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The Manufacture of Vacuum Tubes

By M. J. Kelly

THE thermionic vacuum tubes which are sold by the Western Electric Company are manufactured in the Tube Shop of our Bell Telephone Laboratories. Fifteen different coded types of standard tubes were under manufacture in this shop during 1925. The water-cooled power-tubes that are used in the high-power broadcast stations; the peanut tube which is used in our audiometers, deaf sets and radio-receiving equipment; the small power-tubes of the public-address systems and power amplifiers; and the repeater bulbs for our voice-frequency repeaters and carrier circuits are all products of our Tube Shop.

The Tube Shop is located on the third floor of the Western Electric building at 395 Hudson Street, to which it was moved from West Street in May, 1924. At that time the demands for space in our Laboratories were so great that even with the additional space to be provided by the new section "H" the West Street building could not take care of this shop and provide room for its future expansion. A search was made for a new home, and the present location was chosen as being most suitable. This choice has proven to be wise, as the conditions have been found ideal.

At Hudson Street we are sufficiently near West Street to make use of its centralized services. For example: W. F. Johnson and his purchasing specialists are ever looking for suppliers that can furnish raw materials that will satisfy our exacting requirements. The Engineering Shop makes for us parts which would otherwise require an uneconomical installation of machinery in the Tube Shop, and J. W. Upton and his helpers are always available and frequently used for consultation on our mechanical troubles. B. B. Webb gets our manufacturing schedules from the Western Electric Company, and keeps it informed as to how we are producing. R. F. Newcomb pays all of our bills and brings around the very necessary weekly pay-envelopes. E. J. Santry tells us how much money we are spending, and to what use each bit of it is put. G. B. Thomas recruits our new people and handles the personnel problems which arise in our shop.

When the Tube Shop requires special electrical installations or changes in existing equipment, C. Cole, engineer in charge of the Hudson Street building, takes care of them for us,

Miss Lena Sproat "raising the arbor" on the stem press of the 101-D tube

and also gives us much help in our power plant. His experience at West Street, where he was for many years in W. B. Sanford's department, has enabled him to give us a service which it would be extremely hard to obtain in any other similar building.

In the Tube Shop the work is organized into four departments whose heads spend their entire time at Hudson Street. P. Schwerin, who has twenty-one years of service and has been in vacuum-tube work from its early days at West Street, is in charge of the operating group. J. R. Wilson, who was previously in the development group on vacuum tubes at West Street, is in charge of the manufacturing development and engineering. H. E. Crosby, who was formerly in the Building Organization at West Street, takes care of equipment design, installation and maintenance. O. J. Short, who was formerly in charge of storerooms at West Street, has the storeroom and clerical service for the Shop. These men have the able assistance of many others who have years of experience in vacuum-tube manufacture.

Our methods of manufacture and most of the equipment we use are developments in the Shop itself or by other departments of our Bell Laboratories. This has been necessary because of the pioneer nature of our manufacturing problem, which began to approach quantity production with the opening of the transcontinental telephone line in 1914 and grew with the subsequent radio and carrier demands. It might well be thought that in our manufacture of thermionic tubes we could derive much from manufacturing methods and practices for incandescent lamps. This is not true, although it is true that both the thermionic tube and the incandescent lamp have, in common, a glass envelope and wires leading through it to something inside. The similarity stops rather sharply at that point. The mechanical, physical and electrical requirements which the most simple of our thermionic tubes have to meet are legion in comparison to those of the incandescent lamp. The tremendous difference in quantity produced is another factor which prevents our taking advantage of some developments in this older industry which physically might be applicable. Machinery suitable for performing an operation tens of thousands times a day is, in general, unsuited for performing the identical operation hundreds of times in the same length of time.

A survey of the more important steps in the manufacture of one of our standard tubes will probably answer many of the questions which rise in the minds of those who use the tubes. The most common of our telephone repeater tubes, the 101-D, is chosen for description.

Historically, this tube is the oldest high-vacuum thermionic tube used in commercial communication (wired or radio) in the world. In the thermionic tube family it stands supreme, for to our knowledge there is no other standard high-vacuum thermionic tube of as long life and of as high quality. It has been used for over twelve years in the telephone repeaters of our Bell System; in fact, ever since its proportions were established by H. D. Arnold.

The first operation in its manufacture requires that glass tubing of approximately 0.6 inch diameter be cut into lengths of approximately 1.5 inch. This operation is performed on a high-speed cutting wheel mounted on special bearings so that it runs very true. Each of these lengths of tubing is the foundation for a tube. They are put successively through two machines; a flare machine and a press machine. The first puts a flared edge on one end of the tube by heating it as the tube rapidly rotates, and when it is sufficiently plastic flaring it with a carbon reamer. This flare is later necessary in sealing the tube parts into the bulb. The second machine forms "vacuum-tight" seals enclosing four wires at the other end of the tube. These wires are to provide electrical connections with the filament, grid and plate. We call this glass unit with the wire inserts a "stem press."

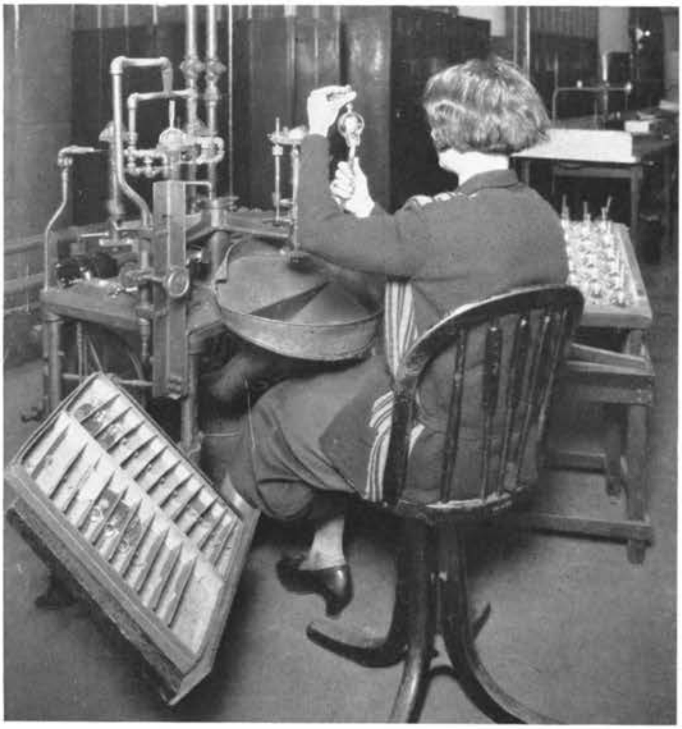
In forming the seal the glass is heated to a temperature where it is sufficiently plastic to be pressed around the four lead-wires. If these lead-wires are not specially shaped where they go through the glass, it is necessary for them to expand just like the glass under temperature changes.

A section of the Assembly Department, where the elements of the tube are constructed and attached to the glass stem unit

We use a wire developed for incandescent lamps called Dumet which has the same temperature coefficient of expansion as the glass. If the expansion coefficients were not the same, when the stem press is taken through temperature cycles the metal would either expand too rapidly and shatter the glass or would contract too much and tear loose from the glass. The particular action would depend upon the relative temperature coefficients of expansion and the condition of making the seal. In either event such a stem press would not be vacuum tight.

The stem press has been subjected to two successive heatings. While it cools slowly after each heating, strains are set up in the glass due to the unequal heating and cooling at different points. Glass in this condition will crack easily with temperature change or mechanical shock. To relieve these strains, the stem presses are heated in a special electric furnace as hot as possible without deforming them and are then slowly cooled to room temperature. This process, called annealing, removes the strains in the glass. The temperature cycle of these ovens is followed with recording pyrometers; and the elimination of strains is frequently checked by a special polariscope.

The annealed stem press is now ready to have attached to it the piece of glass cane (glass rod) which acts as a support for the elements. We have called this operation "raising the arbor." It is a hand operation, and requires an operator of considerable skill. The weld between the arbor and the stem is so perfectly made that when completed tubes are subjected to destructive mechanical shock tests the glass is no more liable to fail at this point than at any other. The annealing operation makes it possible for the operator to raise arbors at a more rapid rate, as the time in getting the stem press up to the temperature required to make the weld is much less.



Mrs. Martha Frykholm operates the glass-sealing machine which seals the mount into its bulb

The ten support wires for the tube elements are next inserted in the arbor. In a machine which was developed by P. Schwerin

A section of the Vacuum Pump Department

all ten wires can be simultaneously inserted. The arbor is heated at the points where the wires are to be inserted. When the operator sees that the glass is heated sufficiently, he moves two levers which advance the ten wires to the proper depth in the glass. By his next movement of the levers the ten wires are cut to proper length, and the fires turned out.

We have called this unit the "stem press and arbor assembly." It has gone through two heating operations in which the parts are heated and cooled unequally so the glass is full of strains. It is given an annealing treatment similar to that of the stem press. After this annealing it is given chemical washes, which remove any organic matter, such as grease or oil, from its surface and any oxides from the surface of the wires. The unit is now ready to have mounted on it the filament, the grid and the anode.

The anode is made from two stampings of sheet nickel boxed together with four nickel wires. These wires are fastened to the plate by electric welds. The grid is made from nickel wire of three different diameters. These wires are all connected together by electric welds. Both the plate and grid are formed on specially designed fixtures and electrically welded on special welding machines.

The grid and plate units, as well as all metal parts, are "pretreated" in

Miss Tessie Taddeo assembles a mount

high-vacuum furnaces and hydrogen furnaces to cleanse the metals internally as well as to remove all volatile material on their surfaces. The vacuum requirements for the tubes are such that there has to be not only an extremely high vacuum in the space within the tube, but the parts in the tube must also be so free of gas that there will be no gas freed from them during the operation of the tube. The metal parts are heated in these furnaces to approximately 1000 degrees Centigrade. By this treatment they are so cleansed that in the pumping operation it is only necessary to remove the gases absorbed on their surfaces. The time interval between these furnace treatments and the pumping operation is made as short as possible so that the amount of absorbed gas will be a minimum. The

After completing the exhaust of a tube, B.J. McNally seals it off the pumping manifold

Miss Juliette Charpin manipulates the electric welding of the grid

furnaces used in these heat treatments were developed in our Laboratory.

The filament or cathode consists of a platinum-alloy core coated with alkaline-earth metal-oxides. It comes from its manufacturing process in the form of a long ribbon. This ribbon is cut into units for each tube and shaped into its "M" form by a special fixture.

The furnace-treated grid and plate and the M of filament are assembled onto the stem press and arbor assembly by hand operations, using special fixtures for holding the parts in their proper positions and spacing them to the required accuracy. The parts are secured by electric welds to the ten wire supports of the arbor and to the four lead-in wires. We have called this unit the "mount."

The mount is sealed into a glass bulb which has a glass tube about two inches long sealed to its top. This tube is called the "tubulation." It has a constriction just above the bulb which is used at the completion of the exhaust to seal off the tube from the exhaust position.

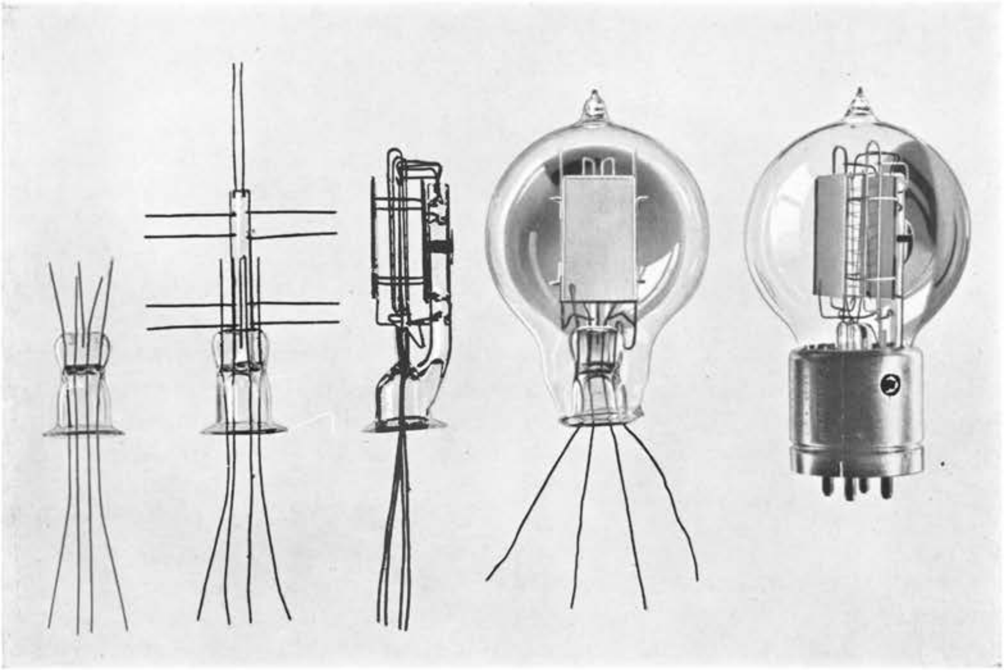
The sealing-in of the mount is done on a special machine. The flare of the stem press and the neck of the bulb are heated sufficiently for viscous flow and are united in this sealing operation. We thus have the mount surrounded by a glass envelope, except for the opening in the tubulation, which is closed after the exhaust of the tube. Four wires sealed through this glass envelope permit electrical connection with the three elements inside.

The pumping system for exhausting the tube consists of a two-stage rotary oil-pump, a mercury diffusion-pump, a liquid-air trap and the pumping manifold. The oil pump by itself is capable of pumping to a vacuum of one-thousandth of a millimeter of mercury or approximately one-millionth of an atmosphere. The mercury diffusion-pump, when preceded by the oil pumps, will pump to a pressure of one-millionth of a millimeter of mercury. The liquid-air trap acts as an infinite impedance for mercury vapor. Mercury, at room temperature, has a vapor pressure much higher than the pressure which can be obtained with the diffusion pump and much higher than can be permitted in the repeater tube. By interposing a liquid-air trap between the mercury pump and the manifold the mercury from the pump is condensed in the trap. The pressure of mercury vapor in the pumping manifold is as low as the vapor pressure of mercury at liquid air temperatures. This is lower than the required pressure for the tube.

Six of the repeater tubes are sealed onto the prongs of the manifold. An electric oven is placed around the tubes and heat is applied after a good vacuum has been obtained by the pumping system. The oven temperature is raised to as high a value as possible without causing the glass to soften and collapse. This is done in order to liberate as much gas as possible from the glass and metal parts of the tube. After a thorough baking out of the tubes in the oven, the filaments are lighted and positive voltages applied to the grid and anode of sufficient value so that the energy dissipated in them by the bombarding electrons heats them to a temperature in the range of 800 to 1000 degrees Centigrade. Gases that were not removed in the high-temperature pretreatments or that have since been absorbed are liberated by this bombardment and are pumped out. As a final operation, a small amount of one of the alkaline metals is vaporized

At the repeater test-boards Eugene C. Russell makes electrical tests on the 101-D tube

within the tube in order to react chemically with any oxygen or water vapor which remains and mechanically to "bury" other gases under the mirror



Steps in the manufacture of the 101-*D tube. From left to right: stem press, stem press and arbor assembly, mount, tube after sealing off pump station, and the completed tube*

coating that is formed on the bulb. The tube is then sealed off the manifold by the pump operator. The pressure in the tube when sealed off is of the order of one-billionth of an atmosphere. All the pumping equipment has been developed in our Laboratories and in the Shop. It has obtained its present form through gradual improvements during the last twelve years.

After an aging process, the tube is given a preliminary inspection to insure that it will meet all requirements; and it is then based. This operation consists in attaching the base unit to the bulb, soldering the four lead-wires to its posts and then sealing the base with a special sealing-compound. Thereafter the tube is given a complete electrical and mechanical inspection. The electrical inspection is performed on a repeater-tube test-board developed by J. Blanchard. The filament resistance, the insulation resistance, the degree of the vacuum, the impedance, the amplification factor and the amplification of the tube in a circuit similar to a repeater are all measured. The amplification in this circuit can be measured to within one-tenth of a transmission unit. The tubes that meet the standard requirements are packed and sealed in individual cartons and sent to the Merchandise Department of the Western Electric Company at Kearny for distribution to associated companies.