Manufacture of Rigid Repeaters and Ocean-Block Equalizers

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Manufacture of two-way rigid repeaters and ocean-block equalizers at a rate equivalent to approximately 7000 miles of cable a year required the establishment of a new plant. A suitable building was constructed and equipped to maintain the closely controlled environmental conditions essential to attaining the quality required to assure a minimum product life of 20 years. An organization was established and trained to operate the plant. Special facilities were developed for manufacture and testing, including automatic readout and transmission of the test information to a data center where the results are recorded in a punched card system and analyzed by machine.

The facilities, their use, production methods from procurement of materials to packing of completed repeaters and equalizers, and precautions taken to attain and assure the required high quality are reviewed on the following pages.

I. INTRODUCTION

Early in 1959 a decision was made to start production of a new rigid repeater for SD submarine cable telephone systems.[1]

Since repeater manufacturing know-how was available at the Kearny, New Jersey, plant of the Western Electric Co. from earlier production of flexible repeaters for SB cable systems,[2] the manufacture of the SD repeater was also allocated to Kearny. The same general philosophy of building integrity into the product to the limit of practicability was again to apply. The same manufacturing requirements on environment, personnel, wage payment, training program, and inspection on a 100 per cent basis were also to be used.

In the following information reference will occasionally be made to flexible repeater manufacture at Hillside, New Jersey, with the assumption that interested readers have previously read or now have access to the information published in 1957.[2]

II. PLANNED CAPACITY AND DELIVERY SCHEDULES

The manufacturing planning was based on a capacity of six repeaters per week on a one-shift five-day basis. It was estimated that this capacity would permit production of up to eight repeaters per week on an all-out basis when all processes had been shaken down and operators fully trained.

The initial estimated manufacturing interval was 90 weeks, which should be reduced to between 60 and 65 weeks when production got underway with fully-trained operators. In reality, operations were started by the middle of September, 1960, and the first repeater was shipped by the end of June, 1962. This initial interval amounted to 92 weeks. The normal manufacturing interval is about 63 weeks, the greater portion of which is used for temperature cycling and aging of components.

Schedules called for delivery of 66 repeaters by the end of 1962 and, during 1963, 108 in the first quarter, 110 in the second quarter, 83 in the third quarter, and 123 in the fourth quarter. To meet these schedules required spurts in the output rate of up to ten enclosures per week. This was accomplished by earlier start of apparatus production and more rapid build-up to a rate corresponding to eight repeaters per week. By providing some additional testing capacity and extending enclosure operations into a second shift, it was possible to assemble repeater units and enclose repeaters at the higher rate required to meet over-all schedules. Nearly a year was required from the time of shipment of the first repeater to build up to maximum production capacity.

III. HIGHLIGHTS OF CLARK BUILDING

From the design information available at the time authorization to go ahead was received, a rough shop layout was made. Based on Hillside experience and the nearly sevenfold increase in quantity of apparatus to be manufactured, a minimum need for 85,000 square feet of floor space was indicated.

After inspection of several buildings contractual agreement was entered with a contractor to build and lease to Western Electric a 97,000-square foot building at Terminal Avenue, Clark, N. J. This location was deemed satisfactory from the standpoint of availability of the required type of labor within the nearby areas. The building was designed and built to meet the specifications for a repeater shop and other Western Electric standards.

Construction of the building was started in June, 1959, and completed in July, 1960. Only the land and building shell were leased from the contractor. All installations of lights, drop ceiling, special rooms, floor tile, heating boilers, air-conditioning equipment, and cafeteria facilities were provided by Western Electric. Although the building was originally acquired on a ten-year lease with option to buy, it was purchased by Western Electric in July, 1962.

The building is of one-story steel and masonry construction, 360 × 270 feet, with 40 × 30 foot bays. In office areas and "white" (i.e., super-clean, controlled-environment) areas, ducts for power, telephone, and other communication circuits were installed on ten-foot centers, with knock-outs every two feet, in the concrete floor slab. A sheet rock drop ceiling was installed 11 feet above the floor. All air-conditioning ducts, piping, and other services were installed in the six-foot space between the roof and drop ceiling. In office areas and cafeteria, acoustic ceiling tile was used. To avoid pipes in the open, water, compressed air, deionized water, dry nitrogen outlets, and outlets from the central vacuum cleaning system were, wherever possible, installed in partition walls and inside the covering over the building columns. The back wall of the building was constructed with future expansion in mind. The columns are provided with plates for connecting joists to them, and the wall is cinder block construction for ease of removal in part or whole. A general block layout of the building is shown in Fig. 1.

To meet the New Jersey manufacturing building code without having to erect internal firewalls which would have interfered with the general layout, ten-foot-wide main aisles are provided. These aisles would allow movement of standard mechanized fire-fighting equipment and thus provide the required protection.

The state code also specified heat vents in the roof, which would have required undesired openings in the ceilings of the white areas. However, mechanical fire baffles in the air-conditioning ducts and means for exhausting the return air completely to the outside in case of smoke satisfied this requirement and eliminated the need for openings in the ceilings.

Since eating in places other than the cafeteria is undesirable in a plant of this type, the size of the cafeteria had to be increased somewhat over the normal requirements for the plant. The cafeteria seating capacity at Clark is 354, with facilities for cooking, dishwashing, etc.

The conditions of temperature, humidity, and ventilation are provided by five separate air-conditioning systems with a total capacity of 600 tons and with one common chilled water supply for cooling. Two of the systems, each with a large plenum chamber which includes the filtering equipment and a circulating blower, cover the main portion of the building. The filtering equipment consists of a mechanical filter

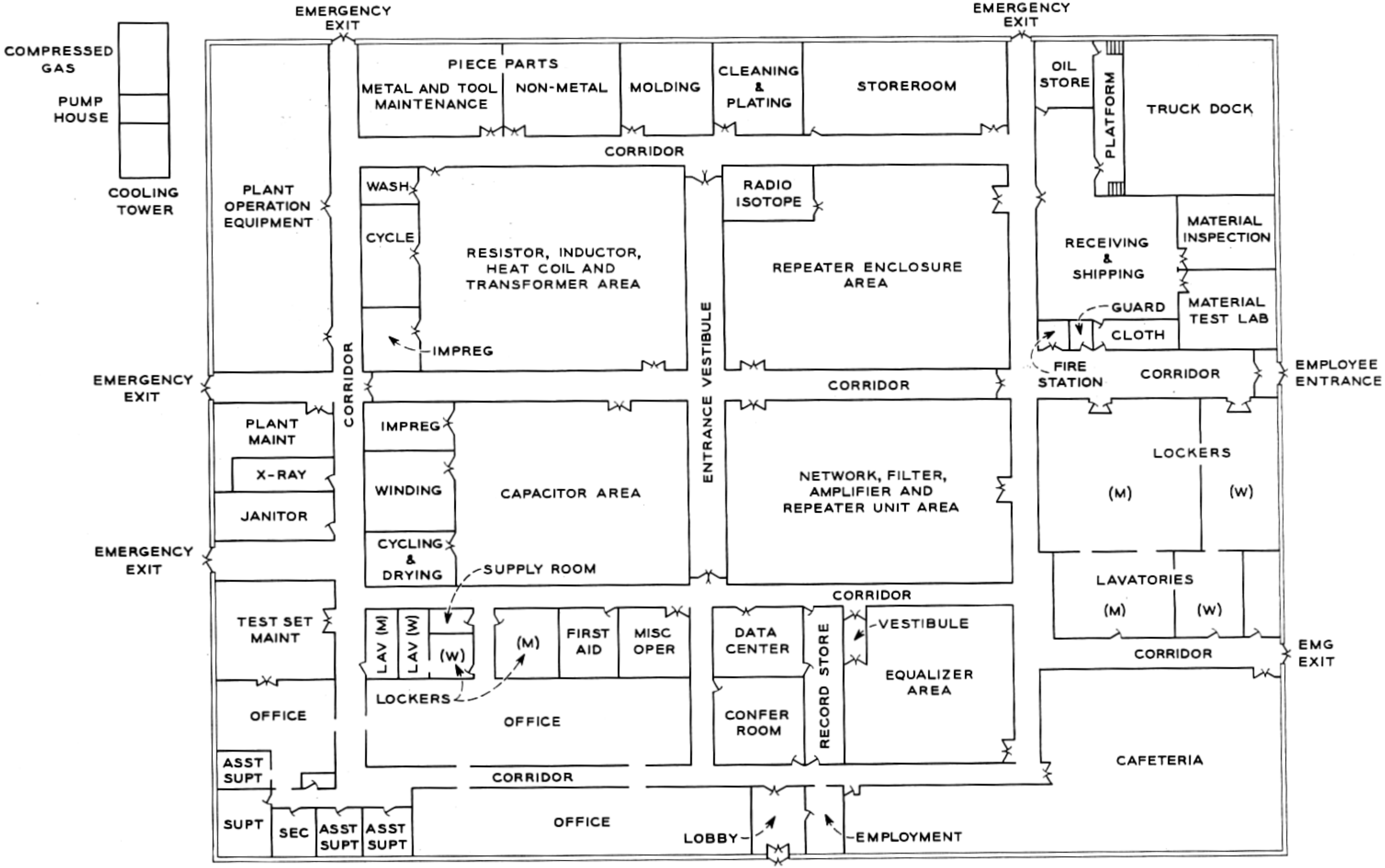

Fig. 1 — Plant layout.

followed by an electrostatic filter and a second mechanical filter. Originally the design called for a cold water spray for cooling the air, which would have been simple and efficient and would have stabilized the humidity at the desired value. However, this proved unsatisfactory due to minerals and algae in the water, which were precipitated upon evaporation and circulated out through the ducts in the form of fine dust. To attain the desired low dust count, a change was made to the use of cooling coils in place of the water spray; the change eliminated direct contact between the chilled water and the air and the associated evaporation and precipitation. The air is circulated by two blowers in series: one 40-hp unit in each plenum chamber, which provides positive pressure in the supply duct, and a 15-hp unit at the end of the return duct in a penthouse on the roof above the entrance to each plenum chamber, which provides a negative pressure in the return duct. The latter blowers also provide the means of exhausting directly to the atmosphere any smoke or fumes from fire or other causes through a system of louvers operated by a photoelectric smoke-detecting device. One of these main systems serves the four large white areas in the center of the building, shown in Fig. 1. The second system provides air conditioning for all of the peripheral areas, including offices but excluding the cafeteria. Means are also provided to interchange these systems.

Since smoking is permitted in the cafeteria, a separate system is used, which recirculates and provides the necessary make-up air for the cafeteria only. The air supplied to the locker and toilet rooms is not recirculated. To maintain uniformity of temperature during severe outside climatic conditions, means are provided for heating or cooling the air above the drop ceiling. In case of extreme cold, the space above the drop ceiling is heated by steam coils installed in several locations. To attain the desired low humidity of 20 per cent maximum in the capacitor winding area, a secondary cooling system is used which takes the approximately 55-degree air from either of the large plenum chambers and cools it down to approximately 22°F to precipitate the moisture. Since this is below the freezing point of water, dual cooling coils are provided: one is defrosted while the other one is in use, and vice versa. This switching is done by an automatic timing device.

The cooling facilities consist of three separate 200-ton centrifugal refrigerator units with chilled water outputs connected to a common header. The chilled water is retained in a closed-loop circulating system. A common cooling tower is used for cooling the water from the individual condensers. This arrangement permits one, two, or three of the machines to be used as required, resulting in good efficiency for the varied load encountered during the year. Except during the very few days of extreme high temperature and humidity encountered during the year, two of the units are sufficient to carry the load. This provides the required standby capacity for maintenance and repairs.

Two 200-hp boilers provide the necessary steam for heating and humidifying during the cold season and for dehumidification during hot weather. (To remove excess moisture, the air is cooled to approximately 45°F and then reheated to meet temperature requirements in the different areas.) One of these boilers is sufficient to carry the load, except possibly during a few days in the year when extreme temperatures may be encountered. During the winter, steam heat is also provided under the outside windows throughout the plant to offset cold air circulation and draft.

Approximately $2\frac{1}{2}$ miles of ducts are installed above the ceiling for circulation of the air. The supply air is admitted to the rooms through the outer opening of coaxial diffusers, and the return air is pulled back through the center opening. The circular return ducts from the diffusers run right through the supply ducts to the return ducts, which are located directly above the supply ducts. Sufficient blower capacity is provided to change the air in the building completely every five minutes. Up to 25 per cent of make-up air can also be provided. This is adjustable to the comfort needs of the building population.

The control circuit for temperature and humidity is air-operated. To ascertain that the air is sufficiently dust-free, a dust count is taken every morning in a number of different locations. A special Bausch and Lomb microscope is being used for this purpose. In making a test, air is pumped past a slide where any dust particles stick to a predetermined surface area. From the amount of air that passes this surface and the number of dust particles found on it, the average number of particles per cubic foot is obtained. In general, the dust count at Clark is comparable to the conditions obtained at Hillside and is considered quite satisfactory.

The over-all illumination of 85 foot-candles is provided by means of fluorescent lights in the ceiling. Certain of these lights are on a special emergency lighting circuit supplied automatically by a motor generator set in case of power failure. Provision has not been made for operating the plant in case of general power failure, since the power requirements are nearly 1500 kva. However, to assure maintenance of power, the plant is connected to a power loop which can be fed from several points.

The floor covering consists of one-foot squares of vinyl asbestos tile, which is a compromise with the original plan of using long lengths of wide material to avoid the possibility of dirt catching in the cracks between tiles. The tile has, however, proven quite satisfactory, since it has expanded and nearly eliminated all openings between tiles.

The walls or partitions for the different rooms in the building are commercial standard steel partitions having a baked enamel finish. Since these partitions were not of sufficient height to reach the ceiling, they were extended by an upper fabricated wall section of mineral boards. The partitions are insulated with rock wool, and the seams between panels are caulked to eliminate seepage of dust. Any openings at the floor are sealed by a flexible plastic base. To provide a more desirable environment, better possibilities for supervision and inspection, and, to some extent, an easy way to view operations, large windows were included in the partitions. For safety, this is wire-type glass.

To attain the best possible clean conditions in the white areas, the ceilings were covered with a washable vinyl fabric cloth. The same type of covering is also used on the portions of the walls above the metal partitions in these areas. For cleaning purposes, a central vacuum system has been included. Outlets are installed throughout the building for connection to the cleaning and scrubbing equipment. The acoustic ceiling tile in the office areas and cafeteria is a washable type which has a smooth surface without perforations. In aisles and locker rooms, the sheet rock ceiling is finished by painting. This also applies to the upper portions of the walls above the metal partitions in these and the non-"white" areas.

IV. CLARK ORGANIZATION

The same basic pattern as used at Hillside on the flexible repeater project, of having the organization report to the engineer of manufacture, is followed. However, since the operation is considerably larger, it is a full-time job for one superintendent, who is assigned to this project only.

There are four levels of supervision: superintendent, assistant superintendent, department chief, and section chief. At Clark there are three assistant superintendents — one responsible for engineering, one for inspection, testing and plant maintenance, and one for operating and production control. The responsibilities in each of these areas are, in turn, broken down into three departments with up to seven section chiefs in each, excluding engineering, which has no sections. On the average there are 16 operators reporting to each section chief.

The total population at Clark is 550, of which approximately 75 per cent are performing actual shop operations. Of the latter, approximately 40 per cent are female and 60 per cent male.

V. REPEATER ASSEMBLY

An outline of the major assembly steps from apparatus to completed repeater is shown in Fig. 2.

VI. TYPES AND QUANTITIES OF APPARATUS

In each repeater there is a total of 201 items of apparatus such as capacitors, inductors, transformers, resistors, heat coils, crystal units, electron tubes, and gas tubes. Crystal units are manufactured at Western Electric's Merrimack Valley Works and electron and gas tubes at the Allentown Works. Composition-type resistors and vitreous enameled resistors are purchased from outside suppliers. The remaining items, 86 codes, are manufactured at Clark; samples are shown in Fig. 3. A tabulation of apparatus used in the repeater is shown in Table I.

In addition to the items used in the repeater, there are 36 capacitors of 33 codes, 35 inductors of 31 codes, 53 resistors of 42 codes, and a stepping switch for the equalizer.

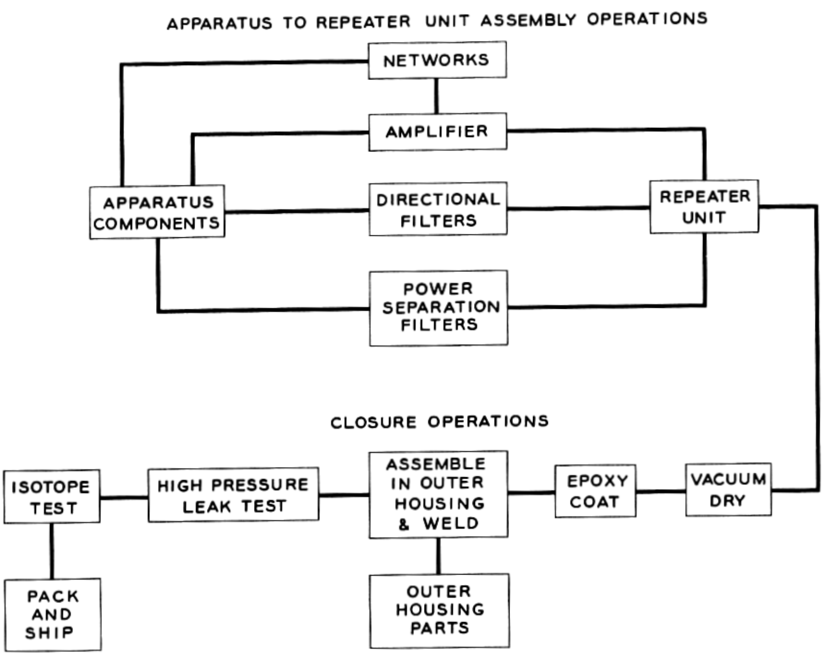

Fig. 2 — Major repeater assembly steps.

In general, the type of apparatus is similar to that used in the flexible repeater. However, the method of manufacture and the detail design in a number of cases are quite different.

VII. TYPE OF MANUFACTURING FACILITIES

A number of new manufacturing facilities were developed.

7.1 *Machinery*

Of the machinery for producing apparatus, capacitor winding machines, mica lamination silver coating machines and washing facilities, and some of the coil winding machines were new. After requesting bids from several companies, a manufacturer specializing in capacitor winding machines was selected to design and build machines to our specifications. Two types of machines, one for high-voltage capacitors and one for low-voltage capacitors, were built to these specifications, which also embodied some of the manufacturer's own outstanding features. The latter included a magnetic braking device to apply the proper tension to the paper spools, dual winding spindles, and electronic means for determining the foil length. The high-voltage capacitor winding machines, shown in Fig. 4, have as many as 18 spindles for paper and foil, which require, among other things, very close mutual line-up and tension adjustment to produce the required quality of winding.

An adaptation of a commercial machine was used for silk screening the silver coating on mica laminations. Better mechanical alignments were required, the right squeegee material had to be found, and the silk screens had to be made to closer tolerances and standards than ordinary. The originally planned number of openings in the screen and the number of parts coated at one time also had to be decreased, because it was not possible to maintain close alignment between the different openings in the screens.

New washing facilities for mica laminations were also developed. At Hillside, acetone was used for washing laminations, but with the larger quantities involved at Clark, the greater amount of acetone needed would have produced too great a fire hazard. A method using hydrogen peroxide and centrifugal drying was therefore selected. The new washing facilities are safe and require less space.

The design of coils for the one-megacycle repeater permitted all of them to be machine wound, whereas for the flexible repeater the majority had to be hand wound. Commercial machines are used for straight

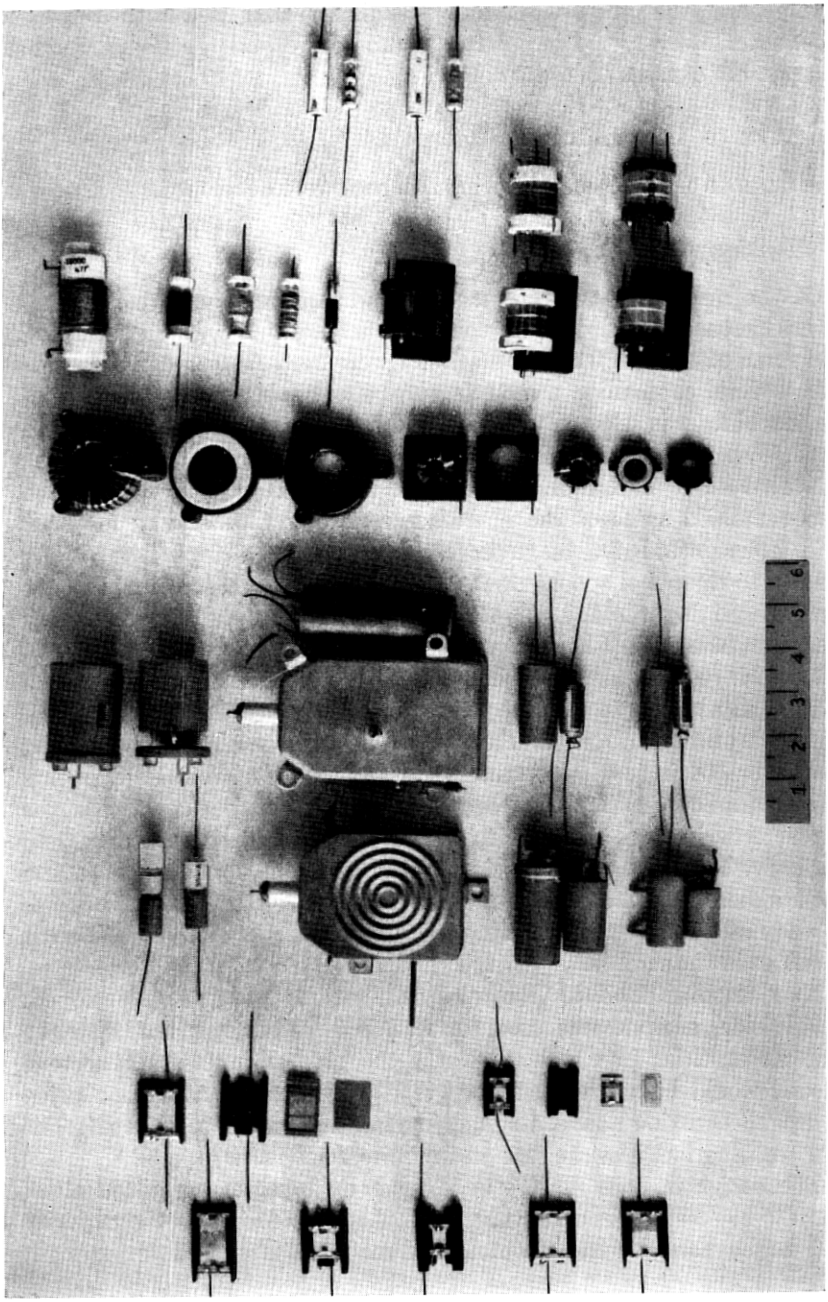

Fig. 3 — Sample parts.

TABLE I — APPARATUS USED IN REPEATERS

Part	No. of Different Codes	No. of Units	Value Range	Accuracy Range
Capacitors				
High-voltage paper	2	3	0.074–0.120 mf	3–5%
Low-voltage paper	9	22	0.001–2.0 mf	2.5–5%
Polystyrene film	6	12	0.0075–0.0192 mf	1–2%
Mica	24	46	0.000050–0.010350 mf	0.2–2%
Inductors				
Air core solenoid type—adjustable	15	24	3.45–415 μh	0.7–1.5%
Air core solenoid type	11	16	0.34–1000 μh	0.5–3%
Dust core toroidal type	4	8	115–9200 μh	1–2%
Transformers				
Ferrite core	4	6	—	—
Resistors				
Bifilar wire wound	14	25	15–600 ohms	0.1–1.1%
Mandrellated wire wound	4	10	1100–3800 ohms	0.4–0.8%
			73.2 ohms	1.5%
Vitreous enameled type	2	3	890.0 ohms	3.5%
Composition type	4	16	11,000–500,000 ohms	2%

solenoid, duolateral, progressive duolateral, and toroidal windings. However, a number of refinements were required to provide the proper wire tension, wire guide, and uniformity of winding.

Operations connected with enclosure of the repeater also required a number of new type facilities. Among these are vacuum drying stations, epoxy coating facilities, repeater assembly machine, welding machine for end covers, ultrasonic testing facilities, high-pressure helium leak testing facilities, isotope testing facilities, repeater handling facilities including trucks and hoists, and polyethylene molding facilities.

Considerable simplification of the vacuum drying stations and lower cost were accomplished with the use of a heating blanket to provide the specified bake-out temperature for the assembled repeater unit. The blanket, which completely surrounds the repeater unit, is equipped with thermostatic control to maintain the temperature.

Considerable development work was done by Bell Laboratories on a process for welding the beryllium copper end covers into the beryllium copper housing cylinder. Based on the process criteria established by Bell Laboratories, specifications for a production welding machine were prepared.

The machine, shown in Fig. 5, has two turntables to hold the repeater in a vertical position and means for centering it on the turntable so that the welding area runs true. The pedestal, which holds the welding head and a milling head, can be turned to either of the two turntable

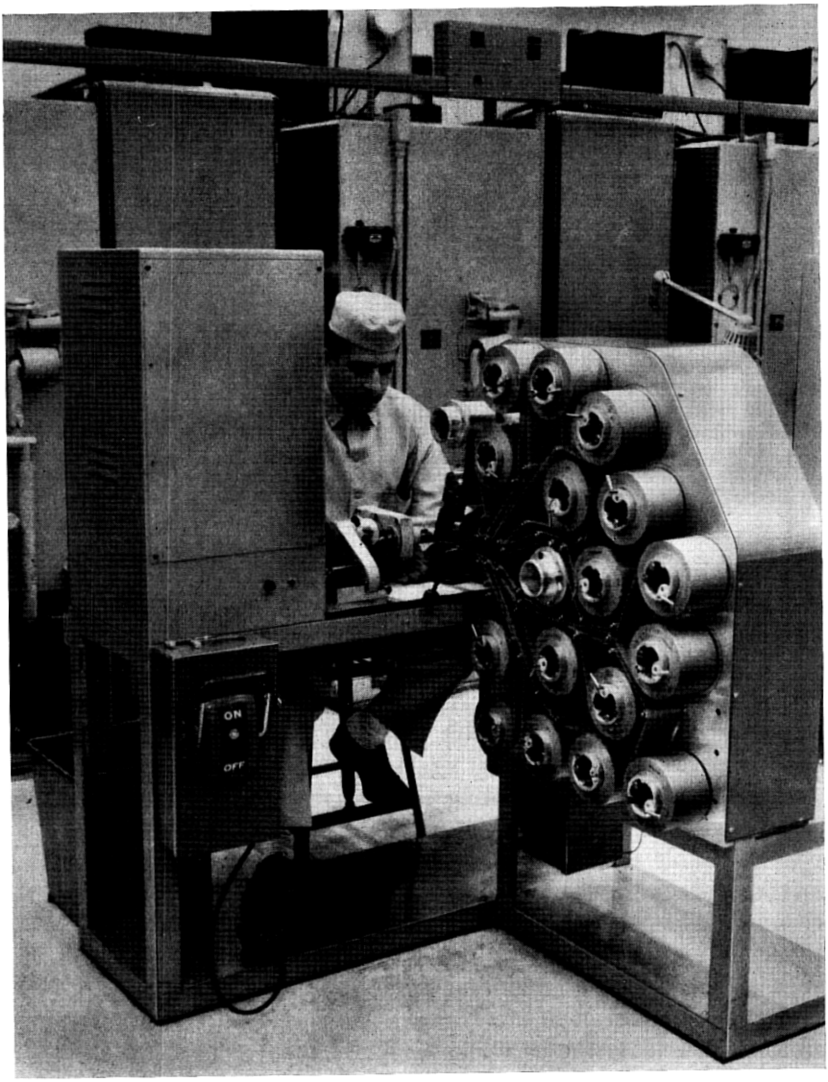

Fig. 4 — Capacitor winding machine.

positions. The milling head can be swung in position over the repeater welding area for removal of the surface layer to expose a clean metal surface for welding. The milling head is also used for removing the weld when repair is necessary.

The welding head uses nonconsumable tungsten electrodes with

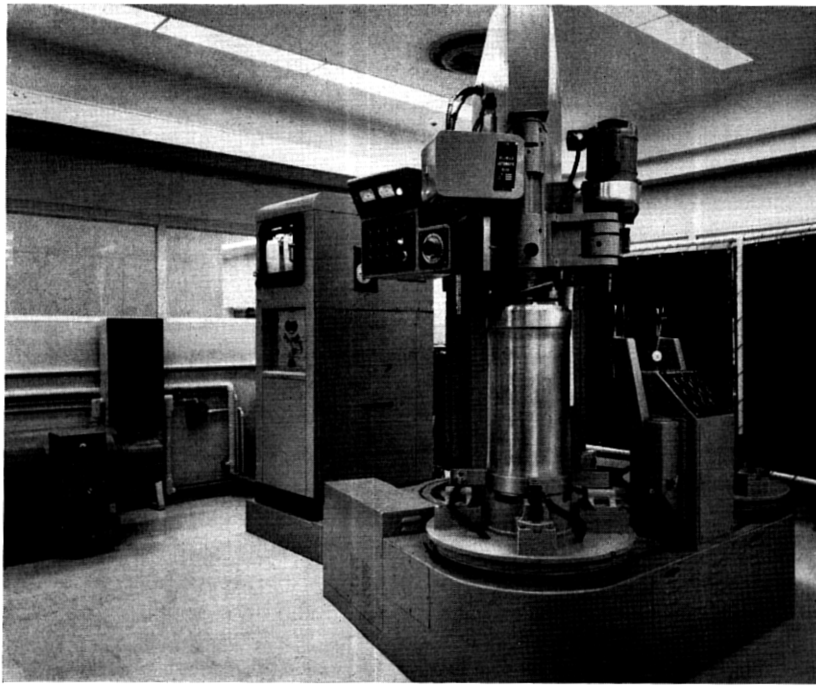

Fig. 5 — Repeater welding machine.

means for automatic control of the electrode gap. The current to the arc is furnished by a balanced-wave ac power supply which eliminates the dc component produced by the rectifying action of the beryllium oxide formed from beryllium in the copper alloy. A large dc component will reduce the stirring action produced by the ac current. A 30 kva regulated motor generator set is provided to eliminate the variations caused by the usual fluctuations in line voltage. The welding arc is shielded by an argon gas curtain.

The whole welding cycle, which takes approximately three minutes, is automatic. The cycle is started by pressing a button, and at the completion of the weld the current is tapered off to eliminate lap in the weld.

The high-pressure helium leak testing facilities will permit testing at pressures up to 12,000 lbs per square inch. Three-stage piston pumps are used with velocity and glass wool filters to keep the helium gas free of oil vapors from the pump lubricant. The pressure vessels are made from alloy steel and all gas-tight seals are made with O rings. The closure plugs for the vessels are held in place by heavy threaded sleeves which screw into the mouths of the vessels. To prevent extrusion of the O rings as the clearance between the vessel and the end plug increases due to expansion of the vessel at the higher pressures, a double O ring arrangement with an auxiliary steel ring is used. The steel ring fits inside the vessel and rests against the closure plug. Between the ring and the vessel is an O ring, and between the end of the steel ring and the closure plug is another O ring. As the pressure inside the vessel is increased, the steel ring expands and is also pushed up against the closure plug by the pressure, thus maintaining a tight gas seal. The lower part of the high-pressure vessels for testing complete repeaters is below floor level in a pit, whereas smaller vessels for testing covers, etc. are above floor level. The high-pressure pumps and test vessels are surrounded by heavy boiler plate enclosures as a safeguard for personnel in case a fitting or pipe should give way. The enclosures are open at the top to permit rapid escape for gas. Access to the vessels is through heavy doors, also of boiler plate, which are interlocked so that pressure cannot be applied while the door is open and so that when pressure is on the door cannot be opened. The application of pressure, the operation of pumps, and the flow of helium are controlled from a common control console. All high-pressure piping interconnecting units in the test set-up is run in troughs in the floor which are covered with heavy steel plates. Hoists on overhead tracks are used for handling repeaters and the heavy fixtures used in the high-pressure testing operations. The hoists are arranged to cover the entire test area.

A lead-shielded room has been provided for isotope testing of the pinch weld on the tubulation which gives access to the inside of the repeater housing. The operation has been automated to a fair extent. The application of isotope solution under pressure and removal of it after a specified pressure holding period and following washing cycle are programmed and controlled by push buttons, eliminating the need for the operator to be close to the source of radiation. The set-up is shown in Fig. 6.

Special molding presses were provided for molding polyethylene in seals and anchor details for repeater couplings. These presses are of three sizes: 10, 15, and 50-ton clamping pressure. Means for programming the molding cycle and recording temperatures and pressures and timing for injection of the polyethylene have been included. Arrangement for stabilizing the temperature of the cooling water for the molds has also been incorporated.

7.2 *Electrical Test Equipment*

To avoid operator error in writing down or transcribing test results, test sets are equipped with automatic readout, and, in some cases,

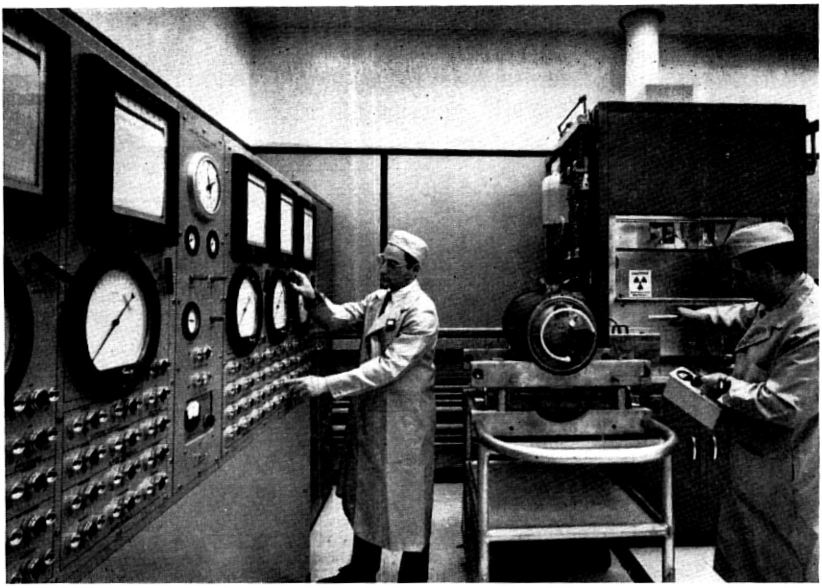

Fig. 6 — Isotope test facilities.

automatic balancing features. For example, in testing capacitors, the operator inserts a section of a punched card, punched with the type of test to be performed, apparatus code, and test limits, in the data transmitter. A smaller card section with the operator's identification and the test set identification number is also inserted in the data transmitter. The capacitor to be tested has a tag attached in the form of a small section of a punched card, punched with the serial number and the apparatus code. This card is inserted in a second data transmitting section after the capacitor has been connected to the test terminals. Next, the operator pushes a button which causes the bridge to balance itself rapidly and show the result on the dials. At this point the operator pushes a button on the transmitting panel which transmits the information on the three card sections, plus the reading of the test set, to a data center, where a receiver connected to a punched card punch receives the information and creates a card punched with the complete information transmitted, plus the time the data were received. In the data center the data card is compared to a standard card punched with the test limits and an indication whether the capacitor met requirements or not on that particular test. Upon completion of all the tests on an item of apparatus, the data from the individual cards are collected on a master card which is used for verification that the apparatus item has gone through all of the process steps and has met all requirements. A computer is available in the data center for making calculations where needed and performing the more complicated verification operations. A diagram of the flow of information from the test sets to the data center and processing of the data cards is shown in Fig. 7.

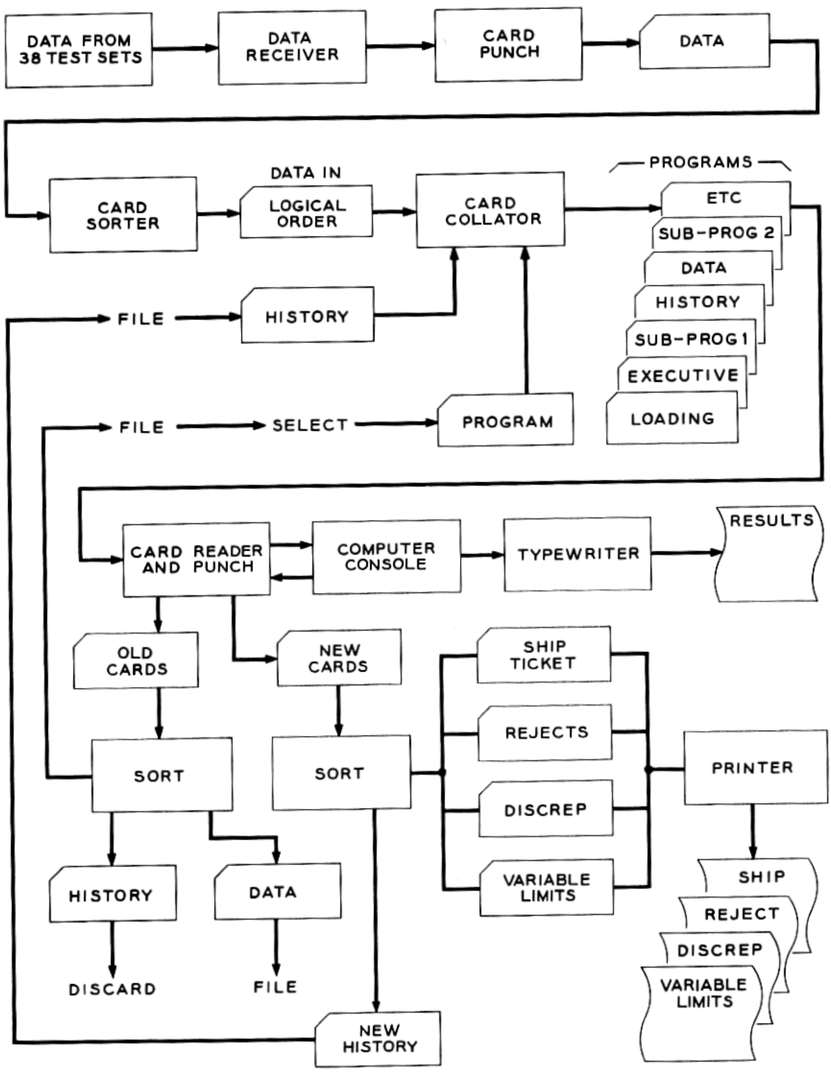

Fig. 7 — Flow of information from test set to data center, and processing of data cards.

A digital voltmeter method is used for measuring the insulation resistance of capacitors, since this method lends itself well to the required conditions of the test and is adaptable to read-out and transmittal of information to the data center. The insulation resistance measurements must, to be consistent, be measured at a predetermined time after application of the voltage, which must also be held precisely at the desired value.

Maxwell-type bridges capable of accuracies of ± 0.02 per cent are used for inductance and effective resistance measurements. This accuracy of measurements is obtained by limiting the range of the bridge and by careful selection of components and their over-all assembly in the bridge. Since only a limited number of frequencies in the 20-kc to 2-mc range were required, it was possible to use the "difference frequency" from fixed crystal heterodyne oscillators, which are simple and quite stable. The detectors used to indicate bridge balances are selective to the test frequency to eliminate errors from harmonics in the oscillator output.

Measurements of resistance on resistors are made by passing a known current from an exceptionally well-regulated current supply through the resistor and then measuring the voltage drop across it with a digital voltmeter. This accomplishes resistance measurements to within ± 0.01 per cent with a simple arrangement for transmittal of the resistance readings to the data center. A standard cell is used as reference in the voltmeter, and Zener diodes serve this purpose in the current supply.

For measuring the transmission characteristics of networks, filters, amplifiers, and completed repeaters, automatic transmission sets covering the 50-kc to 2-mc range are used. These sets are programmed to test at a certain number of frequencies over the desired transmission band. The results are sent in to the data center and recorded, and are also typed out on an automatic typewriter connected to the set. The programming of the set can be changed as required to perform tests at any frequency desired within the range of the test set. The test set, shown in Fig. 8, is housed in three floor cabinets, one containing the heterodyne oscillator and associated power supplies, the second the measuring circuit, and the third the indicating and readout equipment.

Phase and loss test sets capable of outstanding accuracy for measurements on networks, amplifiers, and repeater units outside the transmission band, at frequencies up to 30 mc, are constructed using a number of standard purchased units. These units, the majority of which are of German make, have performed very satisfactorily

For adjusting filter and other network circuits, visual return-loss

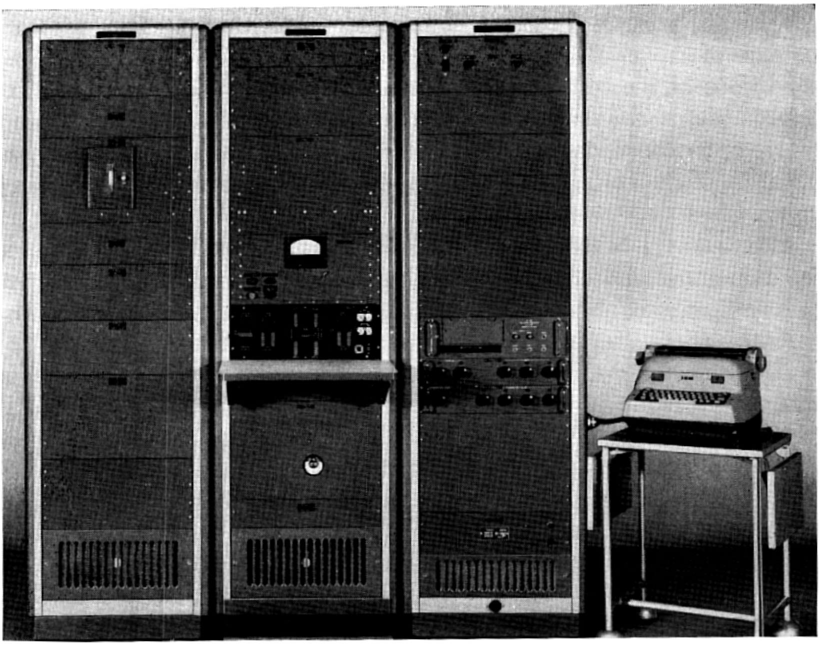

Fig. 8 — Auto-balance transmission measuring test set SID-100799, group 1 (front view).

sets have been provided. On these sets the transmission characteristics with frequency for the apparatus under test are displayed on a 17-inch picture tube.

Practically all test sets are provided with automatic readout, which requires a 150-conductor cable connection to the data center. The cables, which are run in the floor ducts mentioned earlier, are terminated in plug-in sockets under the test sets on the benches or the floor, depending on the type of test set.

VIII. JOB LEVELS AND PERSONNEL

Assignments among the people performing work directly on the repeater have, as at Hillside, been divided into nine different job levels, depending upon the requirement on skill and tour of duties. The lowest level includes assignments such as helper and materials handler, whereas the highest level entails duties which are much more complicated, such as those of the layout operator, whose assignments include operations requiring a long training period and a high degree of skill, and also include some instruction and work assignment duties. At Clark the greater portion of the population is in the four lower grades, with a peak in the third level. This is quite different from Hillside and can be accounted for by a greater breakdown of operations at Clark. The considerably higher production rate of individual components at Clark permits full-time occupancy for one person on just a few operations.

The key personnel — such as engineers, supervisors, and a number of the skilled trades and layout operators — were obtained by transfer from Hillside or Kearny. Other personnel were hired locally, usually within the first three grades. As they acquired skill, they were upgraded into higher grades and trained for the new assignment. The training program used for operators at Clark is similar to the one employed at Hillside.

In establishing the job grades, the requirements and the description of the assignments to be covered were recorded. Based on this and the general knowledge of elementary operations and their "value," the jobs were classified within the nine assignments mentioned. General judgment was used, and the levels and grades were discussed among several supervisors in order to establish a grade which was as realistic as could be obtained.

In hiring personnel and evaluating them, they were interviewed by supervision, in most cases at several levels, and also given standard tests devised for screening applicants for Western Electric employment. In general, the selection has been good and there have been very few cases where employees unsuitable to the assignment have been hired. There did not seem to be any serious objections to the specific work rules applying at Clark with respect to clothing, environment, and other items. As at Hillside, there seemed to be a genuine interest in the over-all project and its success, or what we might call "team spirit."

Communication between operators and supervision in different areas is extremely important. The larger the work force and operation, the more difficult is the task of maintaining these lines of communication. It is believed that the Clark organization of between 500 and 600 people is approaching the maximum which could be safely, from a quality standpoint, and efficiently utilized at one location on a complicated project of this type.

IX. PROCUREMENT AND TESTING OF RAW MATERIAL AND PARTS

Raw material and parts are purchased according to KS specifications and drawings. Ninety-one suppliers are involved, covering approximately 200 different items of raw material and 1,125 different parts. The raw material includes items from metal bars and wire to plastic material and solvents. The parts are practically all of the metal, molded, and ceramic types.

Most of the raw material specifications are written around the A.S.T.M. standards, but nevertheless a good percentage of the material has failed to meet these general specifications and cannot be used in the product. This applies specifically to metal rods and sheet metal, which were purchased in smaller lots from jobbers. The philosophy of 100 per cent testing, as used at Hillside, is followed. This has paid off in many cases, because individual items in lots of material were frequently found to be entirely different from the rest. A special laboratory is set up at Clark for this testing purpose. It is equipped with facilities for chemical analysis and physical tests on material, including tensile, Rockwell, and microscopic examination.

In a number of cases it was necessary, in conjunction with the supplier, to develop materials to meet repeater specifications. For example, Teflon rod was purchased from two suppliers who did their utmost to produce rod to meet specifications. The main reasons for rejections were minute inclusions of foreign material, probably carbon, and cracking of rod materials during a bend test. To obtain satisfactory material, it was necessary to work with the suppliers and make changes in their processing technique to produce this material in reasonable lengths, free from imperfections. This development work enabled the supplier, in many cases, to place a higher-quality product on the market. This also was the situation on the ceramic items which, although they are parts, were mainly considered as raw materials.

Another unusual material is the singly-oriented polystyrene film for capacitors. As far as we have been able to determine, there is only one supplier in the country for this type of material. This supplier has a small shop with only one other employee. A considerable number of trial lots of this material were made by him and he, too, had to devise and learn a number of new tricks and precautions based on Western Electric's tests before he could produce a satisfactory product.

Of the approximately 200 different types of raw material, over 6,000 samples were tested during the first year, which amounted to over 25,000 different determinations. A large number of these were chemical tests which required considerable time to perform and evaluate.

One difficulty which was encountered was caused by the general lack of knowledge and understanding of our needs for unusual quality. In discussing specifications and drawings with suppliers, there was often misinterpretation of requirements and lack of understanding of the difficulties involved. This resulted, in many cases, in too low a bid and inability to deliver satisfactory parts on time. When additional lots of parts were to be ordered, new suppliers were involved, who had to be indoctrinated and developed to produce the required quality of parts. Although this resulted in considerable engineering effort, it did generally produce parts at lower cost of equal and, in some cases, better quality. On critical parts, where the efforts to produce them were extensive, and where the production of the parts would take up a considerable portion of the capacity of the supplier's facilities, dual sourcing was arranged wherever possible. Also taken into consideration was the possibility of human or natural interference with the flow of material. For example, on the beryllium copper housing and end covers for the repeater enclosure, a second source was developed which is about to produce after nearly a year of effort.

Where the suppliers are located some distance from the Clark shop, the Western Electric supplies inspection organization is called upon to do the inspection at the source, to ascertain that the quality is maintained at the desired level. This arrangement involved training of supplies inspection personnel in different fields to realize new types and levels of quality.

In some cases the suppliers were not able to produce to our original specifications even after considerable assistance. In these instances, detailed analysis of their abilities and present-day manufacturing techniques was necessary before changes in the requirements were undertaken to make it possible to produce parts. This, in general, resulted in changes and tighter requirements on associated parts.

X. MANUFACTURING EXPERIENCE AT CLARK

10.1 *Paper Capacitors*

High-voltage capacitors which must be capable of operating at potentials up to 6600 volts dc are wound with eight layers of 1-mil thick paper between aluminum foil. Proper alignment and tension of the large number of papers and foil did initially present problems, which have been greatly reduced as improvements in winding machine design and winding methods were made and operator skill increased. Some unusual difficulties were discovered after cycling and the six-month life test on the early lots of these capacitors. It was found that the weld between the foil and the flag terminals had ruptured, which caused variation in the impedance of the capacitor. The weld rupture apparently was caused by mechanical forces, including expansion and contraction with temperature and vibration, during the temperature cycling and life testing processes. The difficulty seemed to be connected mainly with insufficient flexibility of the internal leads from the capacitor units and insecure wedging of the capacitor units within the can. The problem was solved by increasing the flexibility of leads, improving mounting of the capacitor units, and changing the welding cycle to improve the weld.

Another difficulty was indication of denser metallic particles within the capacitor assembly on X-ray examination. In a number of cases this was found to be inclusions in the steel of the can caused by brazing alloy splashed during the assembly of mounting lugs. To avoid unnecessary rejection, the cans are X-rayed before assembly. Where these inclusions are found, a notation is made in the record so that in the final X-ray of the completed unit inclusions which are not harmful can be disregarded. The selection of paper, winding technique, and impregnation followed the earlier Hillside pattern.

The low-voltage paper capacitors use 0.3-mil thick paper in three and four layers between the foil. The low-voltage capacitors are also manufactured in a manner similar to that used at Hillside. However, one difficulty which was experienced might be worth mentioning. Some of these capacitors have a combination enclosure consisting of a ceramic cup and a metallic cup. The metallic cups were made from steel rods by turning. It was found that the steel, although it met all test requirements, had minute inclusions in it which were dissolved during the chemical cleaning and plating processes, producing a porous condition. This did not in many cases show up before the leak test of the completely assembled capacitor. The difficulty was overcome by a change to a cup drawn from sheet steel.

During impregnation, special precautions had to be taken to assure that the oil level in the capacitor was of the proper height. If the capacitor cooled down too rapidly, the excess oil would not have an opportunity to escape before the final sealing, causing the pressure to build up during cycling to a point where it would rupture the enclosure. By providing an infrared heating lamp over the capacitor in the sealing operation, the temperature is maintained and the desired oil level is obtained.

Based on the experience at Hillside and further study and work on causes for rejects, the over-all yield has been improved to the point where it exceeds that at Hillside. A general picture of the yield is shown in Fig. 9.

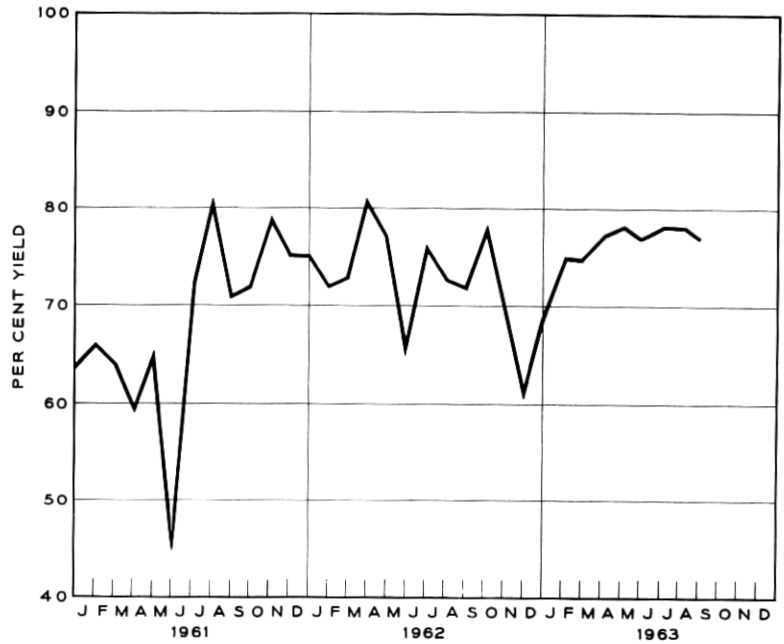

Fig. 9 — Paper capacitor yield.

10.2 *Polystyrene Capacitors*

This is a new type of capacitor used for the first time in Bell System repeaters. A singly-oriented polystyrene film is used. Since this film has a very high insulation resistance and easily becomes statically charged, it has a tendency to pick up dust and foreign particles during winding. It was necessary to enclose the spools on the winding machines with Plexiglas covers and to perform the winding in an area of 35 to 40 per cent humidity. The wound capacitor unit is heat treated to shrink or coalesce the polystyrene film around the foil to exclude air pockets and produce a homogeneous unit. The capacitor units are then mounted in metal cans having ceramic button insulators at one end. No air drying or special treatment is given the capacitor units during mounting.

After manufacturing these capacitors for nearly a year, using the original lot of polystyrene film, difficulties with cracks in the film were encountered when the leads were soldered on the units. Several changes were made in the soldering technique and some in the winding processes to avoid undue strains in specific areas. However, this did not entirely solve the difficulty, since it apparently became inherent in the polystyrene film after storage for a period of time. A new supply of film solved the difficulty, and presently the supply is being held to a maximum storage interval of six months. In reviewing the manufacture of this type of capacitor, a most important aspect seems to be the supply of good polystyrene film. A graph of the inspection yield of polystyrene capacitors is shown in Fig. 10.

10.3 *Mica Capacitors*

In designing the mica capacitors for the SD repeater, greater margin was provided between the silvered areas and the edge of the mica laminations than for the flexible repeater. This has made possible a sizable increase in yield, as has a change in design to omit cementing operations.

The silk screen method is still being used for application of the silver coating to the laminations. However, in place of the hand method, the machine described earlier is used. With this tooling, greater accuracy of size and location and fewer blemishes and other similar defects of the coated areas have been obtained. This also applies to the firing method, in which the silver is fused to the mica. It was found that minute particles in the firing furnace from carbonized silver paste vehicle and lint from operators' clothing and other sources would settle down on the coated laminations before the coating had dried. By predrying

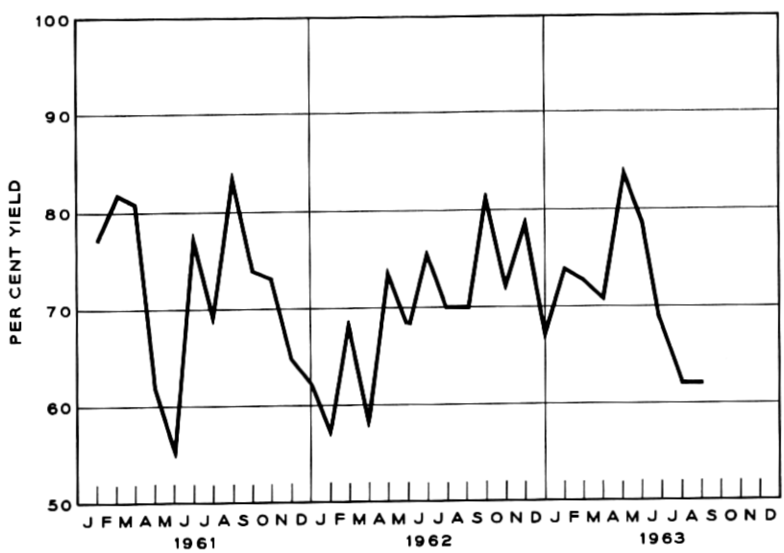

Fig. 10 — Polystyrene capacitor yield.

the laminations under infrared lamps before they enter the tunnel furnace, and providing better exhaust of the smoke from the vehicle, rejects for this cause have been reduced considerably.

Cracking of mica during the crimping of terminals has also been reduced by improvements in method and, to some extent, terminal design. Approximately half of the mica laminations are actually used in repeaters. Fig. 11 is a graph of the yield that has been obtained.

10.4 *Inductors*

All inductors are machine wound, a variation from the flexible repeater procedure, where the majority were hand wound. The winding time per unit has been decreased considerably for inductors with such strict requirements. Most types are wound in an hour or less. The change to polyurethane-insulated wire has made it easier to strip and tin without necking down the wire. A change in the other direction is the extensive use of Litz wire having up to 90 strands of No. 40 wire. However, it has not presented any unusual problems from the standpoint of cleaning and soldering. The Litz wire is used mainly in the coils for directional filters where a high and uniform Q value is important. To obtain the desired uniformity, all wire needed for foreseeable projects was manu-

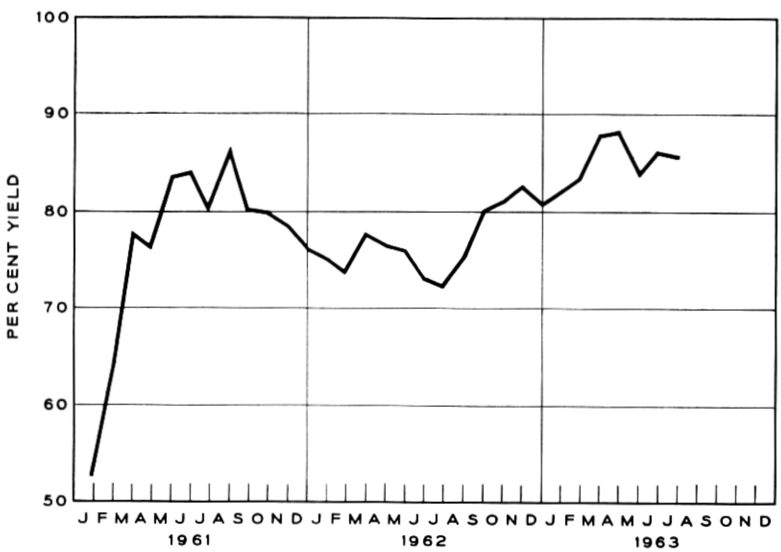

Fig. 11 — Mica capacitor yield.

factured at one time. This is important, since the type of equalizer used in the cable system is determined by the directional filter characteristics which, in turn, depend to a great extent on the Q value of the inductors.

As far as winding is concerned, there were, in general, no unusual problems that required extensive development work to solve. One exception to this was the progressive duolateral winding of some of the filter coils. Here the adjustment of tension, speed of the machine, play in the machine, and several other factors required considerable cut-and-try effort and development before a satisfactory winding could be produced.

When we speak about inductors, we may separate them according to the winding type: (1) single layer, (2) double layers in parallel, (3) progressive duolateral, (4) straight duolateral, and (5) toroidal with Permalloy dust cores. A number of the solenoid inductors are adjustable over an average range of ± 1 per cent by means of carbonyl iron cores. Difficulty in cementing the cores into the threaded carrier was resolved by applying the cement to the bottom of the carrier and then inserting the core. The most tedious coil to wind is a toroidal coil, where Mylar tape insulation has to be applied under the winding and between layers of the winding. This particular coil requires close to a full day for winding, although it is small and requires relatively few turns.

Practically all of the solenoid coils are wound on Mycalex cores which are held to close dimensional tolerances. The majority of the coils therefore require adjusting only by the adjustable core, since the number of turns per inch is also held to close limits. Fig. 12 shows the yield obtained on the inductors in general.

10.5 *Transformers*

The six transformers used in the repeater have ferrite cores which are manufactured at Hawthorne. Two of the transformers have Mycalex winding forms and the remaining four have diallyl phthalate forms. The secondary winding is wound on an inner spool and the primary on an outer spool in single layers. Some difficulty was experienced in obtaining the desired uniformity of winding and placing the shields between the windings properly to obtain the required direct and distributed capacitance values, which are important to meet the desired transmission characteristic. Cracking of the ferrite cores was also experienced. This was connected with the process of cementing the core sections and the winding form to the core. By changing the cementing technique, undue stress in the cores from the shrinking of the cement while drying was avoided and the difficulty cured.

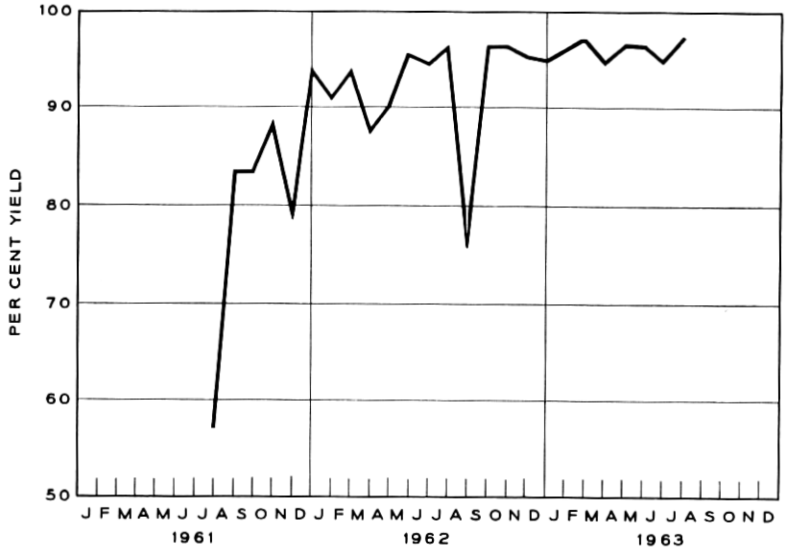

Fig. 12 — Inductor and transformer yield.

10.6 *Resistors*

Two types of wire-wound resistors are made at Clark, one using straight resistance wire, the other mandrellated wire made at Buffalo. Both types are wound on Mycalex spools which have gold-plated nickel pigtail leads. The ends of these leads at the spool winding area had to be flattened and notched to produce a fork-like terminal to hold the resistance wire. Originally this was incorporated in the lead wires before molding into the Mycalex spools. However, difficulty with closed slots and dirt in the slots from the molding operations caused considerable trouble. To overcome this, a special tool was developed for flattening the leads and producing the notch after molding of the spools. No unusual difficulties in brazing the resistance wire, such as experienced at Hillside, were encountered. This could be accounted for by the knowledge gained on facilities, materials, and operators' skill from Hillside. The yield on resistors is now running above 90 per cent, as shown in Fig. 13.

10.7 *Composition Resistors*

The composition-type resistors are purchased to specifications which stipulate special precautions on an otherwise standard product. Purchased resistors are then subjected to a selecting and screening process, followed by a six-month life test. Special precautions are taken with some of these test procedures to avoid secondary effects caused by a change in moisture content, which affects the resistance values considerably. In the low-temperature cycling test, where the resistors are brought down to $-100°F$, the humidity of the air in the test chamber was reduced to less than $\frac{1}{10}$ of 1 per cent. Four different resistance values are used, from 11,000 to 500,000 ohms. The yield, surprisingly enough, varied considerably among codes and lots of resistors. Over-all, approximately 28 per cent of the resistors purchased end up in repeaters.

10.8 *Enamel Resistors*

The two codes of vitreous enameled resistors used in the heater circuit and heater protection circuit are purchased. The manufacture of these resistors required special facilities, including air-conditioned space, at the supplier's plant. Considerable change in his methods and procedures was also necessary.

10.9 *Networks, Filters, Amplifiers, and Repeater Units*

From the standpoint of manufacture, the mechanical assembly of networks (shown in Fig. 14), amplifiers (shown in Fig. 15), and repeater

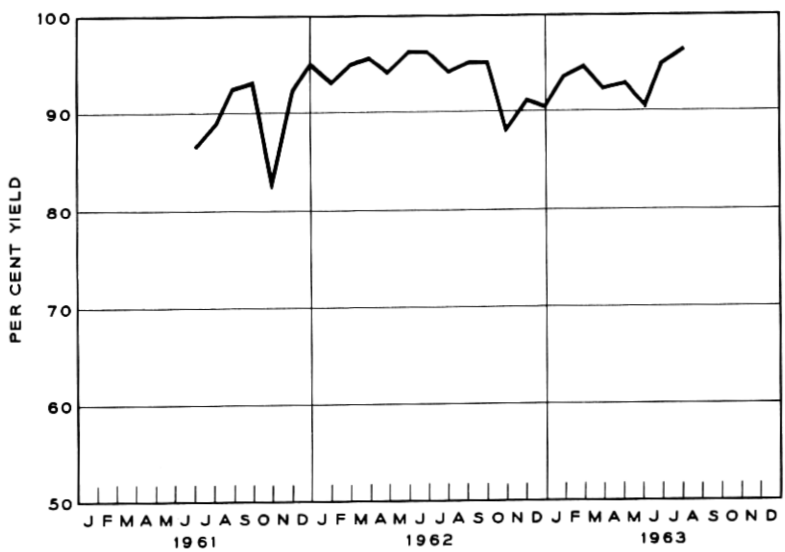

Fig. 13 — Precision resistor yield.

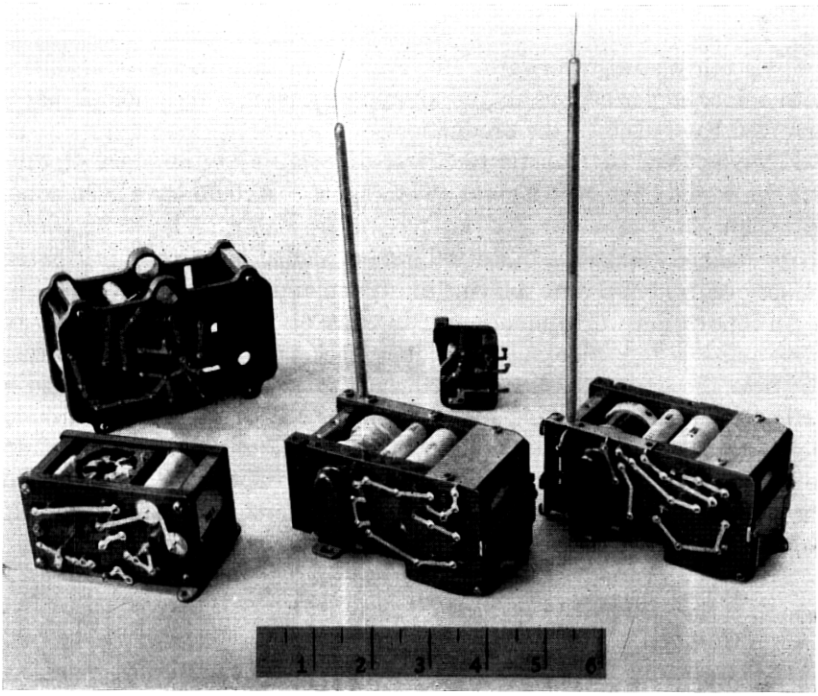

Fig. 14 — Networks.

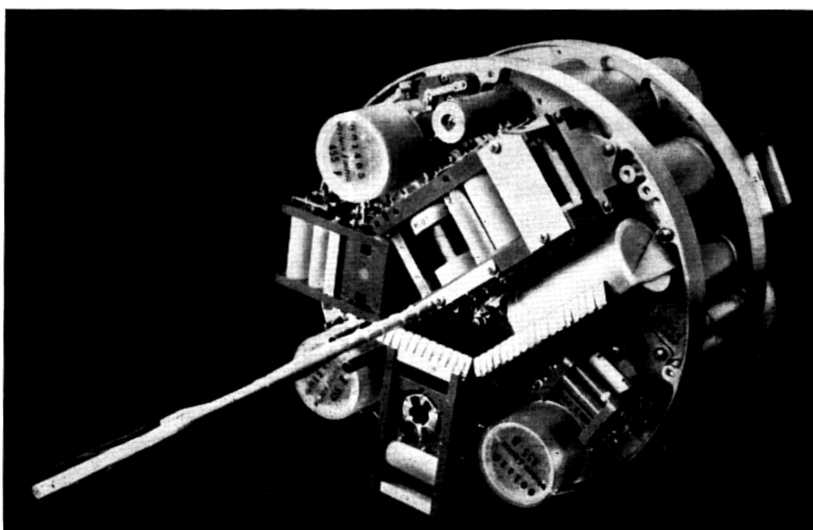

Fig. 15 — Amplifier.

units is fairly straightforward. However, from time to time difficulties with minor imperfections in the aluminum castings and molded parts involved have plagued the production.

Establishment of realistic electrical test limits at the start of production would have been a great advantage if this could have been done. Although the well controlled mechanical assembly and use of wiring strips defined parasitics quite well, small deviations from anticipated values occurred and were difficult to explain and trace.

An innovation worth mentioning in connection with the assembly of these units is the soldering technique developed for connecting wiring strips to the apparatus leads. Preformed rosin-core solder rings and a carbon electrode for heating are used. The solder rings are placed around the leads on top of the straps. A metal electrode is placed on the strap to be soldered, and a current is passed through the carbon electrode and the solder ring to the strap. A timing device limits the heating to a safe value.

10.10 *Repeater Closure*

After assembly of the repeater unit, it is tested for gas tightness, using a helium mass spectrograph leak detector, and then vacuum dried approximately 100 hours while heated to 130°F. This is considered to be the start of closure operations.

After vacuum drying, the repeater unit is covered with an epoxy coating to provide the necessary electric insulation between it and the outer housing which surrounds it. The housing is at ground potential, while the repeater unit is at cable potential. The coating is about $\frac{5}{32}$ inch thick and covers the repeater unit completely. The epoxy, a mica-filled compound, is carefully mixed immediately before use and degassed in a bell jar under vacuum. In applying the coating, small epoxy areas or lands are first cast on each end of the unit. These lands are used to locate the final mold, which completely surrounds the repeater unit. Each end requires approximately 24 hours for the epoxy to cure. The mold consists of two cast-aluminum half cylinders which are locked together around the repeater unit and have attached to them end covers matching the repeater unit shape. The end covers rest on the epoxy lands and line up the rest of the mold with respect to these lands. In filling the mold, the epoxy compound is poured into an injection cylinder, the lower part of which is connected to the bottom of the mold by means of a flexible hose. Air pressure is then applied to the cylinder above the epoxy compound, which is forced into the mold from the bottom. Since a considerable amount of heat is developed in the compound from the curing, which starts as soon as the compound is mixed, the injection cylinder is water cooled to limit the temperature and slow down the curing. Two transparent plastic tubes are provided on top of the mold as risers for the compound, which shrinks to some extent as it cures. To eliminate voids in the coating, a slight air pressure is applied through the risers on the epoxy in the mold. This will permit the epoxy to flow slowly as it cures from the bottom up. To favor curing from the bottom up, the mold is heated by a warm air heater placed externally at the bottom. Any voids that appear after the casting process are filled in, using a tinker's dam.

After epoxy coating, the repeater unit is inserted in the outer beryllium copper cylinder, where it is held in place by Fiberglas springs resembling venetian blind slats. These springs serve as additional electrical insulation and at the same time as a cushion against shocks to which the repeater may be subjected during laying operations, such as hitting the sea bottom. A hydraulic jack is used to push the repeater unit into the outer cylinder. The cylinder is then placed in the assembly machine, Fig. 16, where it is held in place in the center of the machine while two end covers with the required seals in them are held in the fixture just outside the cylinder and lined up with the bore in the end of the cylinder. While the end covers are held at some distance from the cylinder, the leads are spliced together, and the joint is over-molded with polyethylene to insulate it and X-rayed. The X-ray, which is taken in two planes, determines the concentricity of the polyethylene insulation and ascertains whether it is free from foreign particles or voids.

After making all connections to the repeater unit and shielding and taping the leads, the leads are coiled up inside the end of the cylinder while the cover is being pushed in place. Coiling of the lead is done automatically in the assembling machine while the cover is pushed in place. As the heavy circular-disk Fiberglas spring attached to the end cover of the repeater locates the repeater unit in an axial direction inside the cylinder, a certain amount of pressure is applied to the repeater unit from the end covers. The covers are secured with steel clamps, which are bolted to the cylinder using the threaded holes in the periphery of the cylinder. The repeater is then removed from the assembly machine and is ready for welding the end covers in place.

After the repeater is trued up on one of the turntables on the welding machine, the milling head is swung out over the repeater and the surface of the edges of the cover and cylinder lips is milled off to remove the fine layer of beryllium oxide which forms fairly rapidly on beryllium copper. Next, the milling head is swung out of the way, the welding head is moved in place over the repeater, and the starting button is pushed.

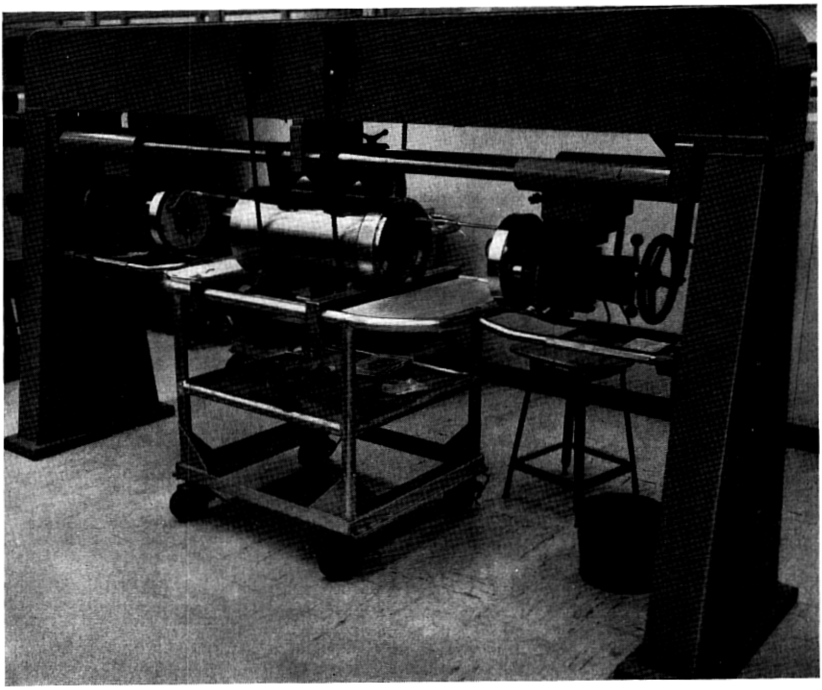

Fig. 16 — Repeater assembly machine.

This starts the turntable, turns on the argon shielding, and starts the arc by means of a high-frequency discharge between the electrode and the repeater. The arc is played on the lips of the cover and cylinder and melts both to form them into a rounded bead over the area while they are being rotated. An ac voltage of about 14 volts and a current of approximately 270 amperes is used, and the repeater is rotated at $\frac{1}{3}$ rpm.

To ascertain that the weld is of sufficient depth, an ultrasonic test is performed in a water bath at a number of points around the circumference (see Fig. 17). The required minimum is $\frac{1}{16}$ inch, but the welds usually run close to twice this.

The repeater is now ready for a high-pressure helium leak test, during which it is subjected to helium at a pressure of 11,600 pounds per square inch on the outside, while the inside is evacuated and then connected to a mass spectrograph leak detector. Before the repeater is placed inside the large steel test vessels, it is surrounded by a "dead man." This consists of an aluminum cylinder in two halves placed on the outside of the repeater cylinder and blocks at each end, which are hollowed out to fit

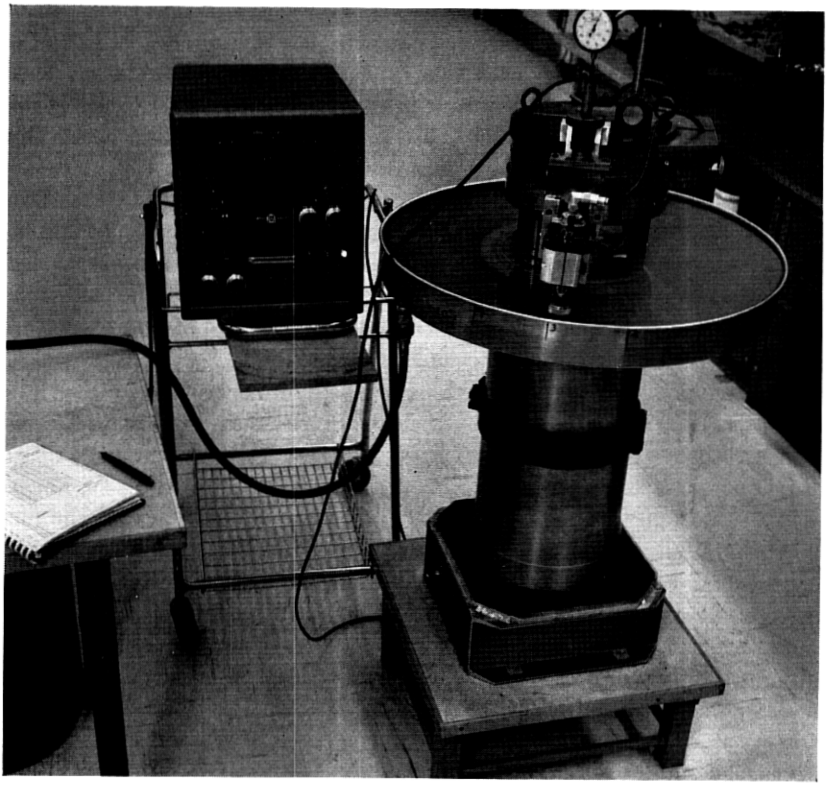

Fig. 17 — Ultrasonic test of weld.

closely over the covers and seals. This reduces the free volume in the test chamber and thus keeps the total amount of energy stored in the compressed helium to a minimum for the sake of safety. The pressure on the repeater in the vessel is increased gradually to the test pressure, held there for close to an hour, and then decreased over a period of about an hour to avoid damage to the polyethylene leads. Before inserting the repeater in the test vessel, the polyethylene-insulated pigtail leads are wrapped with polyethylene tape to avoid penetration of helium into the insulation, as this may produce minute blisters as the pressure is reduced.

The helium gas is reused; only a small amount is exhausted for each test. From the regular gas cylinder, two larger storage vessels are filled at a pressure of 2,000 psi. From here, the gas is pumped into a smaller high-pressure storage vessel at 13,000 psi, from which the gas is controlled through a console and slowly bled into the test cylinders until the desired pressure is obtained. During this operation, helium is pumped into the storage vessel to maintain pressure. When pressure is released, the gas is first bled back to the 2,000-psi storage vessels and below this pressure into a low-pressure storage tank, where it is held at approximately 100 pounds pressure.

When a repeater has passed the high-pressure helium test, the tubulation which connects the leak detector to the inside of the repeater is still open and must be closed. This is done by pinch-welding while the inside of the repeater is filled with dry nitrogen to a pressure of approximately 2 pounds. To ascertain that the pinch-weld is satisfactory, a test using a radioactive isotope is performed. A small cylinder is placed over the tubulation and held in place by a heavy fixture. The cylinder is filled with an isotope solution on which pressure is applied to bring it up to 11,600 pounds per square inch. This pressure is maintained for six hours; then the isotope solution is drained off and the tubulation and the cylinder thoroughly washed. Any penetration of the isotope solution would be detected by a high count on a measuring instrument. This whole process, which has a fairly involved filling and washing cycle, is done semiautomatically. Valves are opened and closed automatically, permitting wash water, air, and the isotope solution to be moved in and out of the small test chamber as required to perform the test.

Electrical tests are performed on the repeater before welding and after the complete leak test to ascertain that it meets requirements. The last operations are forming and annealing of the pigtail leads, mounting of the end cones, and painting. After this the repeater or equalizer is ready for packing and shipping.

Included in the closure operations is manufacture of the seals for the repeater unit and the repeater. The seals use polyethylene for insulation and permit electrical connections to the inside of the repeater or equalizer circuit. In the case of the repeater a seal against sea pressure is provided. The repeater unit seal is a barrier to water vapor. In molding the seals the metal outer housing and center conductor, which have a layer of oxide applied chemically to assist bonding them, are held in place in a mold, and polyethylene is injected to fill the spacing between, and bond to, these metal parts.

The molding of satisfactory seals has been the most difficult operation on the whole project to master and control. There are still unknown factors which are difficult to control and evaluate.

The main difficulty is obtaining a good bond between the polyethylene and metal and at the same time attaining the required electrical characteristics. Nearly a year was required to bring this process under reasonable control. Numerous small changes were made during this period to improve the design. They consisted mainly of controlling the bonding areas by restricting bonding to the outer shell to certain limited areas to avoid internal stress in the polyethylene. Also, a period of rest in the order of four to ten days was required for the seal after molding, to permit relaxation of stresses in the polyethylene.

XI. VERIFICATION OF COMPLETED REPEATER

As in the case of the flexible repeater, the rigid repeater is verified before shipment to ascertain that every operation has been performed and all requirements have been met. This includes every raw material item, piece part, and subassembly.

All electrical test results except simple go or no-go tests are punched on cards. The results of the go or no-go tests and mechanical inspection are entered manually on the punched card section attached to the apparatus by the inspector performing the test. This inspector also verifies that prior operations have been performed satisfactorily as indicated by the entries on the card section. When an apparatus item is completed, inspection visually verifies from the card section that all operations have been performed and accepted. A final-acceptance punched card, indicating that all operations have been completed, is originated and forwarded to the data center for verification of the electrical requirements before releasing the apparatus for use in the product.

In the data center the test data cards are sorted by group code, serial number, and operation number, to put them into logical order. The test data cards and unit history cards are now collated by group code and serial number. Next, the data and history cards are collated with computer program cards by group code. Finally, the combined cards are placed in an IBM 1620 computer where the data cards are read and the limits checked, as called for by the program card, and a punched output of verified test data is produced. Any errors in the data cards or in the processing of them are detected by the computer and a listing is automatically typed. Before proceeding with the verification, the items listed are corrected. After removal from the computer, the punched cards are run through a printer, where the components are listed as satisfactory to ship or to be rejected, depending on which is to apply.

All data pertaining to the assembly of a repeater are compiled in two data books — one covering mechanical items and the other electrical information. The data are entered by hand in these books by the individual operators and inspectors. All component apparatus assembled into a repeater is listed in the mechanical data book and identified by code and serial number. Pertinent electrical test data, which are compiled on punched cards, are printed or typed on a sheet which becomes part of the data book. These two books are jointly associated with the repeater assembly until completion of the repeater, at which time the books are merged into one repeater data book for a specific repeater. This data book is verified by Western Electric inspection representatives and then pertinent data (primarily electrical) are check-verified by the customer's representative before the repeater is accepted and released for shipment.

For each repeater and its components there are about 3,750 separate electrical tests involving 38 test sets of 20 different types, in addition to all other tests and inspections. Approximately 3,000 punched cards, punched with up to 40 items and with up to 40 written-in items, are required, along with approximately 17,200 entries in the data books.

XII. PACKING

In preparing for shipping, the open end of each of the end cones on the completed repeater is closed with a Lucite cover. An impactograph to register any shock to which the repeater may be subjected during handling and shipping is mounted on one cover. On the other cover is mounted a min.-max. temperature indicator which will show whether the repeater has been subjected to temperatures in excess of 120°F or below 0°F during storage and transport. Next, the repeater, which weighs around 500 pounds, is mounted on a $5 \times 2\frac{1}{2}$-foot flat between two rigid foam plastic housings which fit over the ends of the repeater and are held together with the repeater between them by four $\frac{3}{4}$-inch steel tie rods. In case of excess shock, the foam plastic will crush and reduce the shock on the repeater. The housings, in turn, are bolted to the flat and a wooden cover is placed over the assembly and strapped to the flat. The cover has a sliding door at each end for reading the impactograph and temperature indicator. The packing arrangement, which is reusable, is identical for both repeaters and equalizers and is designed for handling by a fork lift truck. It is also relatively inexpensive, which is of particular advantage in cases where it would be impractical to return it for reuse.

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