THE MANUFACTURE OF VACUUM DETECTORS*

By

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Altho the majority of radio engineers are familiar with the use and operation of vacuum tube detectors, a brief description of their manufacture may be interesting.

In the early experimental work on this type of device, we strove to produce a detector which would combine maximum operating efficiency with inexpensive manufacture. The next point considered was the production of desirable conditions, i.e.; tubes that possessed oscillating characteristics, tubes that were exceptional detectors, and tubes that displayed both qualities. The third consideration was the production of a device easily handled and shipped without disturbing the adjustment of the elements and damaging the filaments.

Tubes and bulbs of various shapes and sizes were tried using a gaseous medium ranging from one millimeter to 0.025 millimeters of vacuum, many materials being employed as elements. Various exhausts were applied but it was soon found that the employment of a gaseous medium introduced considerable difficulty in the matter of accurate reproduction of a desired result. Gases at pressures ranging from one millimeter to 0.0013 millimeters were next experimented with.

I found that a tube containing a platinum filament in an atmosphere of hydrogen, at pressures comparable with one millimeter, gave fair results. Tungsten filaments were then tried in higher vacua as well as at the so-called "gaseous medium" pressure. It was immediately noticed that conditions could be duplicated as soon as vacua above that which allowed a "gaseous medium" to exist, were obtained. Moreover, tungsten was ideal as a filament not only because of its refractory qualities and low volatility but also because it acts as a purifying agent by attacking any traces of residual gases that may remain in the tube and forming compounds which are then volatilized on the walls of the tubes.

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element audion which permits of gas conduction is not used in the tubular "electron relay," wherein all gas phenomena must be eliminated.

To produce the high vacuum necessary, I have found that a Gaede mercury pump capable of producing a vacuum of 0.00001 millimeter, backed by a piston pump, such as the Geryck type, is the most satisfactory method of evacuation.

The manifold to which the tubes to be exhausted are attached and the vacuum line connecting the manifold to the pumps are preferably made of large diameter tubing. A container filled with pentoxid of phosphorus is connected in the vacuum line between the pump and the manifold. The manifold is contained in an oven heated by gas and arranged so that the tubes during exhaustion may be heated to high temperatures.

The lead glass tubing, used as the container for the elements in the tubular type detector, is obtained from the glass works in lengths of 6 feet (2 m.) with an inside diameter of 0.875 inch (2.2 cm.) and a wall of 0.032 inch (0.7 mm.) thickness. This tube is cut in lengths of about 6 inches (15 cm.) and one end is drawn down to a point. Two stems are made of glass tubing similar to those used in an incandescent lamp, one stem contains the grid and two filament leads and the other contains the plate connection and one filament lead. After the wire is sealed into these stems, they must be annealed very carefully. The annealing consists in allowing the temperature to drop very slowly, since quickly cooled glass is subject to internal strains which arise in the following manner: In rapid cooling, a low temperature is soon established at the surface and the outermost layer solidifies while the interior tends to contract, thereby exerting a pressure on the outer layer which is directed inwards. This may cause the stem to crack.

After the stems are annealed, the grid is wound to the proper diameter and the filament is clamped onto the two leads. The plate is mounted on the other stem and the two stems are then connected together by means of the filament. Final adjustment of the plate and grid is then made. The spacing between the elements is not very critical in this type of device, but it is best to wind the grid to a large enough diameter so that it will strike the plate rather than the filament when the tube is jarred.

After adjustment on the plate and grid has been made, the assembly is inserted into the prepared tubes and the end seals made. A short length of small diameter tubing is attached to the seal at one end of the tube, this being for connection to the pump manifold. The tube is then carefully annealed and is ready for exhaustion.

A number of tubes are sealed on the manifold in the oven and the temperature is gradually increased to 900 degrees Fahrenheit (480° C.) at which point the pumps are started. The tubes are heated in this manner before the pumps are started so that the air contained in the tubes may conduct the heat to the central elements and drive off the occluded gases. When the pumps have produced a vacuum of one micron, the temperature of the tubes is very gradually increased to 1000 degrees (540° C.). At this point they must be watched very closely as the melting point of this glass varies greatly and should the walls of the tubes become soft, the vacuum would cause collapse. From one micron, the vacuum slowly increases, and after about five hours of continuous pumping the tubes are sealed off at the manifold and allowed to cool in the oven.

McLeod gauges are used in the measurement of vacua but I have found that a much more accurate vacuum comparison can be made using a large induction coil. For this purpose an electrode is sealed to the manifold or at some point in the vacuum line. One terminal of the coil is connected to this electrode and the other coil terminal is connected to the low vacuum pump. A calibrated spark gap is used on the coil and when the vacuum is high enough and the residual gases are properly pumped from the tube a spark will jump the gap without a glow in the vacuum line or tubes. The vacuum used in the tubular detector will permit a five inch (12.5 cm.) spark between needle points in air.

Prof. Richardson has shown that when new metals are heated to incandescence they emit positive ions, probably because of the impurities or gases in the metal. I have found that this positive discharge must be eliminated to obtain maximum sensitiveness of the tubular detector, and this is accomplished during the manufacturing stage by burning the filament on alternating current for about two hours. Tubes that have not been treated in this manner are found to be less sensitive than those in which the positive ionization has been destroyed.

SUMMARY: Experiments with three-electrode vacuum detectors are described. Various filament, grid and plate metals were tested. Different degrees of exhaustion were used.

The paper then describes in detail the manufacture of a tubular detector and the testing thereof.

H. R. Sprado: Referring to your last paragraph regarding the emission of positive ions, I gather that this phenomena is rather transient. If a tube is left idle for quite a period of time, would it recover the positive ionization?

O. B. Moorhead: The phenomena referred to I have noticed to be an emission from fresh wires only, and when these wires are heated in a vacuum the positive ionization decays rapidly at first and then more slowly until it finally disappears. This rapid disappearance can be facilitated by applying a positive potential to the hot metals. I do not know if it will re-appear when left absolutely idle but it can be revived by burning a fresh wire near it, the old wire being cold. This must be due to a substance which is distilled from one metal to another.

H. R. Sprado: In some research work that I have recently done with the "gaseous medium" type of device, I have noticed that this power of emitting positive ions can be restored if the plate or filament end of the audion is held to one terminal of a high tension coil and a luminous discharge be caused to fill the bulb.

Do you believe that this rapid decaying of the positive ionic emission bears any relation to that phenomenon commonly called "photo-electric fatigue"?

O. B. Moorhead: It probably does, as photo-electric sensitiveness is not recovered after the surface has rested. Have you ever tried your luminous glow experiment on a plate that shows photo-electric fatigue and ascertained if it regains its sensitiveness?

H. R. Sprado: No, I have not. I note that you have experimented with platinum filaments in hydrogen. Did you make any experiments with tungsten in the same or other gases?

O. B. Moorhead: I have found that tungsten in hydrogen operates very poorly and that exceedingly small amounts of gas cause very great changes in the values of the constants. This applies to all the gases with which I have experimented.

H. R. Sprado: While making the above experiments I had occasion to use different pressures of argon in your tube. I found that the saturation currents in this gas have the same values as in the higher vacua. I noted that when small quantities of argon were used the attainment of saturation was greatly facilitated because of the action of positive ions formed by impact ionization, in reducing the effect of the mutual repulsion of the electrons. When argon was present in greater quantities, the saturation current was considerably higher. Have you any theory regarding this increase in current?

O. B. Moorhead: I presume this was due to ionization by collision of the electrons with the argon gas molecules.