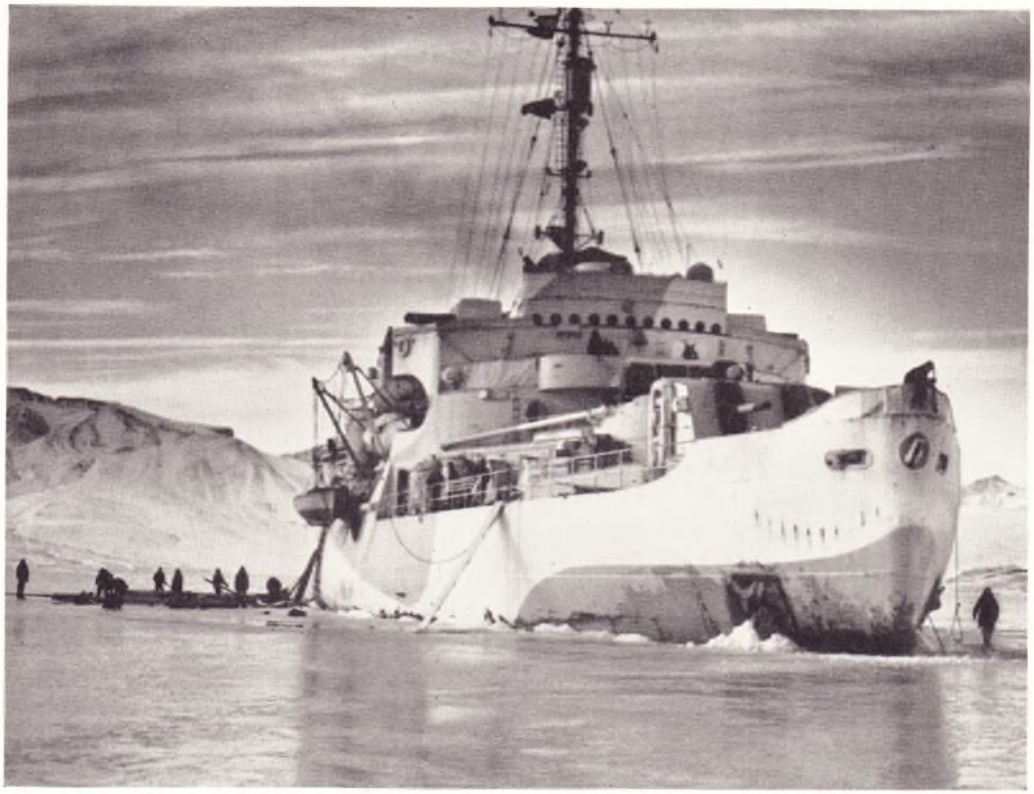
The twelve steps per stair provide flexibility in the combinations of capacitances and voltages. They can be arranged with facility and rapidity and with the number of arrangements available practically all power transformers can be tested. With one generator arrangement all testing is effected automatically. Similar features have been devised to facilitate connecting the transformers for test and other operations. With these facilities the time for testing has been reduced materially—to about one-quarter of the time required formerly.

When impulse testing was first begun in 1931, it was specified as a test of a new type or design of transformer. It served primarily to demonstrate the impulse level and balanced-insulation characteristics of the design. Its merit as an effective tool for controlling the adequacy of the materials, workmanship, and processing in each transformer soon emerged as an important feature of the test. In fact, as the surge-proof transformer design became well established, most failures from impulse testing were found to be more and more confined to details, either in the workmanship or design. This is clearly set forth in table I. Fully 70 percent of the insulation failures have resulted from defects in the materials, in the processing, or in workmanship. Design deficiencies account for the remainder. The bulk of these difficulties required only minor corrections or replacement of the faulted part for the transformer to pass the test. In a few cases design alterations were necessary. Without impulse testing only a few of these defects would have been discovered.

The significance of quality-control impulse testing is set forth even more pointedly from an examination of specific failures. Typical ones are listed in table II and are illustrated in the figures. Each failure naturally was used to stimulate better workmanship and to improve materials, manufacturing, and engineering.

The extension of impulse testing power transformers as a quality control is a logical step. It is effective, economical, and lends itself to production testing. Further experience will show how to simplify and expedite quality-control testing, maintaining at the same time its full effectiveness in assuring power transformers of highest quality.

Modern fighting ships are marvels of engineering ingenuity, to make each vessel supreme for its specialized class of warfare. Not the least of these are the Coast Guard's new ships whose enemy is not men but ice. To meet this worthy foe new, ingenious techniques have been devised, which enable them literally to live up to the corps' motto, "Semper Paratus" meaning "Always Ready."



Semper Paratus—for Ice

In the shadow of Greenland's icy mountains, two Coast Guard ice breakers won the battle of the weather by smashing German weather stations ashore and liquidating their armed-trawler supply vessels. The enemy thus lost sources of invaluable meteorological information pertinent to aviigation and navigation in the European area. One of the factors largely responsible for the success of this operation was the ability of the Coast Guard ships to maneuver through heavy floes and thick ice.

Into the design of these breakers has gone the latest ideas for combating the ice of northern waters. A feature of their construction is a powerful bow propeller that is used to create a turbulence under the ice ahead of the ship. This facilitates crushing the ice in the path of the vessel.

Probably the greatest innovation in ship design is the forced heeling and trimming of the ship to break it free and keep it free of imprisoning ice. This is accomplished by pumping water into tanks located within the double hull of the ship, first on one side and then the other. As water is pumped into the port tanks, the ship lists to port. Pumping the water from port to starboard causes the ship to trim and then list to starboard. Should the bow propeller require aid in breaking through particularly tough ice, there are forward and aft tanks into which water can be pumped alternately to make the ship pitch, first down by the bow and then by the stern.

The vessels are unique for their class in that most machinery and gear aboard are electrically operated. The power is provided by Diesel-powered generating equipment. Normally controlled from the bridge, the ship can be maneuvered from the crow's nest by remote control which enables the breaker to weave through ice floes when visibility from the bridge is impaired.

Because of the rigorous demands made on the ship during ice-breaking operations the electrical rudder control is completely automatic. A Rototrol, familiar to industry as an automatic speed and load control for machinery, balances two rheostats in the pilot and steering compartments, permitting smooth, positive control of the rudder under all conditions.

Photos courtesy U. S. Coast Guard

Overcoming the hazards of Greenland's ice packs, the Coast Guard combat cutter "Eastwind," shown in the upper picture, together with a sister ship, liquidated a German radio-weather station. In the lower photograph, the captured enemy supplies are turned over to the Danish Sled Patrol.

Ship-Propeller Milling with Tracer Control

The machine tool—astoundingly accurate, fast, automatic, repetitive—far surpasses human skills in many ways. But it has still lacked an important one, the ability to produce and reproduce smooth, complex curved surfaces. A new type of electrical control gives to the machine tool a sense of touch by which it can feel the contours of a model and sculpture its exact likeness many times enlarged in metal. The result: ship propellers, dies, engine cylinders—better and faster.

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A sensitive electrical tracer mechanism now enables a milling machine or other machine tool to cut smooth surfaces of any complex curvature. This scheme, the first to act by control of motor speed in conformance to contours of a model, has been first applied to the production of ship propellers.

Methods of finishing ship propellers until recently have been very laborious and time consuming. The excess metal that had to be removed from the rough casting to produce the desired contour was taken away by hand chipping, grinding, and polishing. Because these screws transmit such large amounts of power, they tend to erode rapidly. Erosion and cavitation can be minimized and the efficiency of power transmission increased by the use of smooth, accurately finished propeller blades.

The large size and cost of a machine tool suitable for propeller machining undoubtedly discouraged its early development. The first attempts to produce such a machine were made about 17 years ago by using modified planers and shapers arranged to generate a helix. In 1937, the Morton Manufacturing Company designed and built a special machine for shaping the pressure-face side of propeller blades. This machine generates the helix through the action of pitch gears much like a screw-cutting lathe. However, it is not capable of machining the back or suction-face side of the blade because this surface is not a true helix. Furthermore, it cannot be used on pressure-face sides of blades whose pitch is not constant from hub to tip. These machines thus were limited seriously in their application. The need for a machine that could generate any contour accurately and quickly became very urgent with the rapidly expanding shipbuilding program. In 1940, the Morton Manufacturing Company and the Westinghouse Company undertook the development of such a machine for the United States Navy.

For several years before beginning this development, contour machining had been given very careful consideration. For a long time, duplication of parts from a scale model was accomplished primarily on a type of machine whose feed was done by many engagements of magnetic clutches operating two or more motions that resulted in fine incremental motions or steps. The idea of the new design was to produce a continuous stepless contour by maintaining a predominant feed in one direction and superimposing on this a second component with a motion normal to the first. The resultant of these components is a continuous but infinitely variable feed rate under tracer control.

The general arrangement of the machine is shown in Fig. 1. This is a view of the installation in the Philadelphia Navy Yard. The machine will accommodate propellers up to 24 feet in diameter that have a rough-cast weight of 50 or 60 tons. The propeller is mounted on an arbor to rotate between a substantial headstock and tailstock. The method of mounting and the position relative to the cutting rams are shown in Fig. 2. The bed is 32 feet long, and the rams carrying the cutter heads are 21 feet long. The two cutting heads are arranged to mill both sides of the

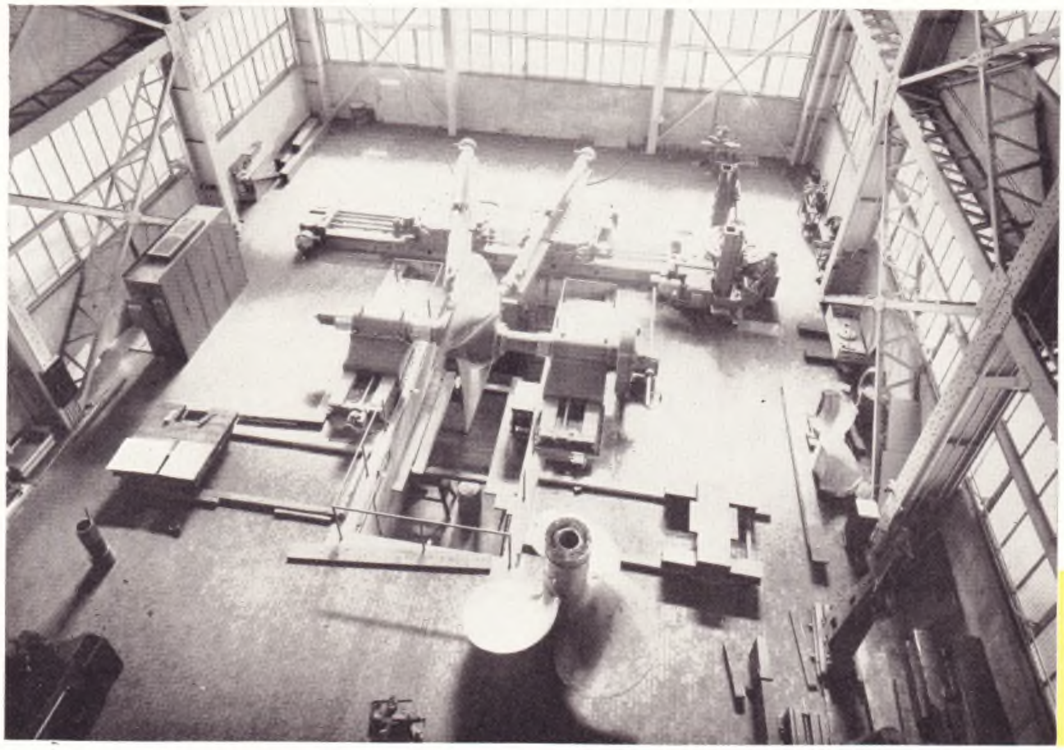

Fig. 1—The propeller being milled is shown in the center of the picture. The model that determines the profile contour is at the upper right.

blade simultaneously which speeds up the machining operation and also equalizes the cutter forces, thus reducing the deflection of the blade. The bed parallels the work arbor. Mounted on the bed and independently movable thereon are two adjustable saddles that support two cutter rams. A close-up of the cutting-head positions is shown in Fig. 3.

Each cutter ram is mounted on a saddle that is moved along the bed by a nut engaging a rotating screw. Each screw has its own driving motor whose speed and direction of rotation are controlled by position regulators developed especially for this application. Because of the close clearances in overlapping propeller blades, the driving motors of the cutter rams are at the end opposite the cutter heads. The rams can be moved preselected increments in the saddle with a motor and a device that measures motor revolutions.

The model table, shown in Fig. 4, is located at one end of the bed and is geared to rotate in synchronism with the work arbor. Two upright columns, each equipped with vertically movable adjustable saddle and ram, form the supporting means for the tracer mechanisms. Each tracer saddle is geared to move in unison with the corresponding cutter saddle but at a lesser rate depending on the work-to-model ratio. The tracer rams are similarly moved at a reduced rate in unison with the cutter rams. The machine is arranged mechanically so that the models may be smaller in any ratio between 2 and 5 to 1, so that these models can always be of a practical size.

To avoid inaccuracies due to backlash and deflection the machine cuts in one direction only. A unique motor-driven mechanism on each saddle moves the saddle in relation to its nut, thus moving the cutter clear of the work during the return stroke, permitting a faster return.

A separate model is used for the two blade faces. A model is made in the proper form for the pressure face and another similar model for the suction face. Both right-hand or left-hand blades can be machined from the same models. The accuracy of the work naturally is dependent upon accurate models.

The arbor on which the propeller is mounted and the model table are coupled mechanically. While their relative position may be changed for indexing the blades, they are always moved as a unit during the machining operation. When the model table is rotated by the work-arbor motor, the movement of the model changes the position of the probes from their neutral or center position, thus causing the saddle-feed motors to rotate in the proper direction, and at the proper speed to bring the tracer probes back to the center position by moving the tracer saddle. Because the cutter saddles are driven by the same motors, they are moved a proportionate amount.

There is a certain maximum rate of acceleration that can be accommodated by the position-regulating system. The work-arbor drive is arranged to provide controlled acceleration and retardation, so that the limitations of the regulator system is not exceeded. The rate of acceleration is controlled by a motor-operated rheostat that is driven by an adjustable-speed d-c motor. This rheostat controls the fields of the work-arbor motor and its associated adjustable-voltage generator. On most machine tools, it is desirable to maintain a certain optimum surface-cutting speed. This speed depends upon the size and shape of the cutter, the material being machined and the geometry of the machine.

The construction of this machine is such that the surface speed of the cutter across the work depends primarily upon two variable factors; the pitch of the blade which may vary from six to thirty feet, and the radius of the cut which may vary from one foot to twelve feet. The work-arbor drive, therefore, must provide an adjustable-speed range in excess of sixty to one.

Because the work-arbor drive provides the primary feed motion, it must be stable at any operating speed over its entire speed range. This means that the speed regulation with changing loads must be practically constant over the entire speed range. The Rototrol-regulated adjustable-speed drive was selected for this motion because it satisfies all of these requirements.

There is a maximum limit to the speed at which the position regulators can follow and maintain the required accuracy of positioning. A speed of 50 inches per minute was set on this machine as the maximum usable feed speed for the cutter saddles. This corresponds to 500 rpm of the saddle-feed motors and is the maximum speed at which the position-regulating system can follow accurately.

During the return stroke, when the cutters are in the relieved position, high accuracy is not necessary. Consequently the saddle-feed motors can operate at their maximum speed of 1000 rpm at this time. To insure that these limits will not be exceeded, a speed-regulating

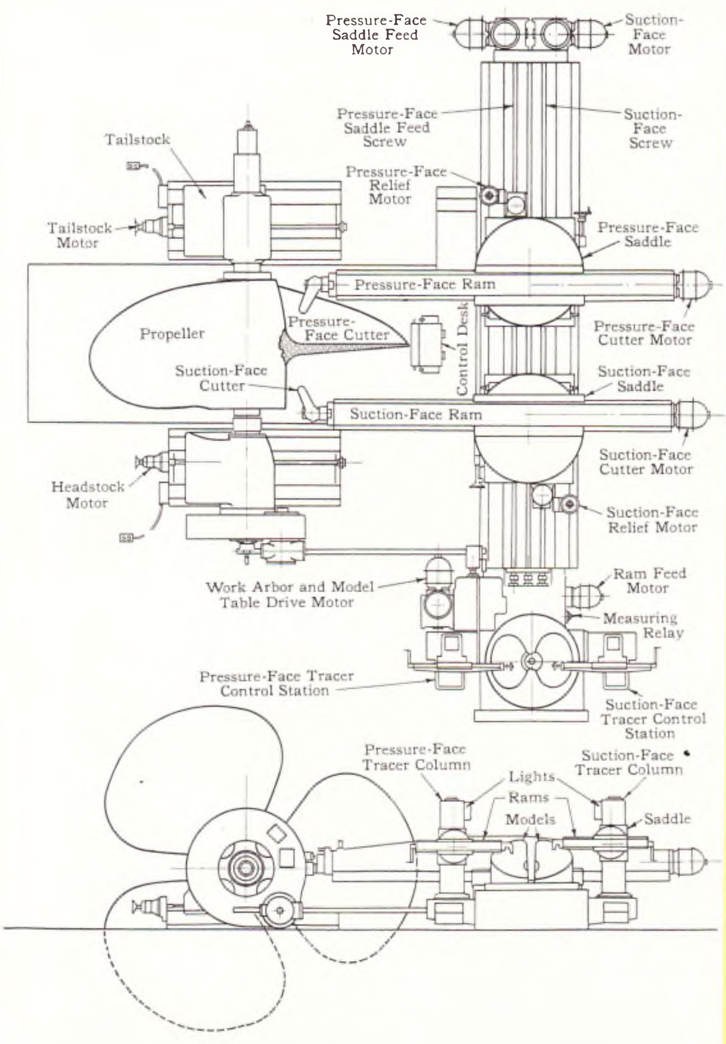

Fig. 2—The relative positions of the components of the propeller profile miller are shown here in the two plan and elevation views.

system is provided for the work-arbor motor. Two voltage relays are connected so as to be responsive to the voltage generated by the saddle-feed generators, and these relays are responsive to the saddle-feed motor speed. These relays are set with a small differential in pick-up voltage, and their contacts are arranged to control the motor-operated rheostat.

When the pick-up voltage of the first relay is reached, the motor-operated rheostat is stopped if it has not already accelerated the work-arbor motor to maximum speed. If the position regulator calls for a greater speed from the saddle-feed motors than that allowed for by the differential setting of the two relays, the second relay will operate, causing the rheostat to decrease the work-arbor speed. The drop-out point of the second relay is naturally higher than that of the first; consequently it will drop out and stop the rheostat before the voltage falls low enough to drop out the first relay.

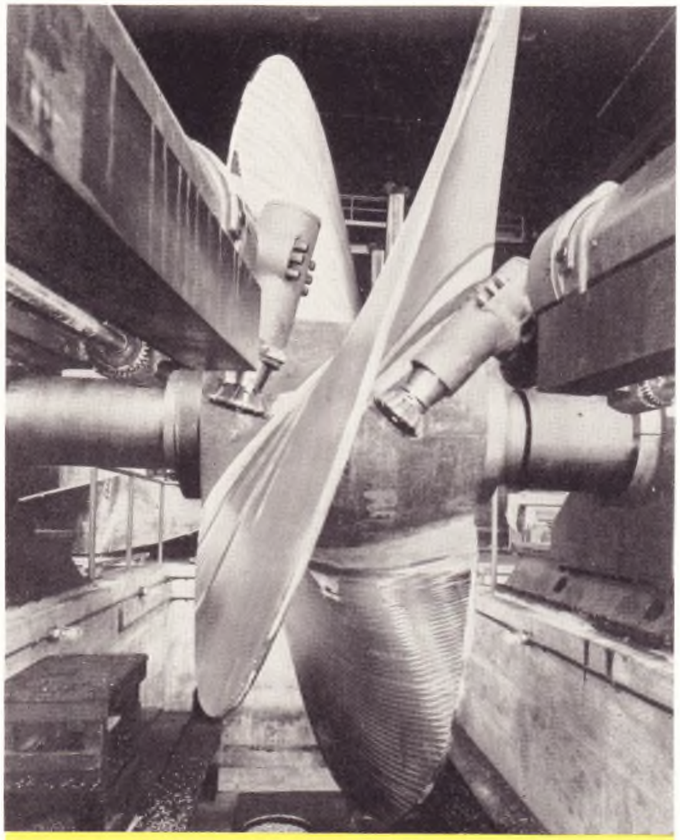

Fig. 3—In this close-up view, the two cutting tools are shown removed from the work, ready for the return stroke.

The pick-up voltage of both of these relays can be set by means of a rheostat that is located on the operator's control desk. The speed of operation of the feeds is set by this rheostat.

Load Control Prevents Overload

The amount of metal to be removed may be much greater in some places than in others and, therefore, the depth of cut may vary considerably. A cutter-load regulating arrangement is therefore provided. This consists of two additional relays similar to those mentioned above but connected so as to be responsive to cutter-motor current. The contacts of these relays control the work-arbor motor rheostat in the same manner as the voltage relays described above. These relays are also provided with calibrating rheostats mounted on the control desk. Through the action of these relays, the work-arbor motor speed is regulated in accordance with the cutter load, slowing down when the deep spots or hard spots are encountered and speeding up again when the cutter load returns to normal.

The regulators limiting saddle speed and the cutter-load regulators provide operating characteristics that protect the machine and cutters automatically, thus relieving the operator from this responsibility while the machining operation is in progress.

The machine is designed for machining one blade at a time. After suitable set-up adjustments have been made the machining operation proceeds in an automatic cycle. When the setting-up operation is completed, the electric circuits are arranged for automatic operation by means of selector switches at the various control stations. This prevents movement of any part by use of the jog button and makes the machine ready for full automatic operation.

The position regulators must be in operation and properly adjusted, the cutter motors must be running, and the relieving mechanism control must be set for automatic operation before the automatic cycle can be started. The automatic cycle is always started in the return direction. Depressing the automatic-return pushbutton starts the work-arbor motor and the motor-operated rheostat. The resistance in the rheostat is gradually cut out and accelerates the motor until it reaches its maximum speed or until one of the tracer-controlled saddle-feed motors reaches its selected maximum speed, at which point the speed regulators take control. The work-arbor motor then continues to operate under control of the speed regulators, and the saddle motors operate under control of the position regulators that follow the surface contours of the scale-model.

As the cutters approach the edge of the blade, the dogs on the model table operate the return-limit switch which starts the motor-operated rheostat in the direction to decrease the speed of the work-arbor motor. When the rheostat reaches its minimum-speed position, the work-arbor motor is stopped. The relief drive motors then move the cutter saddles into cutting position, and the work-arbor motor is started in the opposite direction. This motor is again accelerated by the motor-operated rheostat. There is a separate rheostat on the operator's desk to control the limit of the saddle speed so that a different maximum speed of the saddle may be set for each direction. This permits the operator to set the cutting speed at maximum possible for the cutting conditions present while the return stroke may be made at a much faster rate. The motor-operated rheostat therefore stops when the saddle speed reaches the maximum determined by the setting of the separate control rheostat which limits the saddle speed for the cutting direction. During the remainder of the cutting stroke, the speed of the work-arbor motor is limited both by the speed-limit control and the load-limit control. The positions of the cutter saddles are controlled during the cycle by the position regulators.

When the cutters approach the other edge of the blade, the dogs on the model table operate the limit switch controlling the cut. This starts deceleration of the work-arbor motor through the action of the motor-operated rheostat and again this motor stops when the rheostat reaches the minimum-speed position. The relief-drive motors then move the saddle so the cutters are clear of the work, and the work-arbor motor is again started in the return direction. At this same time the ram-feed motor is started and it operates for a definite number of revolutions as determined by the measuring relay. Thus the rams are moved ahead a definite amount and the cutters will follow in a new path during the next cut across the blade.

The machine will continue to follow this automatic cycle without further attention from the operator except the occasional adjustment of the model-table dogs to make the length of stroke approximately conform to the outline of the blade.

The automatic cycle can be stopped at any time by depressing the stop pushbutton. This causes the relieving mechanisms to move the cutters clear of the work and the work-arbor motor is decelerated just as at the end of a stroke. The work-arbor motor stops when the motor-operated rheostat reaches the minimum-speed position and will not start again until a start pushbutton is depressed. The cutter motors will continue to run and the position regulators will remain in operation.

An emergency-stop pushbutton is provided which is intended for use only in such contingencies as the breaking of a cutter or the like. When this button is depressed, the relieving mechanisms move the cutters away from the work and at the same time quickly stops the work-arbor motor, and both saddle-feed motors by regenerative braking. Also the position regulators are thrown out of operation. To resume operation it is necessary to synchronize the tracers with the cutters again and pick up the cut by adjustment.

Perhaps the most outstanding feature of this machine is the speed and accuracy with which it generates the desired blade contours in conformity with those of the scale models. This feature contributes greatly to the enormous savings in time which are possible with this machine compared with the time required by earlier methods of propeller machining. This superior performance is made possible largely by the use of the tracer-controlled regulators that control the positioning of the two milling cutters. These regulators were designed and built in the Westinghouse Research Laboratories. Two identical position regulators are needed—one being used to control the drive motor for the suction face and the other the drive motor for the pressure face. Each regulator consists chiefly of a standard adjustable-voltage drive with an exciter for the main generator energized by a single-stage direct-current amplifier which derives its positioning stimulus from a Silverstat tracer unit. The unidirectional output of the exciter is applied to the generator field in series with an independent, constant potential to obtain a drive-motor rotation that is continuously variable from a maximum in one direction, through zero, to a maximum in the opposite direction. Each motor drives one of the small saddles carrying the associated tracer unit and also drives one of the large saddles that carries one of the two milling cutters.

As the model table rotates relative to the tracer unit, the tracer probe will be deflected as it traverses the model. This causes a corresponding deflection on the Silverstat tracer and a proportional change in the Silverstat voltage. This voltage change is increased by the amplifier and exciter, and results in a change in generator voltage, which causes the drive motor to move the tracer saddle in the direction that will return the tracer probe and Silverstat to their original positions relative to the saddle. Thus, if the path of the tracer probe across the model contour is rising, the drive motor moves the tracer saddle up to maintain the original relative position of the tracer components. Because this drive motor also drives the cutting saddle, it too will rise proportionally and reproduce the rising contour on the propeller blade.

The tracer unit is illustrated in Fig. 5. It consists essentially of a small Silverstat operated by a double lever system.

These elements together with the Silverstat resistors are compactly assembled within a cylindrical steel case. A probe whose shape conforms to that of the cutting tool is mounted on the tapered nose of the primary lever.

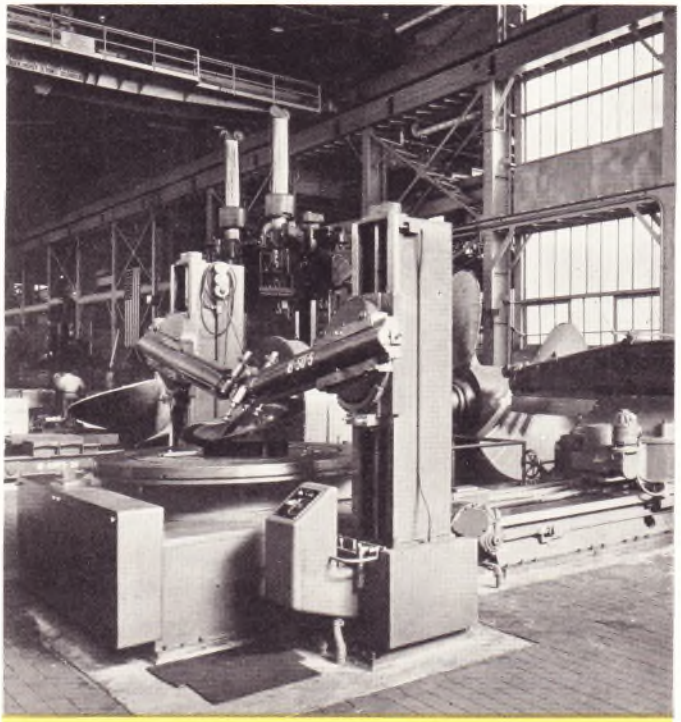

Fig. 4—The models for the two faces of the propeller are mounted on the revolving table. The two probes, shown at the end of the tracer rams, "feel" the contour of the model and the resulting motion is imparted to the cutting tools.

The ratio of the lever system (illustrated in Fig. 6) is adjustable so that the motion of the probe required to produce full Silverstat deflection can be made to correspond approximately to the ratio of the size of the model to that of the propeller being machined. This adjustment in the tracer sensitivity provides means for keeping constant the stiffness of the regulator as the model ratio is changed. In other words, when using a particular size of model the absolute magnitude of the error is independent of the model ratio, and the absolute error of machining a 24-foot propeller is no greater than that in machining a 10-foot one. Since this adjustment affects only the magnitude of the error and does not of itself determine the model ratio, it does not need to be continuous. Accordingly, four positions of the ratio-adjusting pin, corresponding to blade-to-model ratios of 2, 3, 4, and 5, provide a satisfactory wide range of adjustment.

The spring and gravitational forces acting on the levers are

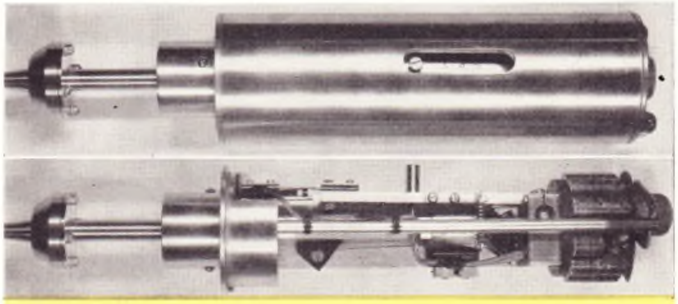

Fig. 5—The upper view shows the tracer unit completely assembled. The figures in the aperture refer to the ratio adjustments possible. The interior of the unit shown beneath discloses the levers and the Silverstat mounting.

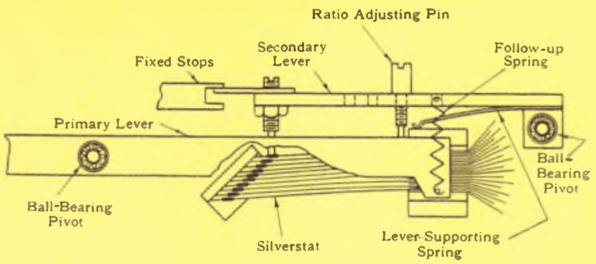

Fig. 6—Relative motions of the primary and secondary levers cause the pin to close one or more of the spring contacts of the Silverstat, shown at the bottom of the sketch.

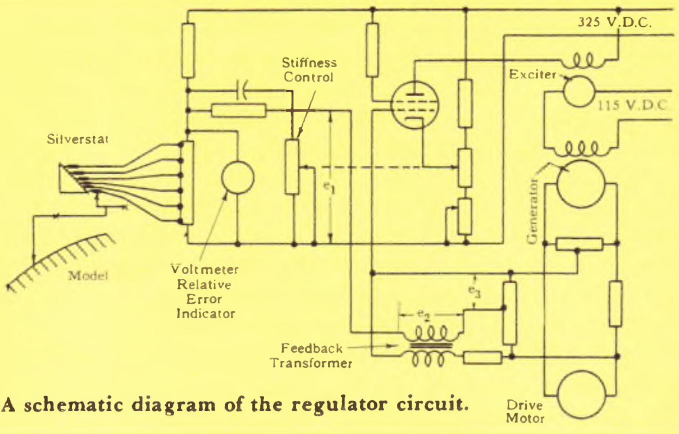

Fig. 7—A schematic diagram of the regulator circuit.

such that the maximum force on the probe need never exceed two pounds. Thus with probes of reasonable weight the force exerted on the model is sufficiently low to permit the use of moderately soft materials, such as wood, for the models.

This device is a position regulator, and as such is more difficult to make both sensitive and stable than the ordinary voltage or speed regulator. Because of time delays inherent in the regulating system, only mediocre accuracy can be realized by applying only the Silverstat positioning stimulus to the amplifier input. The maximum practical stiffness, and hence the accuracy, of such a system is restricted to relatively low values by fundamental design limitations on the ratio of motor-circuit damping to system inertia and also by the time delays that reduce the effective damping of the system. Any attempt to increase the regulator stiffness to improve the accuracy would result in hunting. In this system there are three principal time delays, the exciter field delay, the generator field delay, and the motor and generator armature circuit delay. Consequently, in order to obtain a regulating system with adequate stiffness to insure high accuracy, and at the same time provide sufficient damping to insure rapid decay of free oscillations, it is necessary to introduce strong antihunting influences.

While the basic schematic diagram is shown in Fig. 7, no attempt will be made here to describe the theory of the various antihunting features used.[1] However, the stabilizing features include one that has a stimulus proportional to the rate of change of the quantity being regulated, and when the tracer probe is deflected from its normal position this component of voltage, e_1, appears ahead of the positioning stimulus. Thus a large restoring force is produced which tends to correct for the error before it can attain its maximum value. For this reason this component may be considered as anticipating the positioning voltage, and the circuit producing this component is therefore referred to as an anticipator circuit.

A further stabilizing voltage, e_2, is obtained from the feedback transformer connected into the motor-generator armature circuit. The transformer secondary voltage is proportional to the rate of change of the primary current and hence is proportional to the output acceleration. This voltage is applied to the amplifier input with a polarity such that the torque it produces opposes rapid acceleration of the drive motor. Consequently it is antihunting in its effect.

With the regulator stabilizing devices described so far, it is possible to increase the stiffness to a point where the positioning accuracy at very low speed is quite accurate. However, when the drive motor is running at some constant speed, the steady-state excitation required by the main generator must be produced entirely by the positioning voltage. This means that when the motor is running at top speed the Silverstat must be deflected by the probe far enough from its midposition to produce full excitation of the generator. In other words, a high output speed can be obtained only at the expense of a proportional deviation or error in the tracer-probe position, and at top speed this error may be several times the normal acceleration error.

It is the function of the voltage e_3 to minimize these errors that increase proportionally with speed. Most of the main-generator excitation required to produce the output speed is thus provided by e_3, relieving the Silverstat of the major portion of this duty. By this means, the velocity error is reduced to a small fraction of the value it otherwise would be. The portion of the velocity excitation provided by the Silverstat is just sufficient to insure that the tracer unit retains control of the regulator.

The performance of the propeller-milling machine as a whole is capable of exceeding greatly the specification requirements up to 200 square inches of blade surface milled per hour. This is due both to the inherent cutting capacity of the machine and to the ability of the regulators to maintain a high degree of accuracy at speeds higher than needed. A practical cutting speed for face milling is of the order of 30 inches per minute. At this speed the regulators hold the accuracy to better than ± 0.004 inch at the work. During the high-speed return stroke the velocity reaches 100 inches per minute and the corresponding error is of the order of ± 0.012 inch. As previously mentioned, there is no necessity for maintaining high accuracy during the return stroke so that the latter figure has no particular significance in the operation of the machine. It is indicative, however, of the capabilities of the regulators.

The rates of acceleration and deceleration at the ends of the strokes are limited to values of the order of 10 inches per minute per second, and during these intervals the error is held to approximately ±0.007 inch which is well within the specification requirement of ± 0.020 inch.

The machine has been in successful operation for a period of almost two years and has greatly increased the production of ship propellers and at the same time produced them with an accuracy never before attained.

While both the machine and the regulating system were designed especially for the milling of ship propellers, the fundamental principles involved in the tracer mechanism are quite general and are finding useful applications in a wide variety of regulator and servo problems.

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[1] The details of this system are described in an A.I.E.E. paper entitled, "Tracer Controlled Position Regulator for Propeller Milling Machine" by Mr. C. R. Hanna, W. O. Osbon, and R. A. Hartley of the Westinghouse Research Laboratories.

An A-C Crane Hoist with Reactor Control

The availability and simplicity of alternating current as a power supply are powerful stimuli for the development of an a-c crane-hoist drive with good performance. Engineers have long abhorred unbalanced voltages but have found in them a means of providing control of speed of wound-rotor induction motors over a wide range as is required for crane service. A scheme of control, using reactors, makes effective use of this principle.

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Control Engineer

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The basic requirements of a crane-hoist drive are sixfold. It must: (1) hoist all normal loads at a low, medium or high speed, (2) hoist very light loads at reduced as well as high speed, (3) lower all loads at a slow, medium or high speed, (4) provide a "creeping" speed through the normal range of loading for careful spotting of critical loads, (5) lower non-overhauling light hook at both low and high speeds, and (6) keep the motor current as low as possible to reduce motor heating throughout all operations. Several types of a-c hoist drives have been used but each has in general been able to meet only some combination of four of these requirements. A system of controlling the speed of wound-rotor induction motors by applying variable unbalanced voltages to the primary under the automatic control of reactors meets these six requirements to a high degree. The scheme has to do with the manner of varying the unbalanced voltages and does not require special design of the hoist motors.

Unbalanced voltages of the three-phase supply to a wound-rotor induction motor, normally considered an undesirable situation, do offer the possibility of obtaining a considerable range of speed from the motor. The more the unbalance, the less the torque developed by the motor. This means that when a wound-rotor motor on a crane or hoist is lowering a load, i.e., supplying a braking effect by running overhauling, various amounts of counter torque are available for that load and desired lowering speed.

In the new a-c crane-control system the unbalance is created by placing a reactor in one of the three-phase supply lines. The amount of unbalance is varied by changing the amounts of the reactance introduced by the reactor into the supply circuit. If the reactance is made low the amount of unbalance is negligible so that normal three-phase operation is obtained, representing a condition of maximum torque. The higher the reactance, the more the unbalance, i.e., the closer the approach to single-phase operation, or minimum torque.

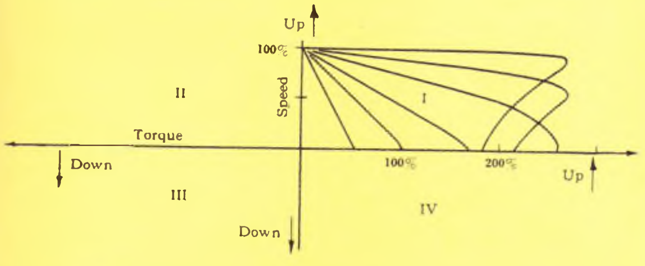


Fig. 1—Speed-torque axes with quadrants identified and hoisting curves for the hoist type of wound-rotor motor.

The amount of reactance is made continuously variable by the use of a saturable-core reactor in which the d-c excitation is proportional to motor speed in the lowering direction. A static-type detector translates the speed into a proportional voltage for control of the reactor excitation. The reactor-produced unbalanced-voltage system is used while loads are being hoisted. It is used to provide a creeping-upward speed, otherwise the unbalanced-voltage control has no part in the hoisting operation.

For evaluating a crane-hoist drive, speed-torque curves as shown in Fig. 1 are helpful. When hoisting, "up torque" and "up speed" are required. Both "up torque" and "down torque" with "down speed" are required when lowering. Performance in quadrants I, III and IV must be considered.

The first five desirable characteristics are graphically presented in Fig. 2. The shaded areas indicate the portions of the graph that must be covered by the speed-torque curves. For example when areas *A*-1, *A*-2, and *A*-3 are amply covered, all normal loads can be hoisted at slow, medium, and high speeds. Similarly area *B* must be covered to hoist a light hook at slow speed; areas *C*-1, *C*-2 and *C*-3 for lowering of normal loads; area *D* for lowering of all loads at creeping speed, and areas *E*-1 and *E*-2 for lowering a light hook.

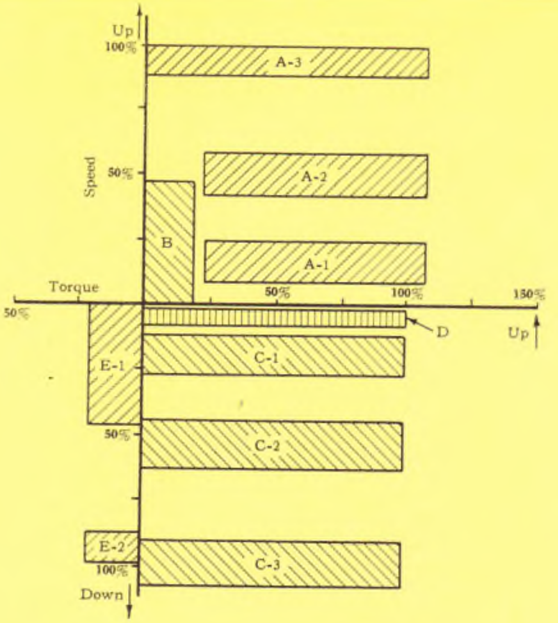


Fig. 2—Speed-torque plot designating the desirable performance characteristics of a successful crane-hoist control.

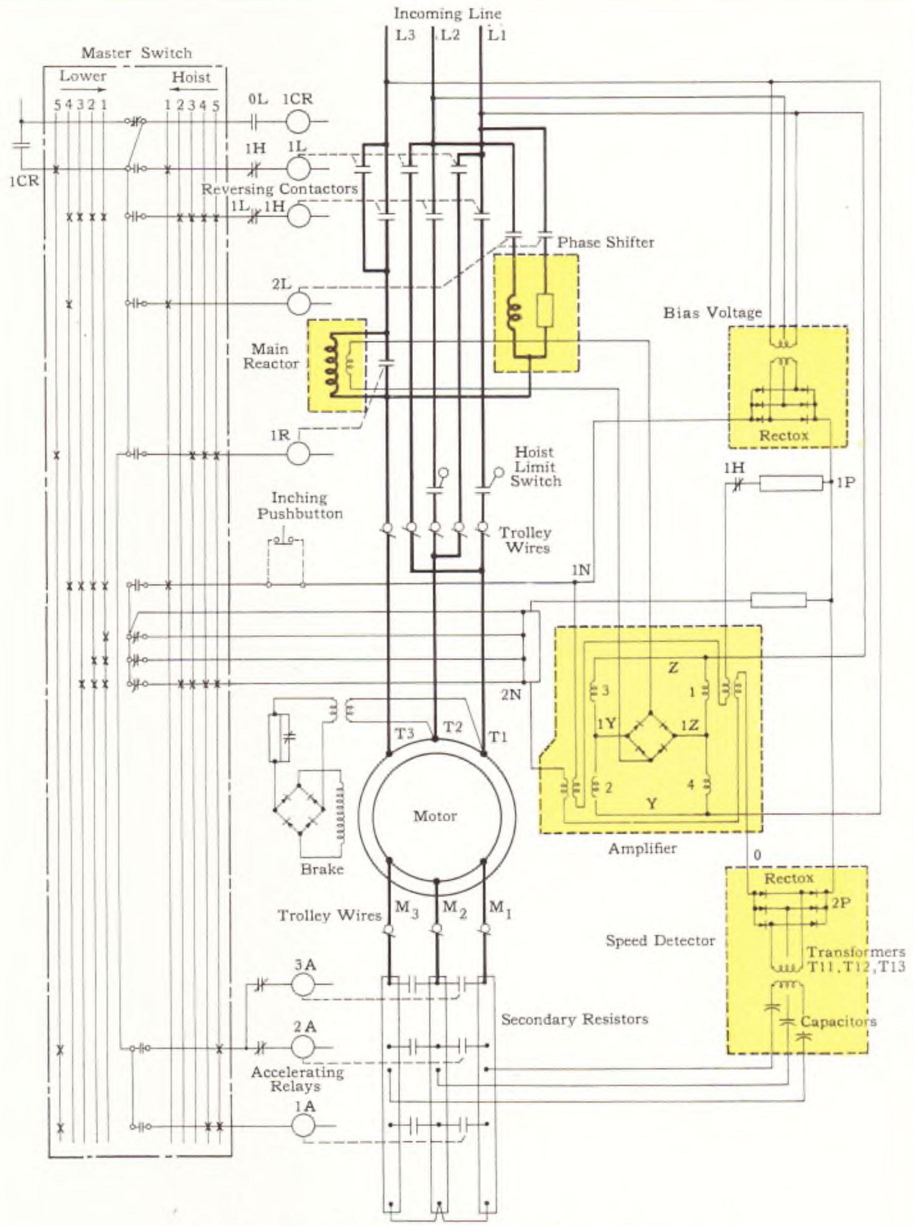


Fig. 3—Schematic wiring diagram of reactor control.

In the following discussion of the components of the reactor control and their operation, all references will be to Fig. 3 unless some other figure is specifically mentioned.

Main Reactor—The main reactor, by introducing a variable reactance in the motor primary in effect varies the motor performance from that of normal three-phase operation at high speed to that of single-phase, zero-speed operation.[1] This variable-impedance saturable reactor[2], Figs. 4 and 5, has two iron cores. The a-c coils on each core are connected so that the magnetic flux in each is always equal in magnitude, but of opposite polarity. The d-c coil is wound so as to enclose both cores, but because the a-c fluxes in the two cores are always in opposition, the net a-c flux linking the d-c coils is zero, and no a-c voltage is generated in the d-c coils.

The ratio of maximum to minimum impedance obtainable by variation of the d-c excitation is 55 to 1, which is a measure of the ability of the reactor to cause voltage unbalance. In combination with the motor, maximum impedance of the reactor produces vector voltages on the motor windings as shown in Fig. 6. In effect, single-phase voltage is applied across windings *T*1 to *T*2, and no appreciable voltage is applied to the winding, *Y* to *T*3. At minimum impedance, and with a motor-rotor resistance that provides 125-percent current at stall with balanced full voltage on the primary, the drop across the reactor is about 23 percent of line voltage. The resulting unbalanced three-phase voltage on the motor windings is shown in Fig. 7. The current through the reactor varies from about 5 percent of full-load motor current at maximum impedance (0.17 ampere per horsepower at 220 volts), to 85 percent at the condition of minimum impedance[3].

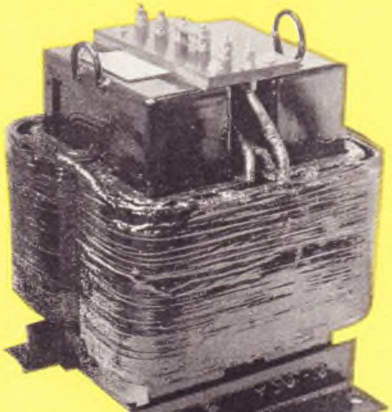
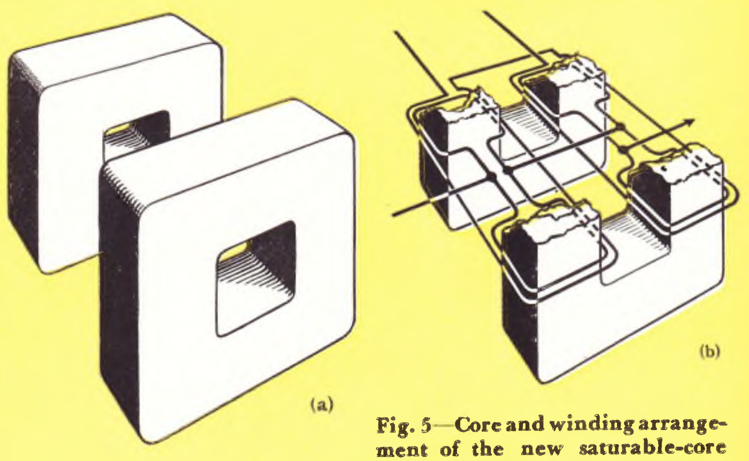


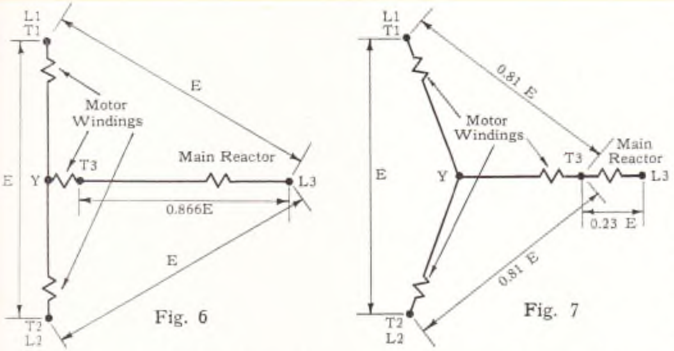
Fig. 4—This improved saturable-core reactor has twin cores wound as shown in Fig. 5.



(a)

(b)

Fig. 5—Core and winding arrangement of the new saturable-core reactor in Fig. 4 is shown here.



Figs. 6 & 7—Vector voltages on motor windings with maximum and minimum impedance on the main reactor.

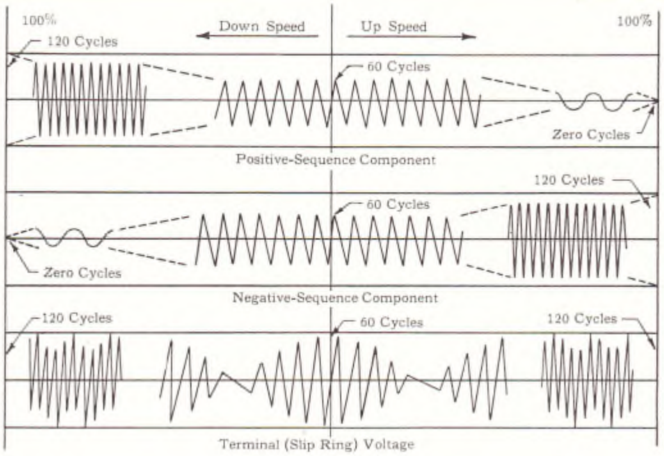


Fig. 8—Components of motor-secondary voltage → with 60 cycles applied to the primary windings.

Speed Detector—To excite the main reactor in response to speed, the excitation must be controlled by an electrical quantity that varies with the speed. The speed responsive electrical quantity is a voltage taken from the motor secondary circuit, through capacitors, transformers *T*11, *T*12, *T*13, and a three-phase rectifier, all of which are referred to as the "speed detector." The secondary voltage has two components that increase with speed, one resulting from increased slip and one from decreasing unbalance in the motor voltage. The effect of the latter must be minimized if approximate speed indication is to be secured. The capacitors and the highly saturated transformers (*T*11, *T*12, *T*13) serve this purpose by amplifying the slip component. As shown by Fig. 8, the frequency of the slip-ring voltage increases in accordance with the positive-sequence component of the power system (60 cycles) at zero speed, to twice the line frequency (120 cycles) at synchronous speed in down direction. The voltage drop across the capacitors decreases with increased frequency, hence amplifying the increase in voltage applied to the transformers. The output of the saturated transformers consists of "peaks." These peaks increase in number and amplitude with increase in the frequency of the voltage applied to the transformers. The result is an output voltage from transformers *T*11, *T*12, and *T*13 consisting of a multitude of "peaks" that vary in amplitude and frequency with the speed of the motor. When this is rectified by copper-oxide rectifiers the d-c voltage between 2*P* and *O* increases in proportion to motor speed.

The character of the modulations in one phase of the secondary voltage is shown in Fig. 8, which also indicates how the positive- and negative-sequence components combine to produce the modulations. The modulations in the three phases are displaced 120 degrees with respect to each other, so that the pulsing in that direct current between 2*P* and *O* is greatly reduced from that indicated by the slip-ring voltage in this figure.

Bias System—As explained, the potential at 2*P* rises with respect to 1*N* with increased lowering speed. However, the voltage at 2*P* at zero speed is about 50 percent of the maximum voltage attained at the highest speeds. Reactor excitation at zero speed should be zero, therefore whatever voltage is present at 2*P* at zero speed must be balanced out. The three-phase bias voltage transformer and associated rectifier produce a voltage 1*N*-1*P* to balance that existing at 1*N*-2*P* at zero speed, and thus prevent current through the d-c coils 2*N*-*O* of the amplifier reactor. Because current cannot flow backwards through a rectifier, a bypass or loading resistor between 1*P* and 1*N* must be provided, so that current can flow through the amplifier coils 2*N*-*O* when the voltage *O*-2*P* exceeds voltage 1*N*-1*P*.

Amplifier—The amplifier has no rotating parts and uses no electronic tubes. It is a system of four reactors connected in a

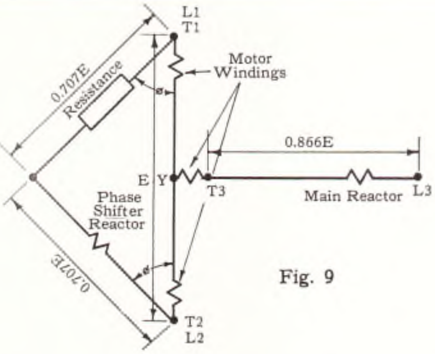


Fig. 9

Fig. 9—Independent vector voltages of induction-motor windings and the phase displacer.

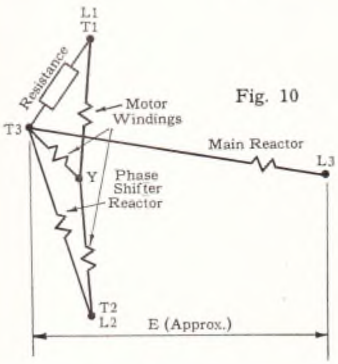


Fig. 10

Fig. 10—Vector voltages on motor windings with phase displacer connected and minimum impedance of the reactor.

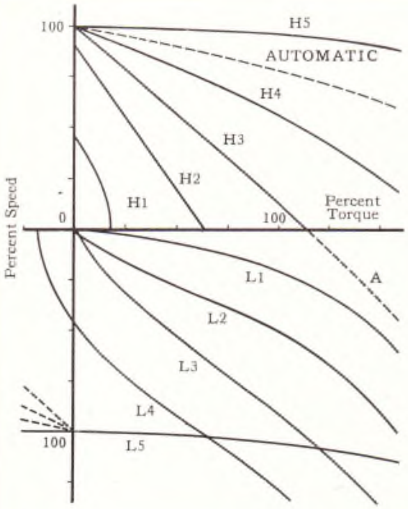


Fig. 11—Each of the numbered curves represents a running point on the master switch. The letters *H* and *L* represent master-switch points on the "hoist" and "lower" side respectively and the points are numbered consecutively both ways from the "off" or center position.

Wheatstone-bridge arrangement. The reactors have equal impedance when not excited by direct current, so that with full potential from Z to Y, potential from $1Z$ to $1Y$ is zero. Direct current from the detector applied to coils $2N$-O reduces the impedance of reactors 1 and 2 in the amplifier. This upsets the balance of the bridge and produces a potential between $1Z$ and $1Y$ that is rectified and the d-c voltage fed to the exciting coil of the main reactor.

Phase Shifter—With the counter-clockwise rotation of vectors, the phase sequence is $T1$, $T3$, $T2$, which produces hoisting torque. The purpose of the phase shifter is to produce clockwise phase sequence (lowering torque), with highly unbalanced voltage and corresponding low motor torque. The reactor and resistor of the phase shifter are designed to assume a vector relation of their own accord approximately as shown in Fig. 9, where the drop across each is about 70 percent of the applied voltage and the phase angles (ϕ) about 45 degrees. When the junction between the two is connected to $T3$, each is paralleled by motor windings, with the result that the phase displacement of the reactor and resistor voltages is greatly reduced. This relationship is shown in Fig. 10.

With the phase shifter disconnected, $T3$ lies within the line-voltage triangle $L1$, $L2$, $L3$. With the phase shifter connected, $T3$ lies outside the line-voltage triangle and the phase sequence is reversed, that is, it is $T1$, $T2$, $T3$. Reduction of the impedance of the main reactor with increase in speed moves $T3$ within the line-voltage triangle and thus reverses the phase sequence without resorting to reversing contactors.

The Secondary Resistor for the motor secondary produces a minimum torque of 100 percent at zero speed when all of it is in the circuit and the primary voltage is normal and balanced. Taps are provided that permit the torque at zero speed to be increased to not more than 125 percent.

Controller Operation—The controller shown in the diagram is the full-magnetic type. However, the reactor system functions equally well with manual or semi-magnetic controllers.

Controller point number 1 in the hoist direction closes contactors $1L$ and $2L$ to provide low hoisting torque and low speed at no load.

Number 2 controller point opens $1L$ and $2L$, closes $1H$, opens the bias-voltage circuit to provide 60 to 70 percent starting torque and somewhat reduced speed at no load. Disconnecting the bias voltage permits maximum excitation of the amplifier coils $2N$-O. This results in minimum reactor impedance.

Point number 3 closes $1R$ to eliminate the reactor and apply balanced voltage to the motor primary and increase the standstill torque to 100 to 125 percent normal. Points 4 and 5 close contactors $1A$, $2A$, $3A$ to remove all resistance from the rotor circuit, causing acceleration to full speed in the usual manner.

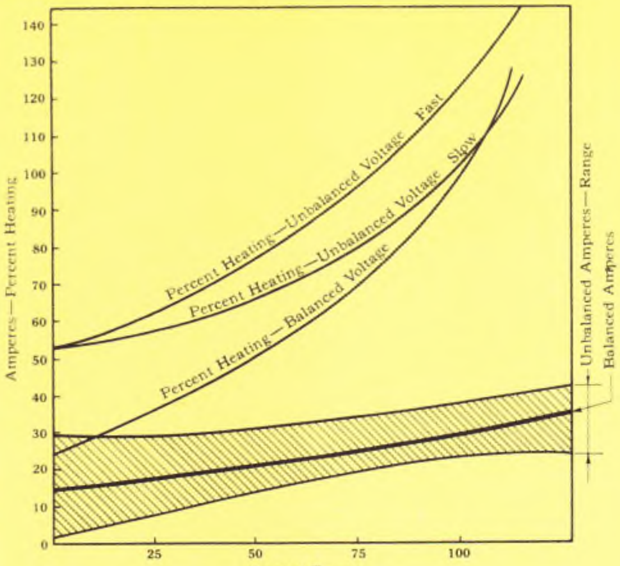


Fig. 12—Current and heating curves for wound-rotor motor using reactor-type control.

A use of improved a-c crane control is the app

Point 1 of the controller, in the lowering direction, closes $1H$ to establish hoisting phase sequence on the motor, with $1R$ open and the main reactor, together with all the secondary resistors, in circuit to produce zero torque while the motor is at rest. If load is sufficiently overhauling to start rotation, the impedance of the main reactor is reduced as a result of increased d-c saturation, and counter-torque appears that opposes the motion. With increasing speed the opposing torque rises because of two factors: (1) the performance of the motor approaches to a greater and greater degree that of true three-phase operation as a result of lessened unbalance in the primary voltage, (2) the negative-sequence torque disappears near negative synchronous speed.

Controller points 2 and 3 in the lowering direction result in higher speeds for a given load, because of insertion of resistance between $1N$ and $2N$ in the amplifier control circuit. This causes full saturation of the main reactor to take place at higher speeds than occurs on point 1 of the controller.

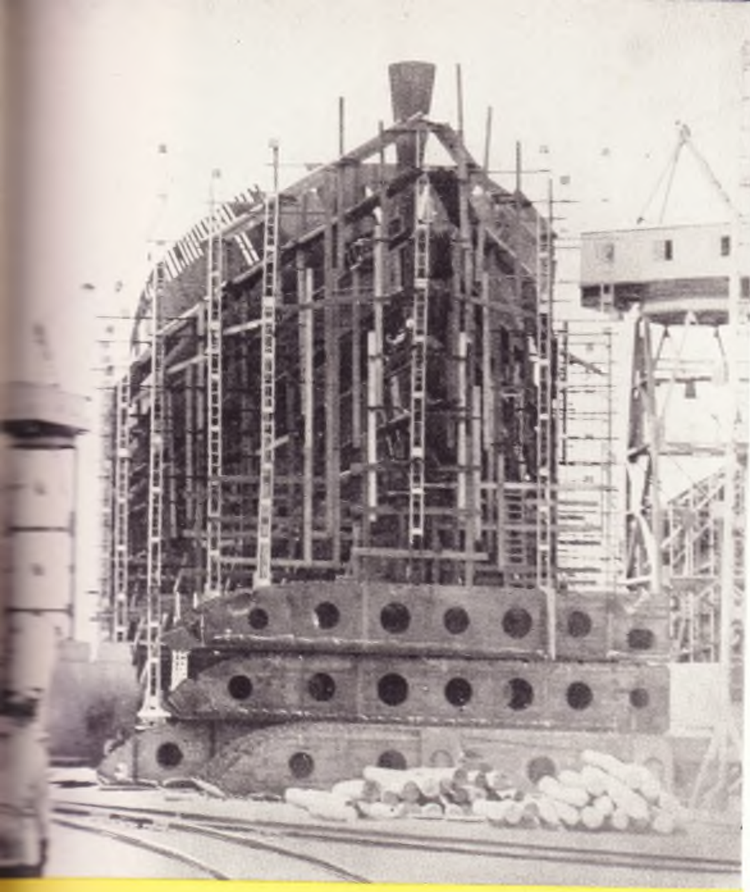
If load is insufficient to start rotation or produce sufficient speed on points 1, 2, 3, the controller is moved to point 4 to close contactor $2L$. This connects the phase shifter, resulting in a driving down torque at very low speeds and lowering heavy loads at higher speeds.

The final lowering point of the controller, number 5, opens $1H$, closes $1L$, to energize the motor to drive the load downward. The result is full speed at no load and regeneration for overhauling loads.

Inching Control—On any of the first four lowering controller points—1, 2, 3, 4—an inching button (shown with dotted lines) can be used to provide torque at zero speed. By proper manipulation, loads up to 100 percent can be brought to rest or inched down with this refined speed control. The button decreases the impedance of the main reactor only while held down.

Application Considerations

Space requirements for the reactor controller are somewhat



gantry cranes such as shown in this shipyard view.

greater than required for a conventional magnetic controller of the same rating. The control panel, master controller and resistors compare with those forming the conventional controller, but the reactor, amplifier and associated transformers and Rectoxes are mounted in a unit separate from the panel. Crane wiring is essentially the same as for conventional types. Eight trolley wires are required where a main-circuit hoist-limit switch is used, and six when the limit switch is omitted—the same as in conventional controls.

Theoretically reactor-control is applicable to an a-c motor of any size. The speed-torque characteristics in Fig. 11 are steady-state values. For light loads retarding torque fluctuates slightly for an instant following a change of the controller point, because of the time constant of the excitation circuit of the reactor. With increasing horsepower, time constants increase, and may tend to limit the maximum horsepower that can be used. No particular difficulty is expected for motors of 200 hp and less.

The best indication of the performance provided by the reactor control system is given in the speed-torque curves of Fig. 11. Points *H*-1 to *H*-5 provide fine control for hoisting normal loads at slow, medium and high speed, thus fulfilling the first criterion for a satisfactory crane drive and control. Curves *H*-1 and *H*-2 are the only hoist curves "relocated" in this control system. *H*-3 to *H*-5 remain the same as on standard hoist systems. Because curve *H*-1 has been made to cross the speed axis at a point below 50-percent synchronous, a light hook or very light load can be hoisted on the first point at a definite slow speed—approximately 36 percent. This satisfies the second requirement for a satisfactory drive.

Points *L*-1 to *L*-5 provide lowering of all overhauling loads at slow, medium, and high speed as set forth in the third requirement. Good speed regulation is indicated by the relatively flat slope of these curves. This is especially desirable in the two extreme speed points, curves *L*-1 and *L*-5.

Condition 4—a "creeping" speed for careful spotting—is provided on the first point lowering. Assuming a 90-percent efficient hoist machine on which the motor is loaded to 100 percent when hoisting full load, the slowest speed at which a full load is lowered is approximately 15 percent. When a reasonably fast-setting brake is used, movements as small as $\frac{1}{4}$-motor revolution have been consistently obtained. These creeping characteristics meet the requirements of most applications. Should critical operations require, an auxiliary button can be added that gives control in the area between curves *L*-1 and *A* and hence provides creeping speeds down to zero.

The portion of curve *L*4 in quadrant III provides slow-speed lowering of a non-overhauling empty hook on controller point four. This combined with the section of *L*-5 in the same quadrant provides slow- and high-speed empty-hook operation on points four and five respectively and amply fulfills the fifth requirement.

The characteristics shown in Fig. 11 are obtained with a maximum of 125-percent steady-state rated current in any motor winding. Intermittent overloading of one phase winding to this extent, as will occur in general hoist work, will not unduly penalize either the motor or associated control equipment. Thus the sixth condition is satisfied.

The limitation of the maximum speed to 125-percent synchronous speed when lowering a full load also is shown in Fig. 11. This is secured with the master switch on lowering point four. The 125-percent limitation leaves a practical margin of safety below the 150-percent maximum safe speed specified for motors of this type by NEMA.

Reactor-type control systems are in successful use on the hoist motions of overhead cranes in such varied industrial establishments as metal-fabricating shops, machine shops, billet-forging shops, and storage warehouses. Installations have also been made on a gantry crane in shipbuilding service and on an aerial tramway system at a coal mine. The reactor system is being applied to a paper-mill pulp-log rake. Here the low-speed, light-load motoring feature is used to take up slack cable gently and to provide slow drum speed during cable inspection and replacement.

The comparative speed-torque curves of the reactor and conventional control systems shown in Fig. 13 may well inspire many future applications unforeseen at present.

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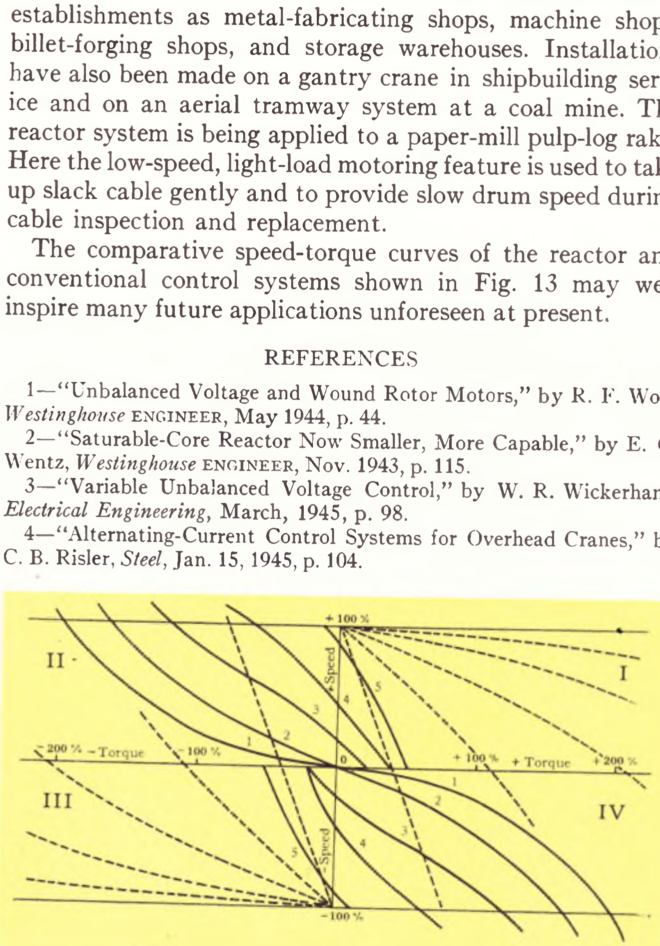


Fig. 13—Comparative speed-torque curves of reactor- and standard-control systems of hoist motors.

STORIES OF RESEARCH

Temperatures Controlled by Vacuum-Tube "Furnace"

Anticipation is a human foible, particularly human in its proneness to error. Not so with a robot anticipator developed by Mr. M. J. Manjoine of the Westinghouse Research Laboratories. This instrument consists of two thermocouples of different thermal capacity and an electric heating element. Changes in electric-furnace temperatures are anticipated and corrective steps taken to minimize the cyclic swings in temperature characteristic of most furnace controls.

When the temperature of a furnace is controlled by a single thermocouple within the heating chamber, the temperature rises sharply until it reaches a predetermined point where the control operates to disconnect the furnace from the power line. Because of the large thermal capacity of the heating elements and the furnace itself, the temperature continues to rise—but less sharply— to a maximum and then begins to fall. At a preset minimum temperature the controls again connect the furnace to the line. Here again the flywheel effect of the furnace thermal capacity causes the temperature to continue to drop until a minimum is reached at which point the temperature again begins to rise. The overshooting on the heating and cooling portions of the control cycle results in a considerable temperature range between the high and low temperatures of the cycle.

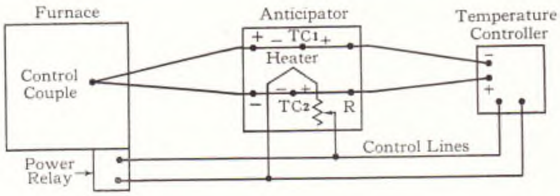


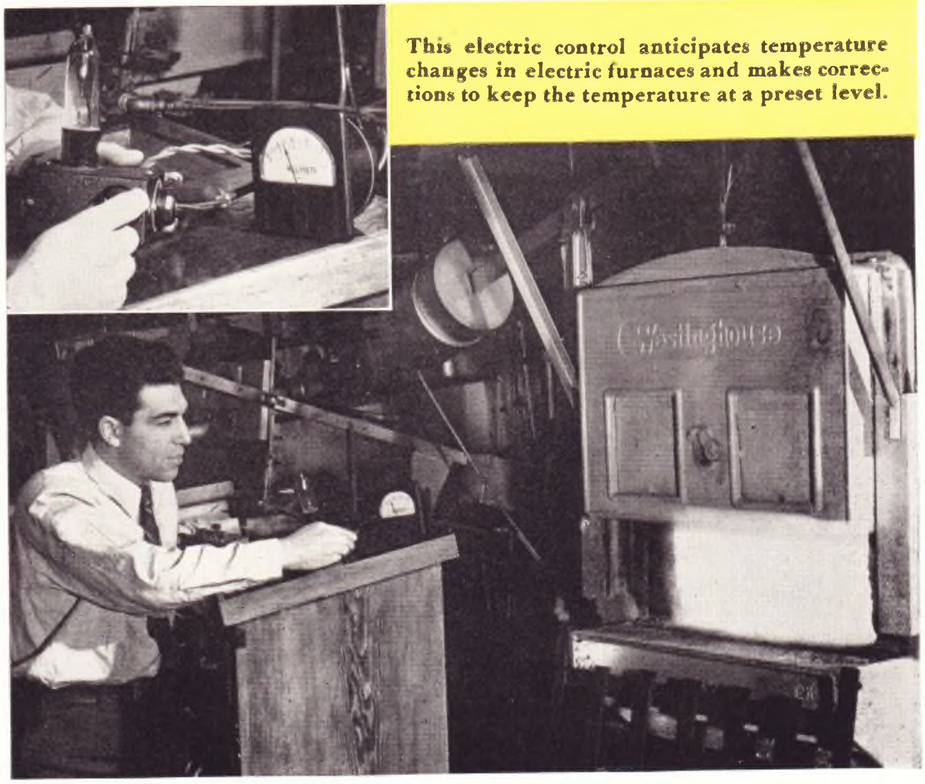
Fig. 1—Thermocouples *TC1* and *TC2* in the anticipator are connected in series with the control couple. *TC1* adds to the control thermocouple voltage and *TC2* subtracts. *TC2* has greater thermal capacity than *TC1*. The heater operates from the line common to the control circuits. When *TC1* and *TC2* are at the same temperature, the voltage at the temperature controller is the same as that of the control couple. When the furnace current is on, the anticipator heating element heats both thermocouples but *TC1* heats faster because of its lower thermal capacity. This increases the thermocouple voltage and the control swings to cooling, preventing overshooting. When the furnace control current is cut off, current to the anticipator heater also ceases and *TC1* and *TC2* begin to cool. *TC2*, because of greater thermal capacity, cools more slowly and the thermocouple current drops because of the reverse polarity of *TC2* and the control swings to heating, preventing overshooting. The resistor *R* controls the frequency of the heating and cooling cycle.

The anticipator, because of the different characteristics of the thermocouples used, reacts to temperature change quicker than the furnace and initiates the control operation sooner and minimizes temperature fluctuation. The two thermocouples in the instrument and the control thermocouple in the furnace are connected in series so that the polarity of the couple with less thermal capacity is additive and the couple with greater thermal capacity is subtractive with respect to the furnace couple.

The heating element of the instrument is energized by the power source connecting the control mechanism and the relays that operate the main power contactors. Thus the furnace and instrument heating elements operate together. The two couples in the instrument are equidistant from the heater but the element with the lesser thermal capacity reacts first to changes in heater-element temperature.

When the two couples in the anticipator are at the same temperature, the voltage from the control thermocouple to the control mechanism is constant. At the time that the control thermocouple institutes a change in control current—for example, starts the heating part of the cycle after having been off—the change is felt first in the two thermocouples in the anticipator. However, the thermocouple with the lower thermal capacity heats faster than the other and the thermocouple voltage at the temperature-control mechanism is increased. This increased voltage causes the controller to change to cooling, thus preventing the furnace temperature from overshooting the desired maximum. When the opposite action takes place and the furnace is in the cooling portion of the cycle, the anticipator thermocouple with larger thermal capacity cools more slowly and its reversed polarity causes the control mechanism to change to heating and keeps the furnace temperature from overshooting the minimum limit. A variable resistance in the heater circuit of the anticipator provides a means of controlling the frequency of operation of this supervisory furnace-temperature control.

Should the line voltage dip (or rise) the instrument heater reflects this change



This electric control anticipates temperature changes in electric furnaces and makes corrections to keep the temperature at a preset level.

Thin films are deposited on surfaces suspended inside the rotating ring shown in the evacuated glass bell. Mr. T. E. Ebert controls film thickness by timing the deposition.

much quicker than the furnace heating elements and the control is properly energized to correct for the power variation before the need is recognized by the thermocouple in the furnace.

Depositing Ultra-Thin Films

An increasing number of occasions are arising in research work that require the deposition of an extremely thin film of metal, a film as thin as ten millionths of an inch. Such a film used on nonreflecting glass (to mention an application not subject to security regulations) must be controllable to within a fraction of a wavelength of light. Under the supervision of Dr. E. D. Wilson, a means has been developed at the Westinghouse Research Laboratories for depositing films of many different substances, either by vaporization or sublimation of the material and subsequent condensation on the surface to be coated.

The equipment is relatively simple. The trick is in the control of the deposition. Essentially, the apparatus consists of a heated trough in which the coating material is electrically heated. The trough shape helps to direct the vaporized substance toward the surface to be coated. This action takes place in an evacuated chamber and is a function of the latent heat of vaporization of the coating material used. Most substances melt and then vaporize; some sublime, going directly from the solid to the vapor state. In the laboratory apparatus shown, the test pieces are attached to the inside of the squirrel-cage framework, which is rotated by a small motor. The mechanism is enclosed in an evacuated glass bell.

The amount of film deposited can be controlled by evaporating entirely a small amount of the coating or by evaporating for a certain length of time a larger amount of material. Because of the vaporization characteristics of most solids, vaporization ceases practically immediately when the heat is removed.

There are two principal ways of determining film thickness. One is to reflect light from the coated surface onto a photocell. Evaporation can then be carried on to a maximum or minimum of reflection. A qualitative method utilizes an estimate of the interference color of the film. Some films are so thin that they approach the thickness of a molecule. When the thickness of the film is some fraction of a wavelength of light, the light rays reflected from the two surfaces form interference. The hue of the color observed corresponds approximately to one half the wavelength of the reflected light. This value can be translated into film thickness.

"Q Meter" Solves Dielectric Heating Questions

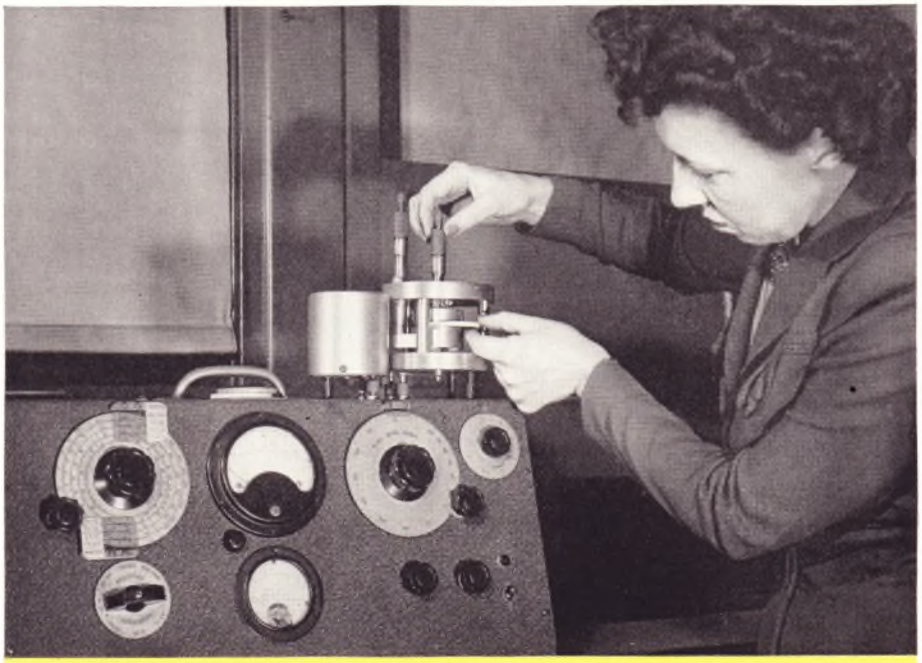
Business is keeping first things first—war work now, postwar projects after the enemies are beaten. Present developments to aid the war effort, however, are scanned with an eye to their implications in the coming era. Of especial interest has been dielectric heating that has made possible new products, shortened the production time of established articles and points to dramatic savings in cost in many lines. The question arises in the minds of manufacturers, "Can dielectric heating help me in my drying or curing processes?" Answering a multitude of these questions in connection with the large number of different materials used in war operations entailed many man-hours and the services of highly trained engineers. The dielectric-sample measuring attachment for the "Q meter" developed by Dr. T. W. Dakin and his associates at the Westinghouse Research Laboratories has reduced accurate testing of dielectrics to a matter of routine.

The sample holder is a pair of specially mounted parallel plates that are moved by micrometer controls. This assembly is mounted on the top of a commercial Q meter. The material is formed into a small disc and placed between the platens.

The procedure for testing dielectrics is now quite simple and within the grasp of trained laboratory assistants. The Q meter oscillator provides a number of frequency ranges so that it is possible to determine the frequency at which the losses are greatest in the sample under test, hence the best frequency for heating.

The watts dissipated in a unit volume of material for a unit voltage is a measure of the economic practicality of heating a material dielectrically. The values of dielectric constant and dissipation factor also are important to the dielectric-heating engineer in applying his high-frequency power to a material.

The variety of materials submitted for test to see if dielectric heating might be efficacious is seemingly unlimited. In addition to the more or less usual glues, resins, plastics, wood and other cellulose materials, cheeses, vitamins, high-grade ceramic bricks, meats, grains, are submitted. The applications of this heating and drying method in the postwar era will be larger. The Q meter tells beforehand which applications are feasible.



Micrometer adjustments insure accurate measurement of the dielectric characteristics of the disc-shaped sample that is placed between the plates of the holder.

Electric-Furnace Brazing—
Its Principles and Practice

The art of fastening materials together is a fundamental function of industry which has limited or accelerated the pace of manufacturing as the art has lagged or led industry as a whole. New electric-brazing techniques in air or controlled atmospheres provide a noteworthy advance in joining metal, performing chores on a mass-production basis not possible by the application of other methods.

A. K. Phillippi
Manufacturing Engineer
Westinghouse Electric and Mfg. Company

Brazing as an art stems from antiquity. As an industrial process, it has come to the fore during the past thirty years. Its importance as a fastening device has reached a peak under the spur of war needs. The complicated machinery required to produce the material of war, as well as the equipment itself, contains many parts necessarily intricate and of complex contour. A great many of the parts that otherwise entailed untold man-hours of machining were broken down into simple, easily produced components and brazed together. Intensified research plotted the techniques, prescribed the metals, the alloys, to produce brazed joints of exactly predictable nature for industrial operation. Brazing takes its proper place in the fabrication of metals along with welding, powder metallurgy, and other war-accelerated processes.

Brazing is the general term applied to joining iron, cast-iron, steel, brass, copper, bronze, nickel, and other metals in similar or dissimilar combinations without fusion by means of a nonferrous filler material. It is usually defined as a group of metal-joining processes wherein the filler material is a nonferrous metal or alloy whose melting point is higher than 1000 degrees F, but lower than that of the metals or alloys to be joined.

The secret of successful brazing is proper utilization of the phenomenon of capillary attraction. The magnitude of this force is not generally appreciated. In one experiment, an iron pipe was driven into another iron pipe with a force fit. The pipes were stood on end in a bell furnace with a ring of copper about the base. When the copper melted it was drawn up the whole 30-inch length of the pipe by capillary attraction. Sections taken of the pipe showed perfect brazing throughout the length of the joint.

In a properly brazed joint, the pieces to be joined are correctly designed, thoroughly cleaned, fluxed (where necessary), and heated to the proper temperature that causes the filler material to melt and flow into the joint by capillary action. Thus the entire area where the pieces touch is bonded. In most cases the strength of a joint made in this manner is as great as that of the base metal itself.

The strength of this type of joint is much greater than if the two pieces are joined by other means. Pieces that are bolted, riveted, tack welded or resistance spot welded rely on the strength of the individual joint or joints made between the pieces by these devices. In brazing the entire contact surface of the two parts being joined forms a joint that is of a much larger area than the sum of the individual areas of these other methods of fastening.

Many furnace-brazed joints have been found to have greater strength than the parent metal. Tests in tension show such samples break in the parent metal rather than at the joint. In a copper-steel joint the brazed section is generally regarded as having a strength greater than the copper but somewhat less than the steel.

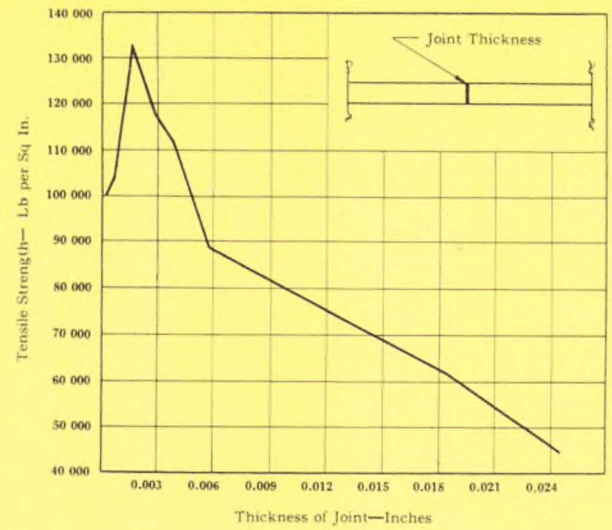


Fig. 1—The necessity for careful design in brazing is shown by this curve of the strength and clearance relationship.

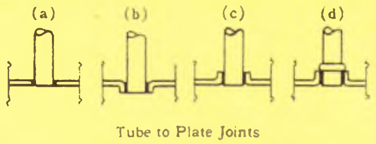


Fig. 2—In (a) the tube is simply brazed to the thin-section sheet. In (b) the sheet has been drawn down to permit brazing between larger areas of the parts. The same scheme is shown in (c) except that the sheet is bent upward to receive the tube. This form is better for use with a brazing torch because the metal to be heated is where the flame can strike it. The assembly has been made self-positioning by the placing of a ridge on the tube wall as shown in (d). This prevents the tube from extending too far through the sheet metal.

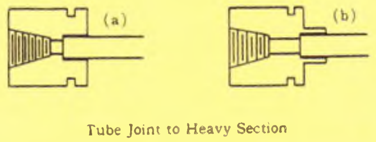


Fig. 3—Joining a tube to a heavy section as in (b) requires less heat for the operation than (a) because there is a thinner cross section of metal to be heated. The summation of a large number of details such as this makes brazing economical.

Selection of Brazing Metal Important

While it is possible to braze most metals, ferrous or non-ferrous, the selection of the proper brazing metal and flux is most important. Many combinations of metals and alloys can be brazed without the use of flux, but, where a flux is needed, it is imperative to use the one designed for the metals involved.

Obviously the brazing metal must flow at a temperature below the melting point of the base metals, must wet the base metal and be so placed that it will, by capillary action, be pulled into and permeate all the interstices of the joint.

The widest adaptation of furnace brazing is to ferrous assemblies in which copper is generally used as a brazing alloy. Some of the alloy metals, such as vanadium, silicon, aluminum, manganese and chromium, form oxides from the furnace atmospheres at elevated temperatures. In order to reduce these oxides a flux must be used. Alloys containing phosphorus should never be used on ferrous metals because of the formation of iron phosphide that materially weakens the joint. Other alloys can be used but those containing a high percentage of zinc or cadmium must be handled carefully in the furnace. Their brazing cycle must not be such as to distill zinc or cadmium in the parent metal of the parts during the brazing operation.

In addition to insuring the prerequisite cleanliness of the parts to be joined by brazing, it is important, particularly for continuous production-line brazing operations, that the pieces be designed with proper tolerances. The fit between pieces must be such as to permit the complete penetration of the brazing metal by capillary action over the entire joint.

Much depends on the clearance between the two pieces being joined together, as it has a definite relation to the strength of the brazed joint. The relation of this strength to clearance is shown in Fig. 1. It is noticeable that when the clearance between two pieces is 0.0015, the maximum strength is obtained. In this case, the brazing medium is a silver alloy. In order to take full advantage of brazing operations, the design of the product plays an important part. When pieces have the proper clearance and are self-aligning and self-supporting, they will maintain their proper position relative to each other during the brazing cycle. When fixtures are not needed to position the parts the operation is faster and the net output is increased. The design development for self-supporting brazed joints is shown in Figs. 2 and 3.

In using alloys other than copper as the brazing medium, a metal to metal fit of plus 0.0015 inch should be provided to allow the alloy room to penetrate the joint. Time and temperature are equally important factors in the success of brazing operations and these, together with the fit, kind of brazing metal, and the flux, are integrated to meet the needs of the individual manufacturing problems.

The elements of properly engineered joints outlined in Fig. 2 are applied to an actual production part pictured in Fig. 4. The manner of aligning these components on the endless belt of the furnace is shown in Fig. 5. The photographs of sections of joints shown in Fig. 6 emphasize the necessity for proper design of components in using this brazing technique.

Brazing Temperature Range Is Wide

The temperature range of brazing is from 1200 degrees F to 2050 degrees F. The lower temperatures apply to brazing mediums consisting of certain combinations of silver alloys with copper, cadmium, and zinc, as well as combinations of copper and phosphorous. The higher temperatures are used for brazing with copper alloys and bronze.

All steels and alloys are affected by heat and the extent of this effect depends entirely on the temperature used in the brazing cycle. In brazing ferrous material, the temperature of the furnaces is generally kept at 2050 degrees F, plus or minus fifteen degrees, which gives a good brazed joint providing the pieces are prepared and assembled as described previously. In brazing non-ferrous alloys such as bronzes, brasses, etc., the temperature used depends entirely on the brazing alloy. In general, from 55 degrees to 75 degrees above the melting point of the alloy gives a temperature high enough to permit the alloy to wet the surfaces to be brazed and to be pulled into the joint by capillarity. When the brazing is done at temperatures higher than the annealing temperature, the curve of the characteristics of the base metal being brazed should be checked to make sure that the annealing effect at the temperature used will not be injurious to the product. When brazed pieces are to be heat treated, it is necessary to prevent the migration of copper except at the joint.

In some brazing operations which take place at 2050 degrees F, the grain growth of the base metal is considerable. Where this is undesirable in the finished product, it is necessary to braze the ferrous metals with a lower-melting brazing medium such as one of the silver alloys.

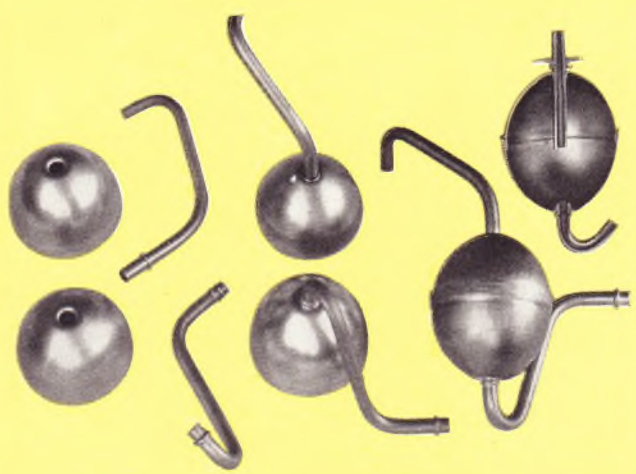


Fig. 4—A practical application of the principles of Fig. 2.

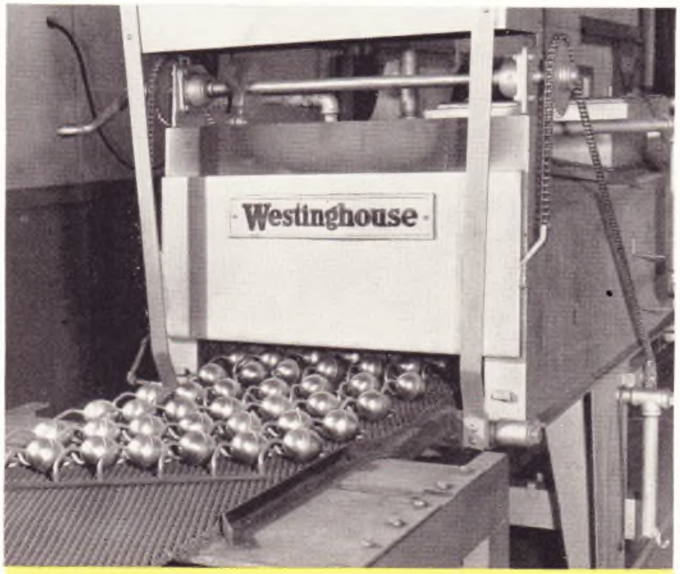


Fig. 5—A channel to support the tube ends positions the assemblies on the woven belt without elaborate supports.

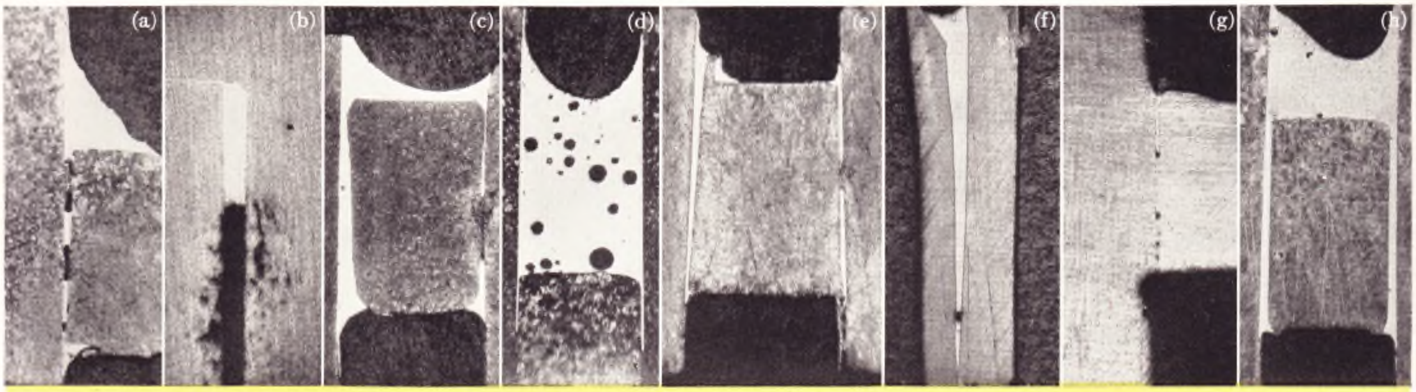


Fig. 6—These sections of brazed joints show the results of poor clearances and dirty surfaces. Because the clearance was too great the fill in (a) is poor and there are voids because of dirty surfaces. In (b) the fine line of alloy at the top shows proper clearance and complete fill. The vertical clearance is too great and the metal could not be drawn by capillarity to fill the space. The plug in the tube shown in (c) was improperly placed and the resulting joint exhibits excess alloy. Voids appear as a result of dirt. A joint similar to (c) is shown in (d) where the heating cycle was inadequate. This is evidenced by the lack of penetration of the alloy in the joint although the clearances are correct. The voids in the brazing metal are due to flux inclusions, another indication of too short a heating period. The joint in (e) is fairly good, the slight non-brazed area on the right is due to dirt. In (f) a tube is flared to receive a section of tube the same size. This is a fairly good joint because it is difficult to maintain parallel wall areas in flaring operations of this type. Lack of sufficient alloy to fill the area between the pieces resulted in the poor brazing shown in (g). With the exception of the surplus brazing alloy at the top, the joint shown in (h) is properly brazed. The clearances are correct, the surfaces clean and the heating cycle adequate. The joint areas are completely filled and all surfaces completely wetted by the alloy. Brazing is effective but requires careful procedures.

Positioning the pieces to be brazed has been shown to be an important factor in good brazing results. There are many methods of holding the pieces together with the proper fit for the brazing medium and base metal involved. Where the metal is not too heavy and the expansion of the pieces at the brazing temperature used does not make the fit too loose, a pressed fit is often used. Staking the parts together is another commonly used method. Other positioning means involve tacking or spot-welding the pieces or putting a shoulder on one piece to prevent its sliding too far into the piece to which it is to be brazed. Other solutions applicable to individual brazing problems present themselves but have not found extensive use.

The several types of brazed sections, illustrated in Fig. 7, show a marked similarity but the variations of these sections encountered in industry are limitless. The parts to be brazed, the facilities available for brazing, the temperature used, the brazing medium, the flux or controlled atmosphere used to insure a clean surface, and proper wetting action are all factors that determine the design of the brazed joint, the brazing alloy, and the brazing procedure.

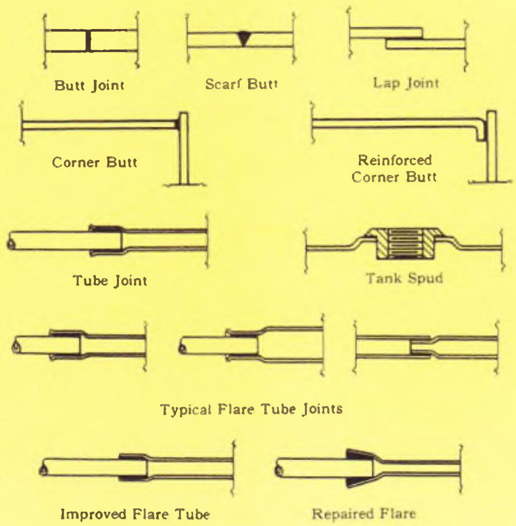


Fig. 7—These joints, typical of those encountered in industry, are made quickly and well by electric-furnace brazing.

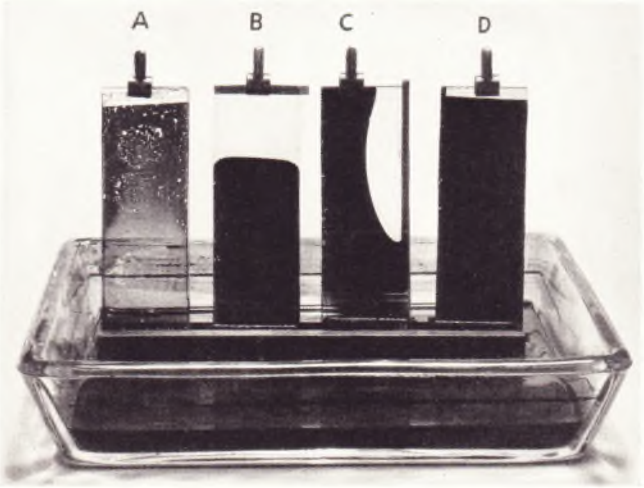
Furnace Heating for Brazing

Electrically heated furnaces are playing an increasingly large part in the joining of metals. Economy, increased rate of production, and the high quality of the finished product achieved through the use of a protective atmosphere are the principal advantages of this method of heating for brazing operations. There are four standard types of furnaces used for this class of work. They are known as the roller-hearth, belt-conveyor, pusher or batch, and bell type. These electrically heated furnaces are particularly adapted to brazing in controlled atmospheres.

For heavy work, where the production load requires a continuous flow of the product, a roller-hearth furnace is used. The work is conveyed through this furnace (Fig. 8) by a series of transverse rolls on which the work moves. It carries loads up to 50 pounds per roller, the rolls spaced approximately 10 inches apart. This type brazing furnace consists of a charging chamber, a heating chamber, a cooling chamber, and a discharge chamber. The rollers in the hearth, which carry a specific load when heated to a specified temperature, are turned by an external chain and sprocket. The driving mechanism includes a variable-speed device which regulates the speed of the work passing through the furnace. This speed adjustment is necessary because of the variable load that the furnace might be called upon to handle. The bearings of the rolls in the charging, heating, and part of the cooling section are cooled by circulating water.

If the work to be brazed is sufficiently large to rest on three rollers and has a flat surface next to the roller, it can be passed through the furnace without the use of a tray. Trays designed to meet the requirements of the work to be handled are used

In the figure, glass plates are clamped together and one end immersed in ink. The ink is drawn up between the plates by capillary attraction. In (a) the plates are clamped together with a clearance of 0.001 inch. The plates are dirty and have fingerprints on the inner surfaces. The ink does not fill the whole area between the plates and has missed entirely those spots where there is dirt or oily fingerprints. In (b) the glass plates are clamped together with no clearance at the bottom and 0.008 inch at the top. The top portion remains unfilled because the space between the plates is too great to enable the force of capillarity to operate. The effect of incorrect clearances is shown also in (c). Here one side is clamped tightly while the other side has a clearance of 0.008 inch. Again capillary attraction could not overcome the inordinate spacing on the right side but carried the ink to the top on the left. In (d) the plates are clean and the spacing, 0.0015 inch, is proper with the result that the space between the glass plates is completely filled. The phenomena here demonstrated are in every way applicable to the brazing of metal surfaces.



to transport smaller parts through the brazing furnace.

The construction of the belt-conveyor type of furnace, shown in Fig. 9, is similar to that of the roller-hearth furnace. Instead of having rolls on which the work moves, an endless belt of a special heat-resisting alloy is used. This belt travels through the furnace on special-alloy rails which are part of the floor of the heating chamber, and are placed to permit the proper heat circulation. In the charging and cooling chambers, the belt rests on a steel flooring. This contact with the water-cooled floor of the cooling chamber aids in the rapid transfer of the heat.

The relatively close weave of the alloy belt permits small pieces to be placed directly on the belt for brazing without the use of trays. Obviously, for pieces smaller than the open spaces in the mesh, supporting trays are necessary.

While the work is passing through the furnace as designated above, the leakage of the furnace atmosphere is sometimes quite high in the belt-conveyor type furnace because both the charging and discharging doors must be kept open high enough to clear the work passing under them. Unless the work is properly arranged on the belt, gaps between the parts to be brazed permit more of the atmosphere to leak out. A burning gas curtain at both charging and discharging doors prevents room air from entering the furnace.

The pusher- or batch-type furnace is similar to both the roller and conveyor-belt type furnace. It differs from them in that the work is laid in a tray and the tray pushed into the heating chamber where it is kept until it reaches the proper brazing temperature. This furnace is capable of doing both light and heavy work as all work is passed through the furnace on trays. It has three doors—the charging door, the door between the heating chamber and the first section of the cooling chamber, and the discharge door. The charging door and discharging door are both protected with burning gas curtains which prevent oxygen infiltration into the furnace proper.

The heating elements in an electric furnace are generally mounted on refractory insulators on the side walls and top of the interior of the heating chamber. The cooling chamber is enclosed by an inner and outer wall. The work is cooled by circulating water between the walls. By interlocks in the charging and discharging portals and other design details, leakage of the furnace atmosphere is minimized.

The bell-type furnace consists, as the name implies, of a large metal bell that rests on a hearth, the edges of the bell nesting in the groove of the hearth, which is filled with chrome oxide. Heating elements are generally located on the inner wall of the bell but sometimes are in the hearth proper. This type of furnace permits the brazing of extremely large assemblies, too large and too heavy to be handled in continuous or progressive types of furnaces.

After the brazing charge has been placed on the hearth, the bell is lowered so that its edges make firm contact in the chrome oxide. Small gas pilot lights are kept burning continuously around the bottom of the bell to ignite any of the escaping brazing atmosphere. The bell is filled with protective atmosphere and is brought up to the required temperature. This temperature is maintained until the entire load reaches the brazing temperature and the brazing alloy has permeated all the joints.

The power is then shut off and the bell permitted to cool, using the protective atmosphere until a temperature is reached where oxidation will not be too great. Then the bell is removed. Should specifications require that the work have a clean and bright finish, the entire load must be cooled in the

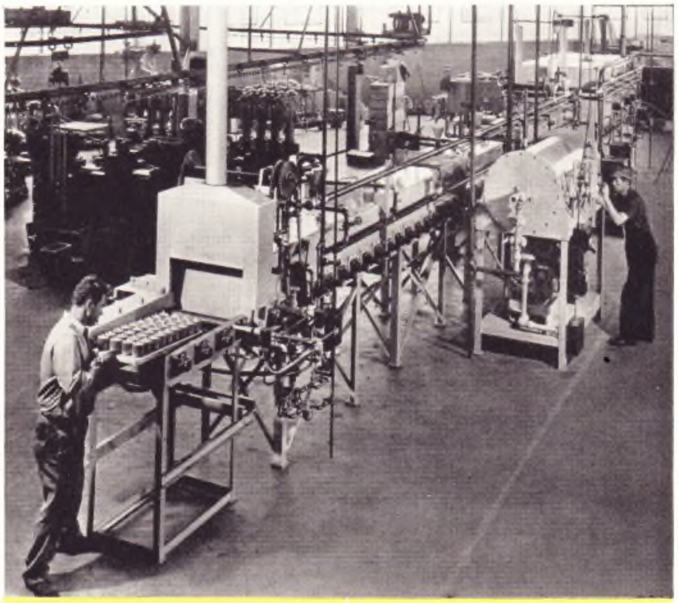


Fig. 8—The tray at the discharge end of a roller-hearth furnace typifies the loading of small assemblies for brazing. At the right is a protective-atmosphere generator.

protective atmosphere until a temperature between 250 and 300 degrees F is reached before the bell is removed.

The four governing factors in the selection and design of a brazing furnace are: the provision of adequate capacity to carry the load, proper heat control at brazing temperature, controlled atmosphere and proper means of retaining the atmosphere while the brazing operations are being carried on, and means of cooling the work below the oxidation temperature before being exposed to the air.

The power required for heating the various type of brazing equipment is not subject to generalization. Each brazing operation presents a specific problem, the answers to which are not necessarily applicable to other problems, even those similar to a considerable degree. Standard furnaces are available having a power-input range of from 5 to 500 kw. Special furnaces of higher or, in some cases, much lower power input are made for special applications. The furnace input depends upon the load and the speed at which the load must be heated.

TABLE I—COMPOSITION OF TYPICAL CONTROLLED ATMOSPHERES

Description	Air-Gas Ratio	Approximate Composition						Dew Point	Gas for 1000 Cu Ft Atmosphere	Nature of Atmosphere
		N_2	CO	CO_2	H_2	CH_4	O_2			
Lean Exogas	10:1 (a)	89.0	0.5	10.0	0.5	0.0	0.0	(b)	115 (c)	Non-combustible slightly reducing
Rich Exogas	6:1(a)	69.0	10.0	5.0	15.0	1.0	0.0	(b)	145 (c)	Combustible; toxic; medium reducing
Endogas	2.75:1(a)	41.7	19.0	0.0	38.0	1.3	0.0	−10°F	200 (c)	Combustible; toxic; most reducing
Lean Monogas	10:1(a)	98.0	1.0	0.0	1.0	0.0	0.0	−50°F	125 (c)	Non-combustible; inert
Rich Monogas	6:1(a)	72.0	11.0	0.0	16.0	1.0	0.0	−50°F	150 (c)	Combustible; toxic; reducing
Ammogas	No air (d)	25.0	0.0	0.0	75.0	0.0	0.0	−60°F	22.2 lb. NH_3	Combustible; reducing
Burned Ammogas	1.88:1(d)	99.0	0.0	0.0	1.0	0.0	0.0	(b)	13.7 lb. NH_3	Non-combustible; inert
Partially burned Ammogas	1.25:1(d)	80.0	0.0	0.0	20.0	0.0	0.0	(b)	14.9 lb. NH_8	Combustible; slightly reducing

(a) Air-gas ratios are representative for natural gas containing practically nothing but methane. For high hydrogen city gas, ratios are about 50 percent of values given; for city gas with medium hydrogen and high CO, ratios are about 40 percent of values given. For propane, ratios are approximately twice the values given in the table, and for butane about three times.

(b) Dew points correspond to approximately 10 degrees F above the temperatures of the cooling water unless auxiliary drying equipment is added. Dew point may be reduced to 40 degrees F by simple refrigeration equipment; to −50 degrees F or less by use of absorbent towers.

(c) Values are in cu ft for high methane natural gas. For various types of manufactured city gas, double the values given. For propane, requirements are half of values given, and for butane one third.

(d) Dissociated Ammonia.

Superiority of Controlled-Atmosphere Brazing

In controlled-atmosphere brazing, many advantages and benefits are realized such as increased life of the brazed parts, because of the high strength of the bond and its great resistance to impact and vibration. Such brazing shows a substantial cost reduction based on a number of factors. Rejections are fewer, and inspecting and finishing operations are reduced. Often, intricate pieces requiring many machine hours can be made of punch-press parts and joined together by controlled-atmosphere brazing with attendant substantial savings in both material and labor.

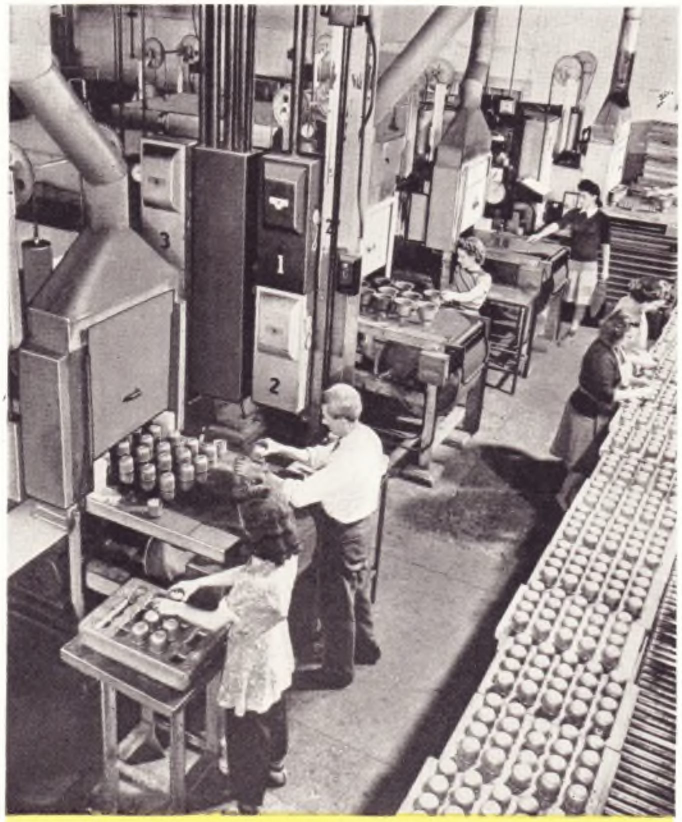


Fig. 9—A battery of four conveyor-belt controlled-atmosphere furnaces used for small brazing assemblies. Insecticide bombs are brazed in the furnace in the foreground.

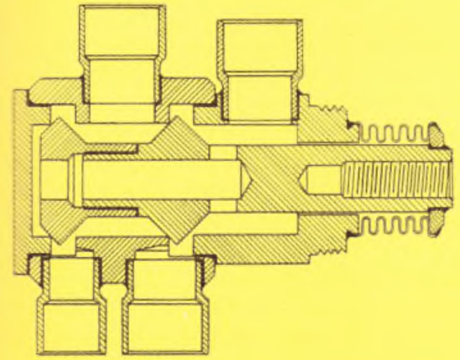
This type of joint has good strength at elevated temperatures because copper, which is generally used as the brazing metal, melts at 1981 degrees F. Such a joint also has good electrical and heat conductivity. Pressure-tight joints of uniform good quality are produced through the uniform control of the amount and distribution of brazing material, the uniform time in the furnace and proper control of temperature and atmosphere. Joints made in this manner are used extensively in refrigeration and air-conditioning systems. Joints typically applicable to controlled-atmosphere furnaces brazing are shown in Figs. 10 and 11. This method, due to the gradual heating and cooling, prevents distortion to a great extent, and does a good job of strain relieving.

Where production rate is high and a number of joints on the same assembly are to be made, furnace brazing in a protective atmosphere is ideal. All the joints can be made at the same time, cutting down many additional operations because it is possible to braze heavy sections to light sections as well as join metals and alloys in a wide variety of combinations in one heating cycle.

Finally, the appearance of the work is good as it is produced clean and free from scale.

When ferrous metals are brazed with copper in the proper atmosphere, no flux is necessary. The atmosphere prevents oxidation and also reduces any slight oxidation that is on the metals being brazed. The work is clean when it leaves the furnace and is easily inspected. No fluxes cover the brazed joint, minimizing the cleaning operation necessary. Non-ferrous alloys are brazed with low-melting alloys. In such brazing, flux is generally required. However, removing the flux is the only cleaning operation necessary if the proper atmosphere is chosen to prevent oxidation of the work.

There are several kinds of furnace atmospheres available for matching the characteristics of brazing and annealing or heat treating the grades of steel that comprise the parts. Endogas is a fuel gas very rich in methane that has been par-



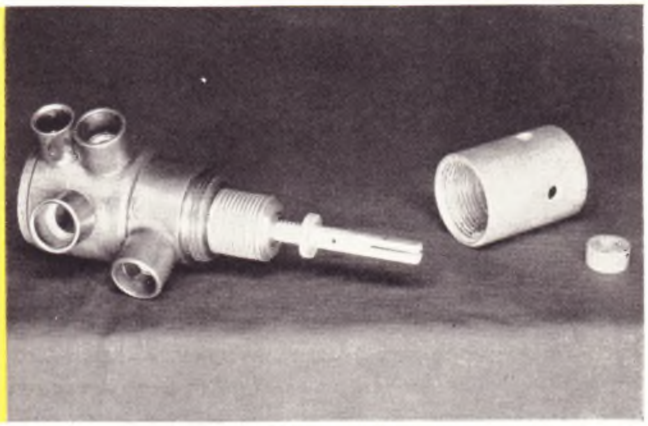


Fig. 10—The complicated nature of this four-way valve for reverse-cycle refrigeration systems is shown by the sketch. It is not feasible to make this valve except by brazing, in one pass, all the internal joints (shown as heavy lines) in an electric furnace.

tially reacted or cracked and passed through a catalyst. By the application of external heat, its reactions are promoted. Endogas is used in brazing operations to prevent decarburization when medium and high carbon steels are involved. Ammogas, which is dissociated ammonia formed by cracking anhydrous ammonia, is high in hydrogen content and has a very low dew point. Exogas consists of a mixture of either manufactured or natural gas and air in the right proportions to secure the desired reducing or inert atmosphere. The gas is formed by pre-combustion in a chamber, the residual gas passing through a catalyst and then a cooling condenser. It is used extensively for shrouding low-carbon steels brazed with copper. It is also used in brass and copper brazing where low-melting alloys are used. Monogas is another gas produced in the Exogas-type of generator. It is passed through a carbon dioxide remover and provides an atmosphere suitable for use when brazing high-and low-carbon steel with copper as the brazing medium. The composition and nature of these gases are given in table I.

Brazing a Nearly Universal Joining Method

The intricacy of the shapes or combinations of the parts to be brazed is no deterrent to the success of a brazing operation. It is required only that the parts to be joined are properly designed, held in their relative positions by one of several methods (fixtures, jigs, spot welding, etc.), with the brazing alloy in place, and finally heated and cooled under the most advantageous protective atmosphere.

Most metals can be brazed but, for maximum results, development work is necessary to compensate for differences in coefficients of expansion of the metal parts, to establish the best protective atmosphere, the proper brazing medium, and most suitable temperature.

Controlled-atmosphere furnace brazing is one of the most economical methods of joining two metal parts now in use in industry today. Because more than one joint can be brazed at the same time, savings of as much as 70 percent have been effected over other methods. One example, perhaps extreme, of the possibilities inherent in this method of metal joining is shown in the brazing of 96 separate parts of one piece of apparatus into a single assembly in one pass through the brazing furnace. This could not have been done by any other method.

For large-scale production of parts, controlled-atmosphere furnace brazing affords a substantial economy as a large number of parts can be brazed in one operation, whereas only a few can be produced by torch brazing or other methods. This type of brazing also lends itself to handling a variety of parts because products both light and heavy can be brazed by adjusting the time-temperature cycle of the furnace. Thus a furnace, properly selected, can be used for a wide variety of brazing operations.

The importance and prevalence of brazing as an industrial tool in joining metals has advanced with accelerated pace because of the cumulative effect of coordination between designers and processers. Every simplification of design, every quirk of production to simplify operations placed more and more joining chores in the category of those that can be done better and cheaper by controlled-atmosphere brazing. The backlog of detailed experience, accumulated under the pressure of the war years by manufacturers and users of brazing equipment, ensures this will be one of the outstanding methods of metal joining in the postwar era.

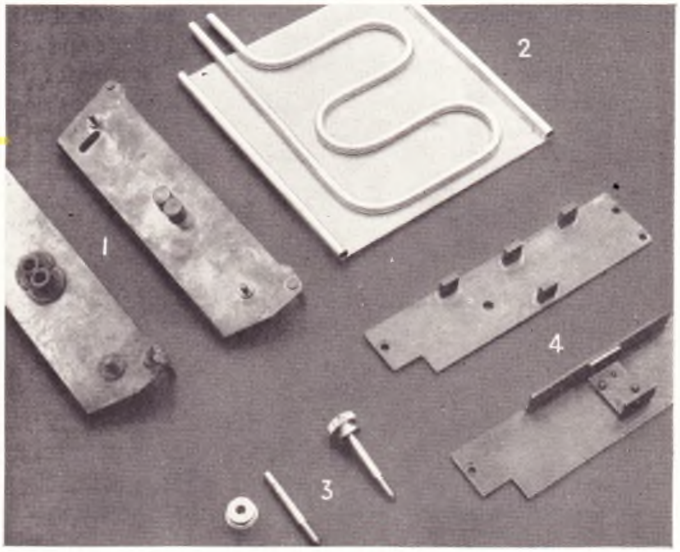


Fig. 11—A small indication of the savings made possible by brazing is shown in this figure. In (1) it is readily seen that two pieces of round bar stock have replaced two machined parts with a great saving in time plus material. Savings in time and material, plus better strength and appearance are achieved in the other parts of this assembly. In brazing tubing to a flat sheet (2), it is necessary only to hold the tubing flat as it goes through the furnace. A great saving of time consumed in soldering, plus savings of critical materials, is represented here. The part shown in (3) required extensive machining with a great amount of metal scrapped. By brazing the knurled head onto a piece of small round stock, as shown, time and material and labor were saved. Four small pieces of square bar stock brazed to the metal sheet replaced the parts that had to be shaped and fastened to the flat plate shown in (4).

An Air-Cooled Steam Condenser

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Condenser Engineering Division
Westinghouse Electric & Manufacturing Company

A steam power plant using air-cooled condensers is another product of necessity. Power trains built as mobile plants for furnishing electricity to war-ravaged areas must be able to function in the almost complete absence of water. Heat-transfer engineers succeeded in producing a novel air-cooled steam condenser, which, although more expensive and not capable of as high a vacuum as water-cooled condensers, proves successful, surmounting such problems as balanced steam flow and freezing.

Among major objectives in modern warfare are public utilities. These the retreating enemy systematically wreck. A partial solution to the quick restoration of these vital facilities has been supplied by the power trains manufactured for the Allies to furnish a mobile source of electric power capable of operating under difficult conditions. Air-cooled condensers make it possible to operate these emergency power-generation plants in localities where cooling water is either hard to obtain or is entirely unavailable. The use of air as the cooling medium and the recovery of the condensate eliminate the need for any outside source of water, except as required to make up for losses.

The condensers on these power trains are designed to maintain a maximum back pressure on the turbine of two pounds per square inch and are expected to operate through a temperature range from 40 degrees below zero F to 95 degrees above. The condenser size and power requirements of the blowers would be excessive if maintenance of a vacuum of any magnitude were attempted. At low ambient air temperatures or at partial loads operation, a vacuum is practical. A single-stage ejector is supplied to take advantage of these conditions.

The condenser for a 5000-kw power train is contained in two cars, eight separate sections to a car. The sections are air cooled by propeller-type blowers.

Each section of the condenser, consisting of ten rows of finned tubes mounted vertically, has 5625 square feet of surface, or a total of 90 000 square feet for the train. The dimensions of the tubes, which are arranged on a two-inch staggered pitch, are shown in Fig. 2. They are constructed of steel with steel fins, with the whole assembly galvanized inside and out. Steel was chosen as the material because it is adequate for this purpose and was more readily available at the time the design was prepared than corrosion-resisting copper-base alloys.

A manifold from the turbine connected to a pair of longitudinal steam ducts running the length of the cars supplies them with steam. The condenser sections are set on these ducts so that steam enters them from the bottom, is condensed, and the condensate drains back into the ducts and is removed by a condensate pump. This counterflow relationship between steam and condensate not only heats and deaerates the condensate, but also keeps it from freezing.

In all condensing apparatus where latent heat of steam is transferred to a cooling fluid as sensible heat, the condensing capacity of the different sections of the condenser inevitably vary. To load equally each part of the condenser with steam, it is necessary either to provide a varying pressure drop to the different parts, or to arrange the flow paths so that they will have the proper resistance to limit the steam to the capacity of the condensing surface. In the ordinary surface condenser this is accomplished in a natural manner by an arrangement of tubes and tube plates. In those cases where the steam is inside the tubes nothing can be done to vary the resistance of the individual flow paths, but resistances can be added to the system in the form of orifices which bring about a balance in the steam-flow paths.

The method here used to secure balanced steam flow is illustrated in Fig. 3. The tube bank is divided into five groups, each made up of two rows of tubes. The first four of these exhaust into the fifth group through orifices, while the fifth group serves as a final condensing section. The orifices are of such size that in order to supply the condensing requirements of the fifth group steam must flow through all four orifices. To accomplish this, it is evident that all four tube

TABLE 1—RESULTS OF HEAT-TRANSFER TESTS

Test No.	1	2	3
Ambient temperature, F	94.25	86.8	70.3
Barometer, inches of mercury	28.95	28.93	28.86
Air temperature from condenser, F	202.2	184.2	171.3
Steam temperature, F	225.4	217.2	202.4
Steam condensed, lb per hr	79 860	78 640	78 140
Air pressure drop in water	2.4	2.53	2.64
Heat load, 1000 Btu per hr	75 330	74 360	75 830
Heat-transfer rate, Btu per hr per sq ft per °F	13.4	11.7	12.0
Face velocity in ft per minute	958	1045	1030

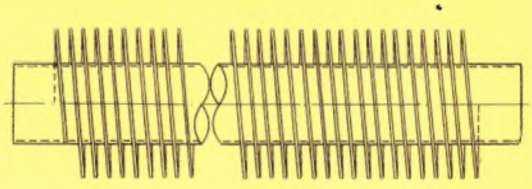


Fig. 2—The condensing sections are composed of one-inch steel tubing 84 inches long. The cooling fins shown above are also made of steel.

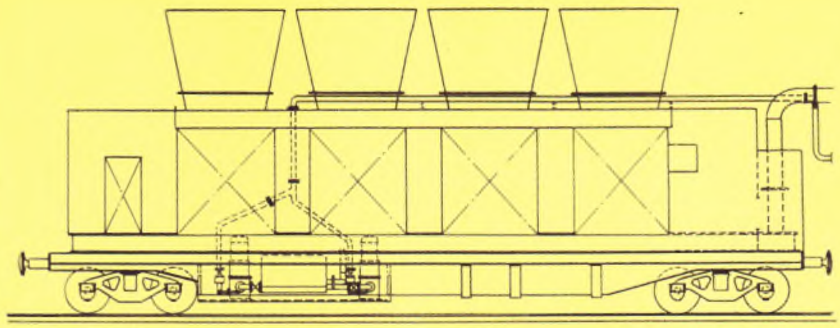


Fig. 1—In each 5000-kw power plant are two of these condenser cars. The four funnel-shaped parts on top each have a large fan in the base.

sections must be full of steam and condensing up to their respective capacities.

The requirement that the condenser operate satisfactorily at a temperature of 40 degrees below zero makes it imperative that every possible precaution be taken to prevent freezing inside the condenser. The greatest danger of freezing arises in those zones which, because of poor distribution of steam at light loading, are not fully supplied with steam. Fortunately, the system that leads to efficient use of the condenser surface by supplying steam to all the tubes in accordance with their capacity to condense it also serves to keep all areas warm and free from ice.

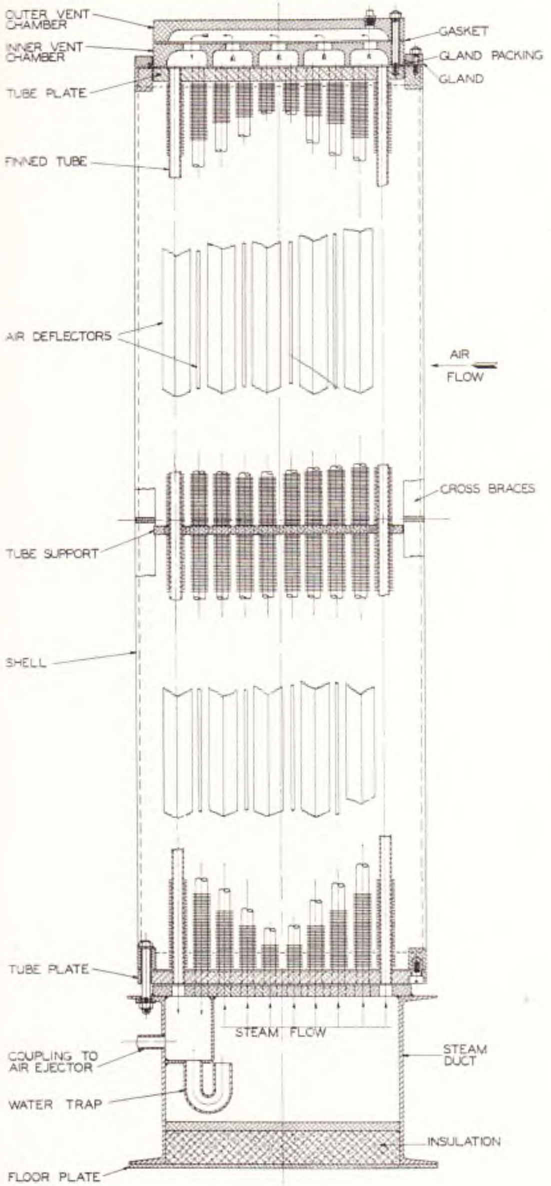


Fig. 3—This cross section of a condensing section shows the steam path through the tubes. The flow is upward through the four pairs of tubing to the right. The steam passes through the controlling orifices, then passes in a downward course through the fifth pair of tubing at the extreme left.

Fig. 4—A view of a condenser car with the tubes exposed.

Under conditions of light load and cold air the vacuum determined from heat-transfer considerations will exceed that produced by the ejector, and the condenser will begin to fill with air until the point is reached at which the remaining surface supplied with steam is just sufficient to satisfy the heat-transfer equation. As soon as a tube fills with air its temperature drops to approximately that of the air outside the tube. If this temperature is below the freezing point all water in the condensate that forms within the tube or flows into it from other sections freezes. The first tubes in which this occurs are those in the air-cooler section but because this section is located on the air-discharge side, the air will have been warmed up to a temperature above 32 degrees in almost all cases. Any reduction in load occurring after the air-cooler section has been blanked off will introduce air at the top of tubes in the first row where danger of freezing is greatest. Each section of the condenser is supplied with a distant reading thermometer, the bulb of which is located in the top of the center tube of the first row, the point where freezing is most likely to occur. This gives the operator a reliable guide on the danger of ice formation. When the temperature as measured by this thermometer falls below 150 degrees F the amount of air circulated should be reduced by closing down one or more blowers.

In the case of extremely low temperatures and light loads, it is possible that even with only one car in service and only one blower operating on that car, the temperature as read on the thermometer will still tend to fall to a dangerous degree. To provide for such an eventuality the condensers are equipped with cover plates which can be used to cover part of the surface of each section to reduce the cooling area and the amount of air flowing.

Tests on the air-cooled condenser for the power train indicate that this type of condenser is entirely practical where conditions justify the cost. It has the advantage that no water is required for cooling and it can be put in operation without connection to an outside source of cooling medium. Because of the poor heat-transfer properties of air and its low specific heat, air-cooled condensers in general require higher auxiliary power, greater investment, and higher back pressure on the turbine than the usual water-cooled condenser. For these reasons, it is unlikely that there will be many applications for it in the power generation field. Its use will be confined to those extreme conditions where water is not available and the increased cost and reduced operating efficiencies can be justified.

A Proved Technique for Sealing Huge Shippin

Americans have long demanded their goods in attractive, functional containers. The extent to which packaging has been carried here has amazed other countries but it has proved economically sound. A new packaging feat, amazing even to us because of its size, also is economically sound in that it protects emergency generating equipments.

SUPPLYING a protective coat by dipping the part in a suitable solution or wrapping the part and sealing the wrapping are two common methods of preventing corrosion in war-needed equipment. It is not possible to dunk or wrap boxcars such as house the generating equipment of mobile electric power trains but the copper, steel and insulation can be protected by sealing each car and providing means for removing moisture from the air inside the enclosed car. Several such cars of special design have each been sealed as shipping packages. Because the cars are too large for the holds of most ocean-going vessels and must be shipped as deck load, it is necessary to protect the electrical generators, motors, transformers, switchgear and auxiliary apparatus as well as the steam turbines, pumps, gearing and auxiliary diesel engines from the entrance of sea water and also from the condensation of atmospheric humidity within. This protection is afforded by covering vents and parts, calking around all doors and covered openings and spraying the entire car with a thick coating of mastic.

The importance of protecting this electrical apparatus and exposed metal surfaces from salt atmosphere and excessive humidity has been emphasized by recent American experience gained in shipping precision apparatus, electrical equipment, and finely finished parts such as gears to all parts of the world, particularly in the South Pacific. Vast quantities of such material have been transported and stored under adverse conditions. Much has been learned regarding the vulnerability of such equipment and the precautions necessary for its protection. Equipment must not only be protected from direct contact with salt water, but also it must not "stew in its own juice." Condensation of atmospheric humidity frequently occurs within conventional packages. The accumulation of condensed atmospheric humidity has been found to produce severe corrosion and rust in metallic parts. Electrical insulation deteriorates rapidly and fungus growth is frequently promoted under this condition. Furthermore, many types of finish which are normally satisfactory in ventilated locations, where not continuously exposed to moisture-saturated air, deteriorate rapidly in a moisture-laden atmosphere. In packaging smaller electrical and metal parts for export shipment, it has been found necessary to resort to elaborate forms of protection. These precautions include careful cleaning and slushing of metal surfaces, enclosing in a completely sealed vapor barrier and dehydration of the interior of the sealed package with desiccant.

The power trains are mobile central generating stations and contain the same general types of equipment as the conventional power station. Such equipment is well suited for operation under normal atmospheric conditions. However, it was recognized that the normal daily temperature cycling of such cars shipped as deck load would produce condensate within the car. This condensation of moisture would cause metallic corrosion, finish deterioration and insulation damage if continued over a several month period without operation or dry-out. The obvious purpose of such mobile power-generating equipment is to produce power quickly upon arrival at its destination. Therefore, critical parts cannot be boxed and sealed separately (except in special instances) as the prime objective is to minimize the time required to set up and start producing power. To accomplish this purpose the best solution appeared to be to treat each car as a unit package and to seal it with suitable precautions with most of the apparatus assembled in place.

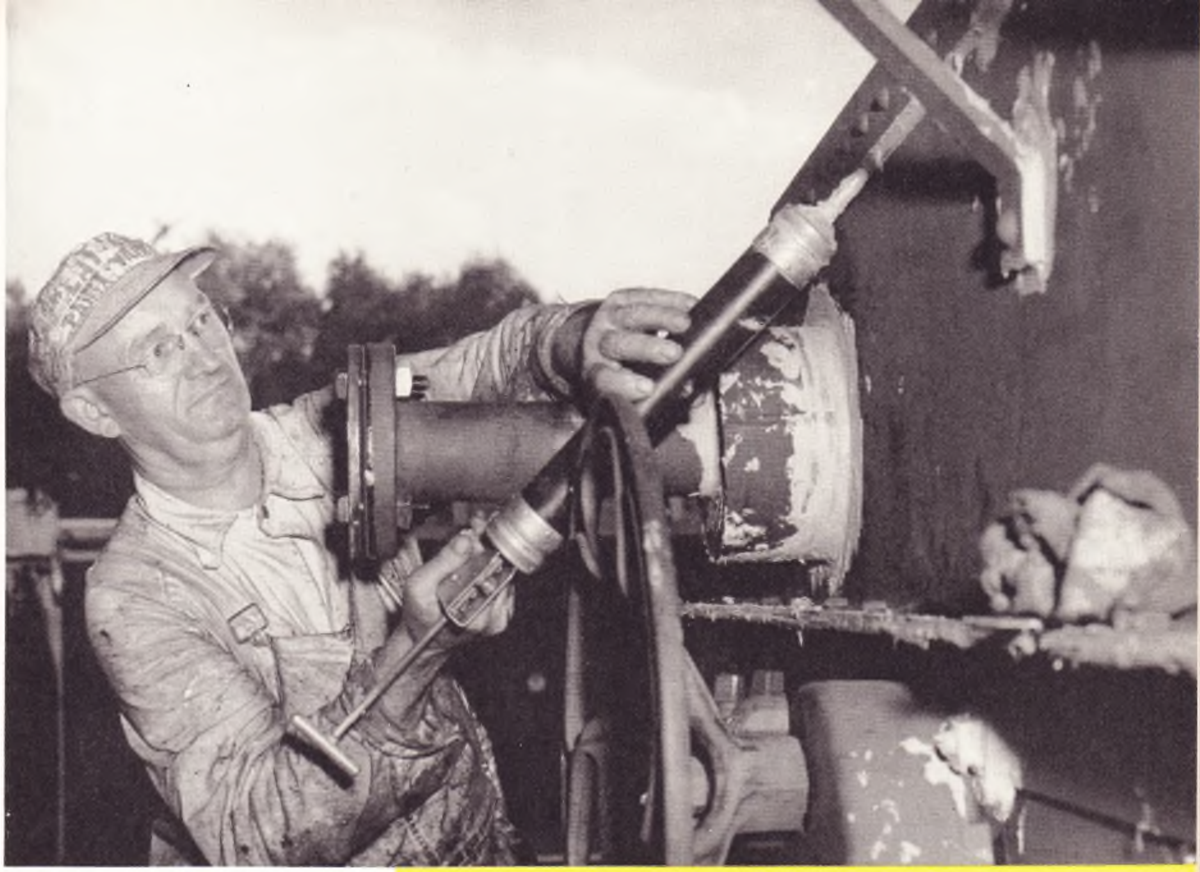
Engineering Test of Sealed Car

To demonstrate that such a program was feasible both from engineering and manufacturing angles, one of the cars of the power train was sealed and tested. The car selected was the service car, which contained machine shop, laboratory, and crew's quarters. The car differed from the equipment cars in that it contained considerable quantities (several thousand pounds) of wood "dunnage," which contained moisture. Dehydration must, therefore,

Larger than ordinary boxcars, this power-train unit is indicative of the magnitude of this weatherproofing problem, and shows the possibilities of the system for treating storage enclosures for other large equipments.

Containers

G. L. Moses
Transportation & Generator Engineering
Westinghouse Electric & Manufacturing Co.



The cracks and joints in the car are caulked much as homes are caulked to make them weathertight. Afterwards the entire surface is covered with a weatherproof mastic that has a filler of mica dust to give it body.

provide for absorption of this moisture as well as atmospheric humidity.

Preparation of Car

All openings were covered with steel plates or flashed with waterproof cloth. Cracks and joints were caulked as shown with ordinary caulking compound such as used to make homes weathertight. Before sealing, 1200 pounds of silica gel, a desiccant, was distributed throughout the car. The whole car was then sprayed with a single coat (1/16 inch minimum thickness) of non-breathing waterproof compound. This material, developed by the Insul-Mastic Corporation of America, which also makes the special spray equipment required, is applied at ordinary room temperature. This non-breathing waterproof material is a compound having a petroleum asphalt base with the addition of a considerable percentage of gilsonite asphalt and an inorganic filler (mica dust). It dries in one to four days, depending upon atmospheric conditions and the thickness of the coating. It is dried by solvent evaporation but retains its plastic moisture-vapor seal characteristics over a wide range of temperatures (−50 degrees C to +50 degrees C). Because of this wide temperature range, the sealing compound is unaffected by extremes of ambient temperatures.

Exposure of Car During Test

In order to insure wide temperature cycling and exposure to high humidity the car, during a nine-day test, was moved from indoors to outdoors several times. During this period it was sprayed for two hours with a fire hose. The weather cooperated by providing temperatures as low as 16 degrees F with a rainstorm during the first outdoor exposure and a six-inch snowstorm during the last exposure.

Test Results

The temperature and relative humidity conditions inside and outside the car were recorded on separate recording Hythergraphs throughout the test. At the end of the test, samples of the silica gel were removed from the car for analysis. At the start of the test, the conditions within the car were: temperature, 60 degrees F and relative humidity, 30 percent. Outside the car the temperature was: 60 degrees F and the relative humidity, 36 percent. The relative humidity decreased rapidly inside the car from 30 percent at start to 20 percent in four hours and 16 percent at the end of 28 hours.

Within the sealed car the extremes observed were: temperature, 59 to 37 degrees F; relative humidity, 30 to 16 percent. Outside the car the extremes were: temperature, 74 to 16 degrees F and relative humidity, 100 to 29 percent. Analysis of the silica-gel moisture content indicated that equilibrium had been reached at a relative humidity of 16 percent.

The seal obtained on this car was satisfactory over a considerable spread in atmospheric temperature cycling (16 degrees to 74 degrees F). The desiccant within the car quickly reduced the humidity to a value below 20 percent (30 percent is considered safe relative humidity) and maintained this low value. Thermal insulation greatly reduced the effect of external temperature variations on temperature within the car, (37 degrees, 59 degrees F) which minimized changes in internal pressure which tend to produce breathing. Temperature cycling of the car air did not produce observable changes in the relative humidity of the car air.

Silica gel (a prepared form of silicon dioxide) is an inert desiccant. When activated by dehydration it absorbs up to 35 percent of its own weight to maintain a relative humidity of 70 percent. The action of silica gel in absorbing vapors is purely physical and there is no change in the size or shape of the particles such as occurs when chemical absorption takes place. Even when saturated, the particles of silica gel feel and appear perfectly dry. It does not give up its moisture except by application of high temperature and, therefore, may be placed on the surface of parts to be protected without danger of corrosion.

While the waterproof mastic is not intended for application directly upon the equipment or parts to be protected because of the extreme difficulty in removing it, it can be applied to the surfaces of smaller containers such as cartons and wooden boxes. A use envisioned for this weatherproofing scheme is the protection of equipment that must be stored outside more or less temporarily. This method of protection is also being used for waterproofing truck trailers in transit that contain special radio equipment.

What's New!

All-Position Welding with A-C

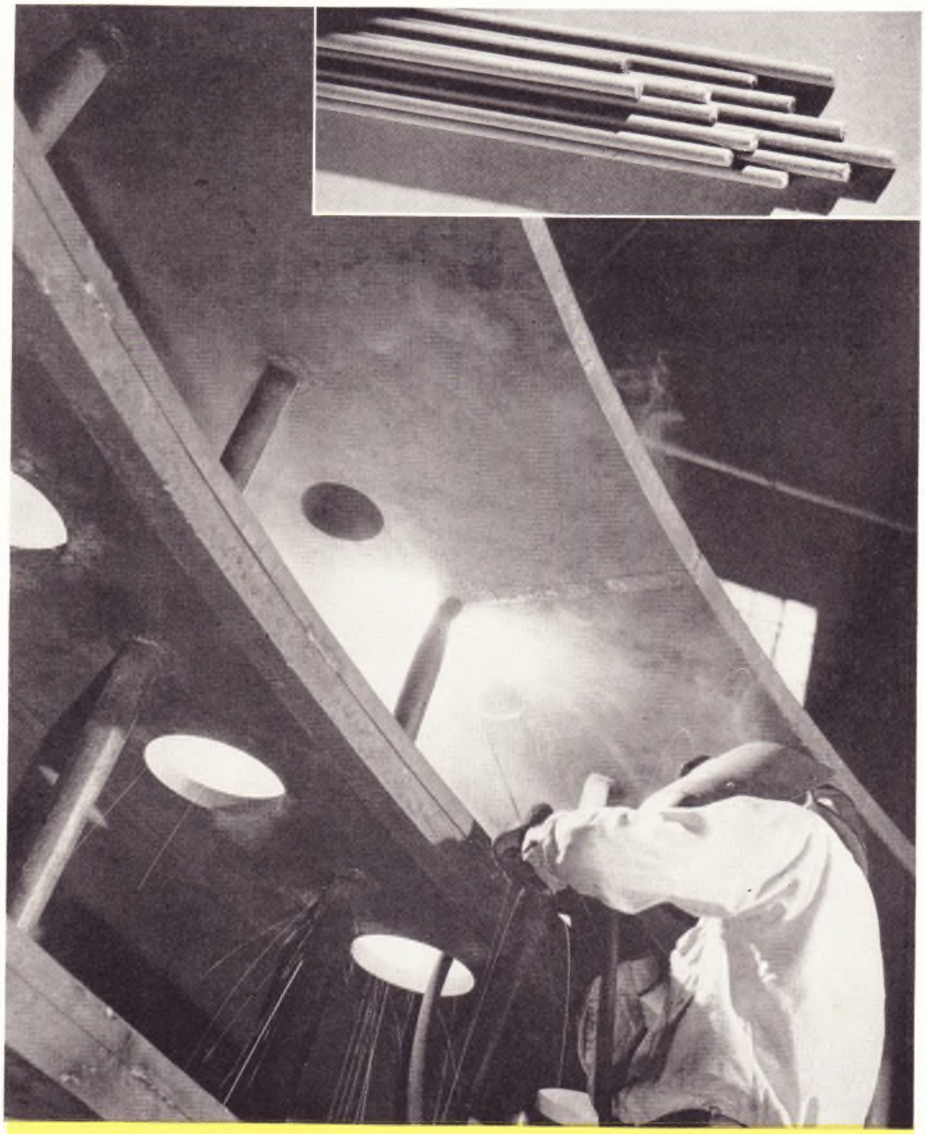
For best performance on vertical and overhead arc welding, a high-organic electrode coating is used. This coating provides an envelope of burning gas that keeps the oxygen and nitrogen in the atmosphere from contaminating the weld metal. This type of coating leaves but a scanty slag over the deposited metal that does not interfere with welding.

Curiously, this high-organic coating works in a satisfactory manner when the current flows in one direction but not the other. Obviously, d-c welding is easily performed in these positions but alternate half-cycles of a-c welding would be unsatisfactory. This restriction has impeded the progress of the much simpler a-c welding for some fifteen years. Good reverse-polarity (electrode positive), all-position, d-c electrodes have been available for years. The secrets of the prerequisite coating for all-position, a-c welding began to unfold some two years ago. The Westinghouse ACP welding electrode meets the requirements established by the Navy Department Bureau of Ships and The American Welding Society (Grade E 6011) for an electrode of this type.

The coating of an a-c welding electrode must provide a number of factors, indispensable to a satisfactory weld. Protection from atmospheric gases, scanty slag, no slag interference with the arc, adequate drive and penetration without undue spatter loss, are some of the factors dependent upon a proper electrode coating.

In addition, two factors of great importance in a-c welding are arc stabilizing and "arc pacifying." When the current goes through current zero, the arc is extinguished and the coating must provide an enveloping atmosphere of highly ionized gas so that the arc will restrike for the succeeding half cycle. Also, assuming the current during the first half cycle has been flowing in the reverse-polarity direction (the direction in which high-organic coatings operate best), the correct amount of "arc pacifier" must be provided for the next half cycle to prevent excessive spatter loss, at the same time avoiding loss of drive and penetration.

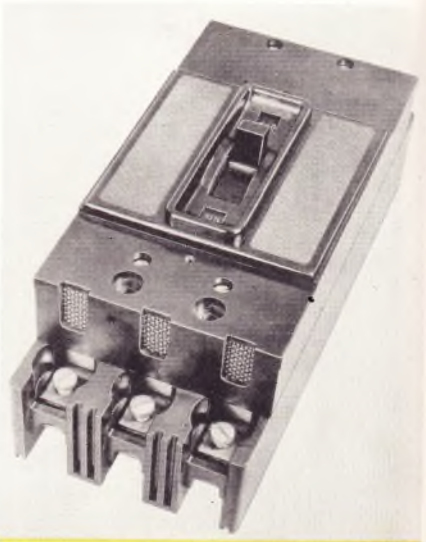
All of these attributes have been incorporated in the coating of the ACP electrode. The availability of an electrode capable of producing welds in overhead and vertical positions, having the high ductility and freedom from porosity necessary to meet the most rigid code requirements, has further accelerated the use of a-c welding.



The ACP welding electrode, shown in detail in the inset, is an all-position, a-c electrode that incorporates the attributes required for this class of welding.

A New Lightweight Large-Capacity De-ion Breaker

A De-ion breaker with a larger capacity for a given size has been perfected. It saves both space and weight. One hundred-ampere, 600-volt a-c, or 250-volt d-c breakers now occupy no more space than that formerly required for similar breakers rated at 50 amperes. This increase in capacity is made possible by using an F-frame that provides better insulation



This new weight- and space-saving breaker is equipped with thermal and instantaneous tripping elements.

and more thorough isolation of the poles.

While thermal capacity is somewhat lessened for heavy-duty applications, this loss is offset by the gains derived from the F-frame construction and from the use of contact points whose pressure increases instead of decreases with wear. The larger capacity of this breaker permits lighter structures for distribution panelboards, built-in applications, and bus-duct plugins. The mounting space required is less than for previous breakers of like capacity.

These F-frame breakers are of the same size, regardless of rating (15 to 100 amperes). They are assembled in one compact frame size with uniform pole spacings and terminal arrangements, in either two- or three-pole units. This fuseless De-ion circuit breaker is equipped with thermal and instantaneous trip elements.

Airport-Runway Lighting Brightness Control

At first blush, it would seem that there should be but one brightness for airport-runway lighting, the brightest possible. Such is not the case. Contact lights—lights installed flush with the ground used to outline the runway—need to be bright in poor weather but the same brightness can be too bright in clear weather. For security reasons also, it should be possible to dim airport contact lights. A new brightness-control regulator, meeting joint Army and Navy (ANC) specifications, provides 100, 30, 10, 3, and 1 percent of the normal brightness of the lamps in the runway circuit.

The complete assembly consists of a rotary-type primary-tap changer for primary-voltage adjustment, an input transformer with five taps for brightness selection, a current transformer, and a resonant-type constant-current network for providing a constant-load current from a source of constant primary voltage. These elements are all mounted in an oil-filled tank and operate as a unit. The terminals are the shielded-stud type.

Of particular interest is the regulator providing constant current to the load. This is known as a monocyclic-square regulator and is a resonant circuit composed of capacitors and reactors. This constant-current device has no moving parts and has greatly improved power factor at reduced loads compared to moving-coil, constant-current regulators.

By means of relays, the control-tower operator can select any of the five degrees of brightness. The output currents of 6.6, 5.5, 4.8, 4.2, and 3.8 amperes give 100, 30, 10, 3, and 1 percent normal brightness of the lamps in the airport runway circuit.

The brightness-control regulator operates on a primary voltage of 2300 and is rated at 7.5 kw. The approximate primary-load power factor varies from 96 to 98 percent.

Add a 400-Ampere Heavy-Duty Welder

To the 300- and 500-ampere Flexarc a-c welders has been added the median 400-ampere capacity unit. Under the exigent demands of tooling up for global war, the 500-ampere welder was used for both automatic machine welding and manual welding. Manual welding provides a poor load factor for this capacity welder and yet often the work is too heavy for the 300-ampere welder. The 400-ampere a-c welder provides adequate welding current capacity for all manual welding operations with good load factor.

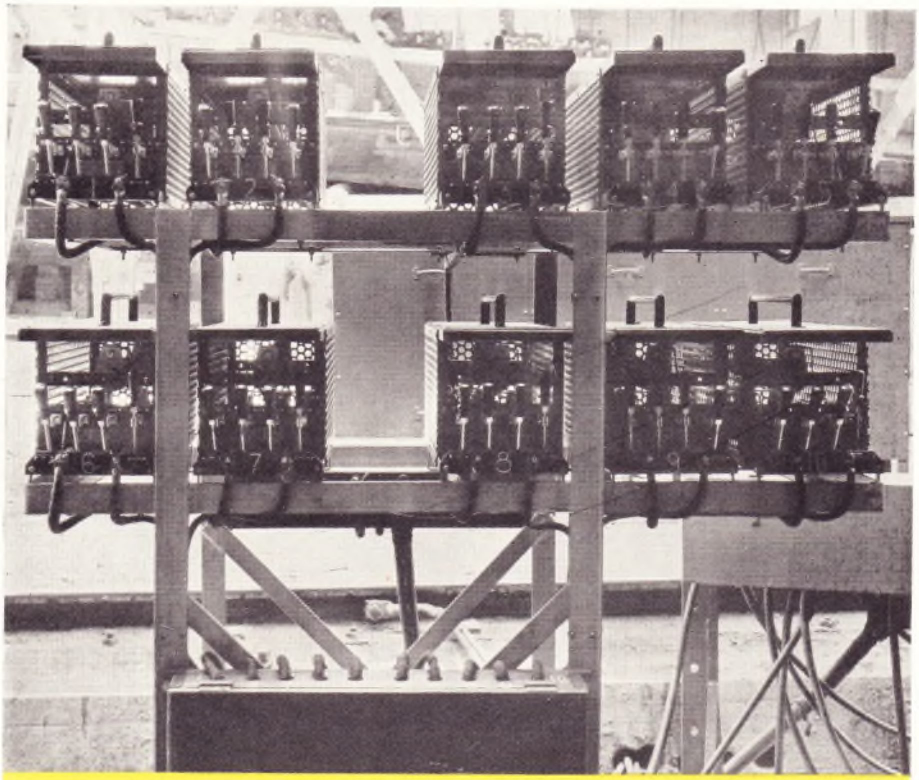
The current range of the 400-ampere Flexarc welder is 80 to 500 amperes. This supplements the 60- to 375-ampere range of the 300-ampere welder and 100- to 625-ampere range of the 500-ampere unit. The current delivered by these machines is continuously variable over the entire range by means of a crank that varies the gap of an adjustable reactor core. The current setting is shown directly on a dial.

These welders have built-in capacitors for power-factor correction but can be had without them if correction is not necessary. A built-in automatic voltage control for automatically reducing the off-arc (open-circuit) voltage to approximately 35 volts is available if desired. In common with the companion units, the new 400-ampere Flexarc a-c welder is enclosed in an outdoor weatherproof case, permitting use in any location. Normally equipped with heavy eyebolts for moving by crane, these units can be furnished with truck mountings.

Basting Steel with an Arc

Much as a seamstress bastes material in place, tack welders baste steel sheets in position with short welds called tacks. They use a tacker control with a source of constant-potential welding power. When the final welding of the plates takes place (called production welding) the multiple-operator m-g sets are used to full capacity. When these higher rated heavy-duty welding panels are used

The current delivered by this welder is continuously variable over its range of 80 to 500 amperes. The adjustment is made with the crank on top and the current setting is shown directly on a dial above the nameplate on the side of the transformer.



These panels provide current for tack welding in ten-ampere steps. These portable units are rated up to 250 amperes and can be used for intermittent welding.

for tacking, only one third or less of the panel capacity is used. Westinghouse tacker panels provide a readily portable outlet of adequate capacity for tacking operators, leaving the heavy-duty panels for production welding.

The tacking panels provide ranges of welding current of approximately 10, 20, 40, and 80 amperes. Various combinations of four switches on the panel give a current adjustment over the range in approximately 10-ampere steps. The resistors are so designed that the panel can be used on nominally rated, 60- or 70-volt, constant-potential systems.

These tacker panels are small, weighing from 31 to 90 pounds, and can be picked up and carried to the job location by convenient handles. The panels are available in four ratings: 150, 175, 200, and 250 amperes. As a supplement to standard multiple-operator circuit-control panels, these tacking panels greatly increase the capacity of the multiple-operator welders.

By a simple reconnection, most single-operator welding sets can be converted to constant-potential sets for use with a number of tacker panels. The usefulness of the single-operator set is thereby multiplied several times when used for tacking. By suitable switching, the reconnected heavy-duty, single-operator welder can readily be changed back for production welding after tacking. In addition to tacker service, the tacker panels can be used for intermittent welding such as welding in place clamps and brackets.

Carrying Fluorescent Lighting to New Lengths

'Round the clock war work has made people lighting conscious. This is reflected in industrial lighting and will be reflected in home and commercial lighting when such changes can be made. A new lighting tool for distinctive commercial lighting is presented in a newly developed family of fluorescent lamps that are made in lengths up to eight feet.

The new lamps, standard white in color, will be available in overall lengths of 42, 64, 72 and 96 inches. The lamp is a slenderized version of the usual fluorescent lamp, hence its name—Slimline. They are particularly adaptable to showcase lighting, both because of their length and because of their smaller diameters. These diameters range from about three-quarters inch to one inch as compared to the approximately two and one-eighth inch diameter of the standard 60-inch fluorescent lamp. The smaller diameter permits the use of a smaller reflector, minimizing "blind" spots in the showcase, shadowed by the reflector itself. Because of the extreme lengths of the lamps, one lamp suffices to provide a ribbon of soft light that extends the entire length of the case and produces interesting effects.

For general commercial lighting in restaurants, night clubs, stations and similar public places, lighting must be both efficient and decorative. These new lamps enable lighting engineers and decorators to introduce a change in pace in usual commercial lighting practices. The unusual lengths permit striking lighting effects to be achieved and the small diameters of the lamps allow their placement in places where space is restricted.

The new lamp will operate on 115-volt, 60-cycle, a-c lines with special ballasts that provide instant starting. These Slimline lamps are of the high-efficiency, hot-cathode type and, depending on the rating of the ballast used, operate at two levels of output. The average efficiency of the group of lamps reaches a new high for fluorescents, 60 lumens per watt as compared to 52 lumens per watt in standard 40-watt fluorescent lamps. The 100-watt incandescent lamp produces but 16 lumens per watt.

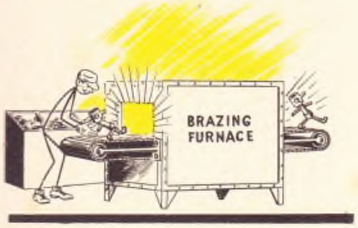
Long, slender lines of light will make show cases, restaurants, and other applications more attractive.

PERSONALITY PROFILES

Colorful men beget colorful careers. Such, at least, is the case with *Peter L. Bellaschi.* Graduating in '26 from M.I.T. with the degree of B.S. in E.E., he came with Westinghouse the same year and completed the student course. In 1927–28 he was back at M.I.T. for his M.S. Upon returning to Westinghouse he early became identified with the Transformer Division and has been there ever since. He has been known best for his technical investigations in transformer development. One of the early workers in the high-voltage laboratory at Sharon, he there fathered much of the impulse-testing technique, particularly as Section Engineer of the Insulation Department. His experimental and analytical work have had international recognition. In addition to participation in the standardization programs of the AIEE and NEMA he has worked with the International Electrotechnical Commission on high-voltage standards and testing techniques. He was so engaged in Europe in the fateful year 1939 when war was declared. Not so eventful historically, but highly satisfactory otherwise was his recently completed four-month tour of six South American countries, lecturing and making field trips. He was signally honored for his achievements by receiving in 1936 the Silver W Award of Merit from the Company and the honorary degree of Doctor of Science from Washington and Jefferson College.

* * *

Few people bring to their work the all pervading enthusiasm that inspires *Arthur K. Phillippi* in his activities in furnace brazing. Coming to Westinghouse in 1916 from Tri-State College of Engineering, where he received the degree of B.S.E.E., his background of experience with the Company has been varied and particularly helpful in the development of brazing techniques, in which field he has become a nationally known figure. Starting right in on the test floor at East Pittsburgh, he was successively occupied in test engineering, works engineering, radio engineering, with additional terms of various lengths in the transformer, elevator and refrigerator divisions. Ten years ago he became a manufacturing engineer in the works department of the Merchandise Division. Particularly in air-conditioning work was his fast-developing flair for furnace-brazing applications given full sway. To say something cannot be made is a challenge to Phillippi, who will quickly show that it can be made, and made better, by brazing. Furthermore, he will set up the manufacture of the article on a mass-production basis and have the time of his life doing it. If he isn't out in a customer's plant, he probably can be found in the basement shop in his home, where his handicraft is readily apparent. To maintain a balance in his activities he "farms" a huge victory garden.



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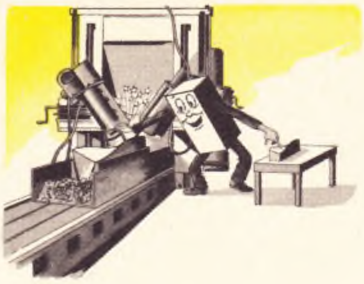
Operating a machine-tool business apparently runs in the family of *H. Earl Morton*, our guest author of the month. The Morton Manufacturing Company was established by his grandfather and father. He grew up in the business of making special types of keyseaters and shapers. Never engaged in mass production of standard lines of machine tools, the company has become widely known as makers of large combination milling, drilling and shaping equipments. Mr. Morton, President of the company, is a happy combination of executive with ability to function as chief engineer and sales manager. Although mechanically minded by training and natural bent, he maintains an open mind in accepting electrical equipment to do mechanically difficult chores.



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G. A. Caldwell was graduated from Purdue in 1927 with a degree in electrical engineering, and came directly to Westinghouse. The ensuing years have encompassed for him a succession of interesting and often spectacular applications of electric drives and controls to many kinds of equipments. Cranes, hoists, all sorts of steel-mill auxiliaries (including a "hot saw" for cutting to length red hot steel pipe as it is formed, a sheet catcher and a flying shear), machine-tool and other industrial drives, have all been grist to his mills. Caldwell returns to our pages—last appearance August 1942—as co-author with Mr. Morton in telling the story of the tracer-controlled profile miller. He is now manager of the General Mill and Resale Section.

* * *

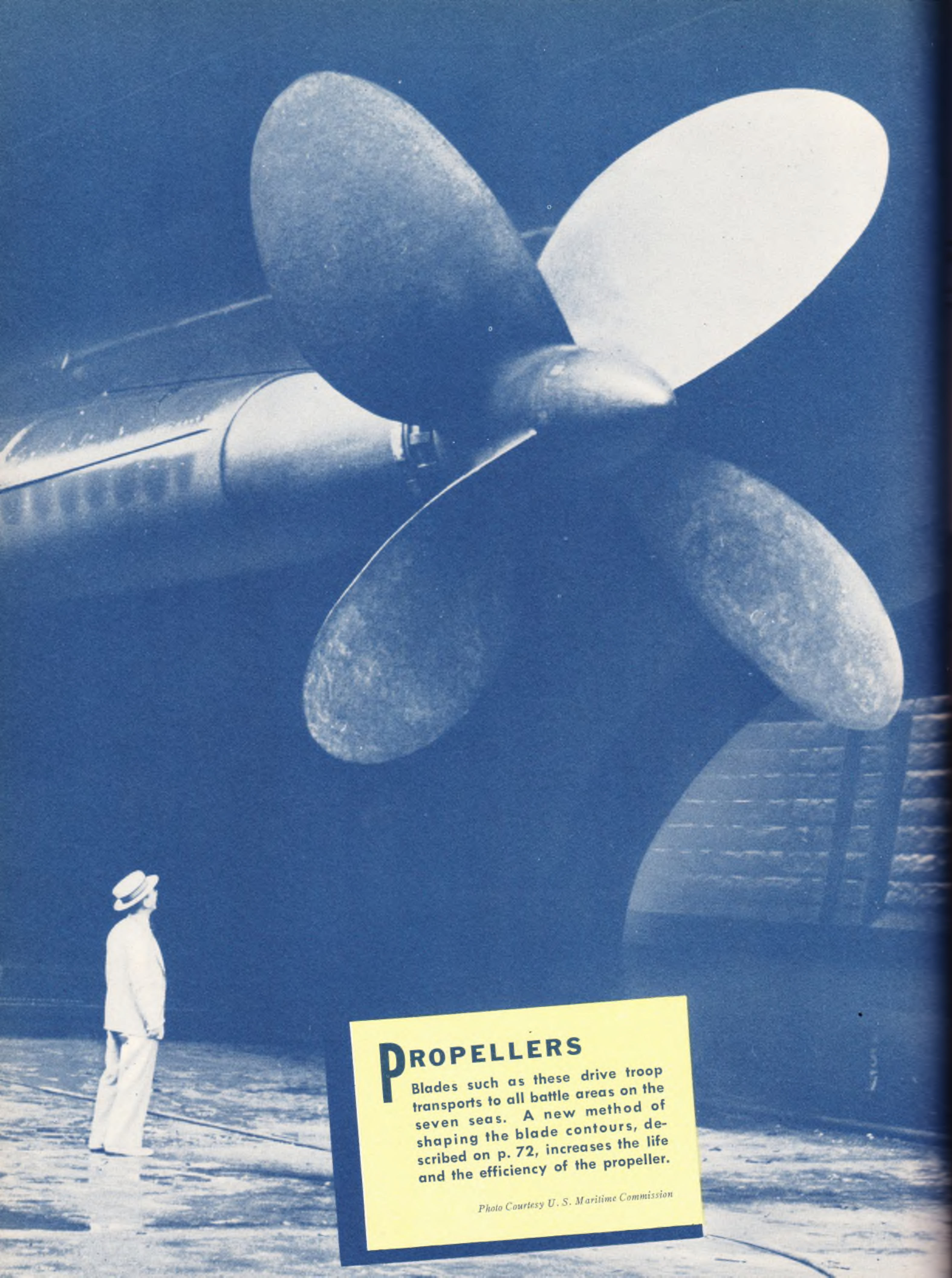
From the Engineering School of Columbia University came *Clark B. Risler* in 1937 after receiving his B.S. and M.S. degrees in E.E. After completing the student course he became identified with the Industry Engineering Department, first Central Station and then General Mill Sections. By background and experience he is well fitted to cope with the abstruse control problems of industry that come his way. A choir singer of repute, he is quite active in church affairs. His title of "Deacon," however, stems from his prayerful attitude when trying to use a little body English while bowling.

* * *

Since 1917, when *W. R. Wickerham* first came with Westinghouse, he has been active in producing controls that extend the application of a-c drives. Beginning his career with the Company in the Control Division, he took the Student Training course later. A graduate of the Carnegie Institute of Technology, he combines practicality with well-grounded theory. Wickerham last graced these pages in May, 1943. He still continues his Civil Air Patrol activities and now is the proud possessor of a pilot's license.

* * *

From Alabama has come a man who has made himself recognized as an authority on heat transfer. *Robert A. Bowman* studied mechanical engineering at University of Arkansas, receiving his B.S. in M.E. there in 1929. He came directly to Westinghouse, and after a year and a half in the Research Department he moved over to the Steam Engineering Department, where he has proceeded from the Experimental Section to the Condenser Engineering Section of which he became manager in 1940.



PROPELLERS

Blades such as these drive troop transports to all battle areas on the seven seas. A new method of shaping the blade contours, described on p. 72, increases the life and the efficiency of the propeller.

Photo Courtesy U. S. Maritime Commission