Some Aspects of Radio Valve Manufacture

By T. F. B. HALL and A. H. HOWE*

Many users of wireless valves, whether for domestic or scientific purposes, can have little or no conception of the many interesting manufacturing problems which have confronted the technical and production engineers of the Industry in producing the modern valve.

In contrast to the general run of precision engineering, which deals with solid pieces of metal which can be readily machined and finished to fine limits of accuracy, the valve engineer has to produce and assemble a wide variety of thin sheet metal and wire components many of which are extremely fragile and require very careful handling to avoid distortion. The wireless valve is an electrical device which depends on extremely accurate spacing of the various electrodes, and it will not be difficult to appreciate that any mechanical distortion will materially increase the effect of the small manufacturing tolerances allowed and largely control the uniformity of the finished product.

The special electrode materials in general use are tungsten, molybdenum, pure nickel, various alloys of nickel with manganese, aluminium or magnesium etc., and have been chosen, not on account of their easy working properties, but for their ability to withstand high temperatures and their general freedom from impurities. A high standard of inspection, both dimensional and analytical, has been set by valve manufacturers on all the various raw materials employed to ensure that the necessary quality is maintained. Uniformity of raw materials is essential for the smooth running of intricate machinery, and to permit strict adherence to approved manufacturing processes.

Another interesting point is that many of the processes are peculiar to the industry and require special plant which, in the majority of cases, is designed and constructed by the manufacturers themselves.

Component Manufacture

In spite of its small size a wireless valve can have as many as thirty or forty separate parts depending on the purpose it has to fulfil. These parts are generally produced by each valve manufacturer to his own design and in order to exercise the necessary degree of control.

The glass bulbs are produced on automatic machines where the quantities are sufficiently large to justify a large hourly production. A vacuum operated device is provided on these machines to collect from a tank of molten glass the correct amount for each bulb, which is then blown by compressed air to the required shape in split moulds. The bulbs are then ejected from the moulds and passed through an annealing furnace to remove internal strains. The hourly rate of production is about 3,500 to 6,000 bulbs per hour, depending on the type of machine. Where the quantities are small it is more convenient to have the bulbs produced by glass blowers, but of course, it is not possible to maintain the same degree of uniformity by this method.

Except in the case of metal valves glass tubing is used for the electrode assembly foundation and also for the exhaust tube. This tubing is produced on a machine in which a stream of molten glass is allowed to fall on to a sloping cylindrical mandrel. As the mandrel slowly rotates the glass becomes deposited as a thick film, which slides down the nose from which it passes on to a series of rollers mounted on the floor of a long shed. A jet of air, emerging from the nose of the mandrel, prevents the tube from collapsing until it has cooled sufficiently to retain its circular cross section. At the end of the rollers is a mechanism for pulling the tubing along at a steady rate, varying from 200 to 300 ft. or more per minute depending on the size of the tubing. The diameter and wall thickness of the tube are adjusted by varying the rate of flow from the furnace, the diameter of the mandrel, and the speed at which the tube leaves the mandrel. Combined with the pulling mechanism is a cutting device, for separating the tubing into lengths of approximately 4 ft., which is a convenient size for handling in subsequent operations. The cutting is carried out by a chisel edged carborundum block mounted on a belt having the same length as that of the glass sticks, and which travels at the same rate and in the same direction as the tube. The belt is set at a slight angle to the glass tube so that a cross rubbing action takes place between the cutter and the tube whilst the two are in contact.

The glass tubing produced by the method which has just been described is used in the making of the valve foot or pinch (Fig. 1). The lengths of tubing are inserted vertically into a flanging machine, fitted with a number of revolving chucks mounted on a small circular table, which is indexed at regular intervals of time. At the first two or three stationary positions of the table, the bottom end of each tube is heated by gas burners until it becomes plastic. Whilst in this condition a spinning tool is brought into contact with the tubes, which are flanged outwards (Fig. 1/6). In the next two positions the flanged tube is cut to length by heating at the required distance above the flange and parted off by two rotating bevelled circular knives, one on the inside and the other on the outside. On the last position the chucks are opened, allowing the length of tube to fall on to a length setting plate ready for the cycle of operations to be repeated.

The flanged tubes are now transferred via a sloping chute to a horizontal circular slotted table, and in

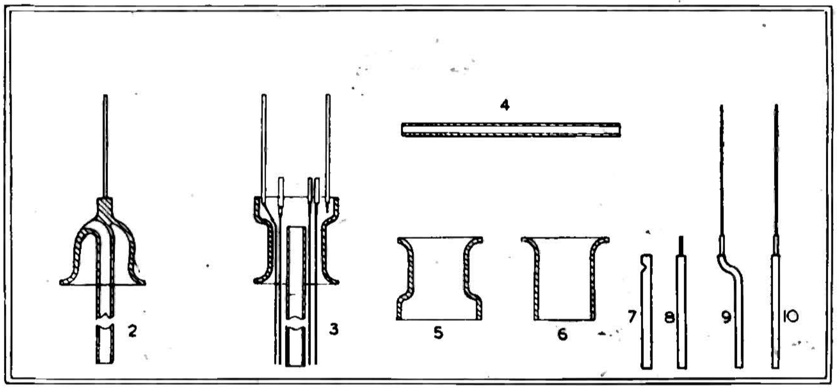

Fig. 1. The glass "pinch" of the valve and its component parts.

*The M. O. Valve Co,. Ltd.

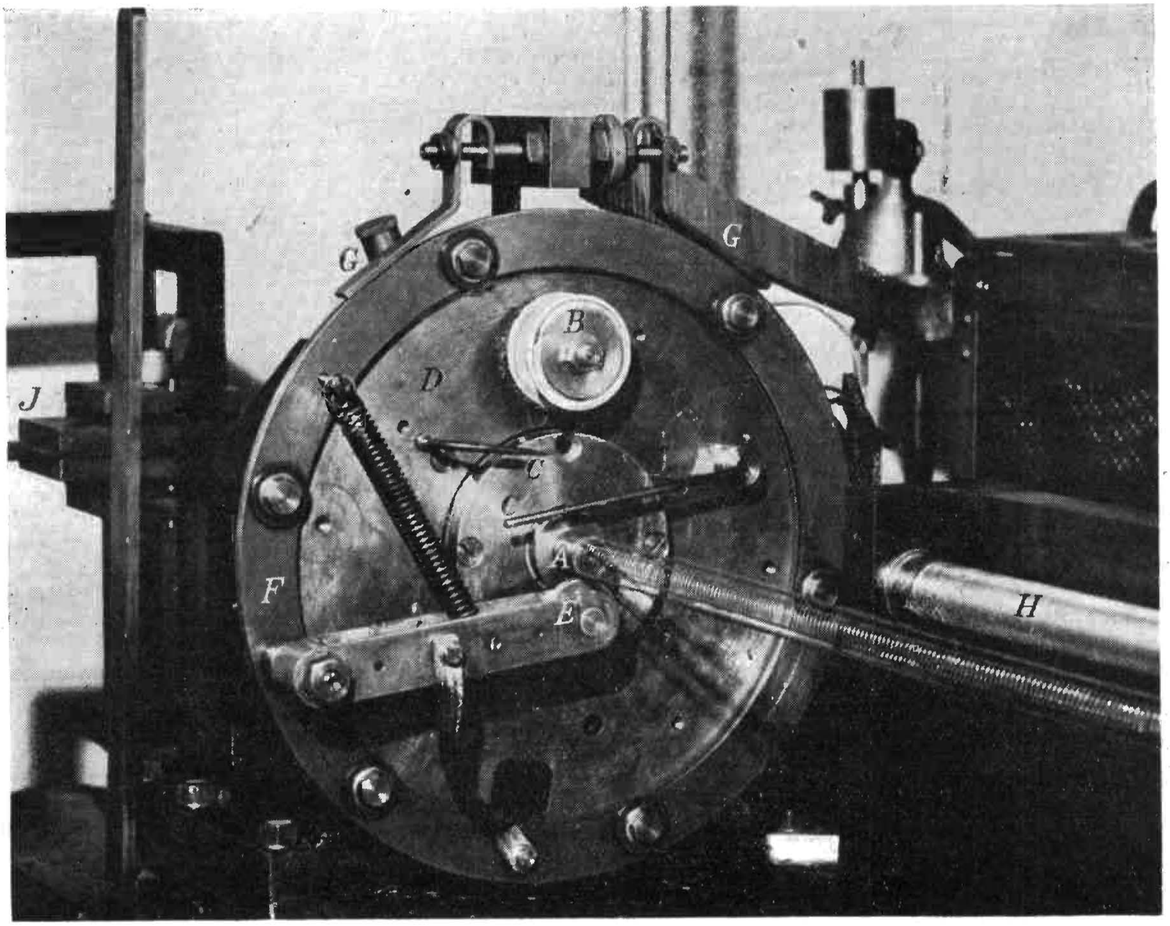

Fig. 5. Close-up of the grid winding machine showing grid wound in a continuous length.

order that they can be supported by the flange, are inverted during their passage down the chute. The table is indexed so that each slot receives a flanged tube, which is heated at the bottom end until it becomes plastic. At a suitable position a pair of blades, similar to a glove stretcher, are inserted and the tube stretched to the shape shown in Fig. 1/5. This operation is necessary in those cases where the two outer electrode lead wires are spaced at a greater distance than the internal diameter of the tube.

The lead wires, which not only support the various electrodes, but provide electrical connexion to them, are in most cases composite in nature. In Fig. 1/10 is shown a three-piece lead comprising (a) an electrode support, usually nickel, (b) a short length of alloy wire which is fused into the tube to form a vacuum tight joint, and (c) an external copper connector. When a very wide spacing is required between the outer supports, the nickel component is pre-formed as in Fig. 1/9. In those cases where an electrode is supported by two wires, one of them does not have an external copper connexion and is made with either a short length of alloy wire (Fig. 1/8), or with a nick (Fig. 1/7), to hold it securely in the glass.

The foot or pinch is made by inserting the lead wires, nickel downwards, into holes drilled in a heat resisting die block. The glass flange and exhaust tube (Fig. 1/4) are supported in Fig. 1/3, *i.e.*, with the welded joints of each of the lead wires lying within the flattened zone of Fig. 1/5. Whilst thus aligned the die block and jaws are indexed through a number of graduated fires to reduce the thermal shock to the glass, which gradually becomes plastic and flows around the lead wires. At this stage a pair of jaws compress the glass firmly around the wires and complete the seal. The inner end of the exhaust tube is now embedded in the pressed portion of the flange tube, and, in order to provide a free passage for exhausting the valve, a jet of air is directed into the outer end, whilst at the same time small gas burners keep the upper surface of the pressed portion in a plastic state. The air pressure in the exhaust tube forces a passage through the wall as shown in Fig. 1/2, which is a view taken at right angles to Fig. 1/3. The final pinch is then thoroughly annealed to prevent glass cracks. The conventional type of pinch-making machine may have from twelve to twenty-four heads, and production varies from 200 to 400 pinches per hour according to type. As a final operation, and depending on the layout of the various electrodes, the lead wires are trimmed and bent to the required shape as for example in Fig. 8.

The metal components can be divided roughly into two groups, *i.e.*, sheet metal pressings, and those made from wire or strip.

Those falling into the first group consist of anodes, beam plates, shields, contact caps etc.:

Anodes are generally two-piece pressings, or single piece as in Fig. 2.

Shields and other pressings in general use are too diverse to describe in detail, but represent general press work technique, except that the thin material used and the accuracy required calls for the highest skill in tool making. It will no doubt have been noticed that some of these are made in bright metal and others in black. Black or carbonised material permits the use of smaller components

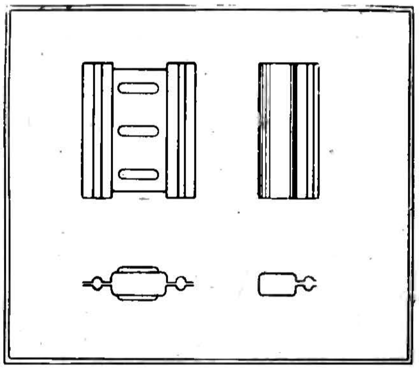

Fig. 2. Various one-piece and two-piece anode pressings.

for a given wattage dissipation on account of its improved heat radiating properties, a very useful factor in view of the modern tendency towards a reduction in the overall size of valves. A large variety of formed wire and strip components are required for clamping, supporting and connecting purposes. These are produced on automatic machines where the quantities required are large, otherwise it is more economical to construct simple hand operated jigs, which do not require careful setting up.

Depending on the function which it has to fulfil, a valve, unless it is a diode, may have from one to six separate grids. The grids are usually the most critical component parts of a valve and it is proposed to deal with their manufacture in some detail.

A grid normally consists of a helix of fine wire attached to one or more longitudinal support rods and may, according to requirements, have one of the various cross sections shown in Fig. 3. The helix pitch in the majority of cases is constant and can vary from 8 turns per inch to nearly 200 turns per inch. In certain cases of high frequency valves used in manual or automatic volume control circuits, the pitch is increased in the centre portion as shown in Fig. 4 (right).

The two methods of attaching the grid wires to the supports in general use are by resistance welding or by a mechanical process of notching and swaging, the latter being in effect a caulking process. In certain older types of transmitting valves the supports are laced to the grid turns by means of a fine binding wire, mainly because the art of welding together two molybdenum wires had not been developed when these types were introduced. Welding by high speed machines is really only practicable when the small diameter winding wire has a higher melting point than that of the supporting wires, so that with the increasing use of materials such as nichrome, manganese nickel, etc., which are considerably cheaper than molybdenum, the use of this process has diminished in recent years. The notching and swaging process provides unlimited scope in the choice of materials; a considerable boon to the valve designer.

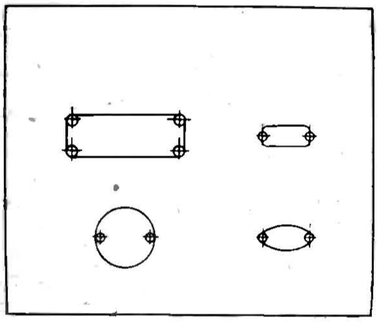

Fig. 3. Cross sections of various types of grid.

Irrespective of the process employed, the basic principle of the winding machine, one type of which is shown in Fig. 5, is that of a screw-cutting lathe. A short mandrel (A) of the required cross section, with longitudinal grooves to accommodate the support wires, is mounted in a non-rotating holder inside the hollow main spindle through which pass the support wires, fed from spools carried in an external cradle. The support wires are adjusted in the initial set up to project beyond the nose of the mandrel and are gripped by a suitable clamp mounted on the slide rest, which is traversed by a lead screw (H) driven by a train of gears to give the required pitch. A face plate (D) mounted on the spindle carries both a spool of winding wire (B) and a spring loaded welding roller (E), which is connected by brushes (G) contacting an insulated ring (F) on the face plate, to the low voltage secondary winding of a single phase transformer. As the face plate revolves around the stationary mandrel, the wire is drawn off the spool over guides (C) and welded to the grid support wires. The machine is now stopped when the slide reaches the end of the machine bed and the length of wound grid severed close to the mandrel, the slide traversed back to the starting point and the clamp reconnected to the support wires.

In the notching and swaging process, shown diagrammatically in Fig. 6 stages A, B and C, the cycle of operations is very similar, except that a rigidly supported sharp-edged circular cutter, which is free to revolve, is substituted for the welding roller. This cutter makes a succession of notches in each of the support wires as they are drawn across the mandrel, and into these the winding wire is laid. A square-edged spring-loaded roller hammers or caulks the material of the support wire around the winding wire, and secures it firmly in position.

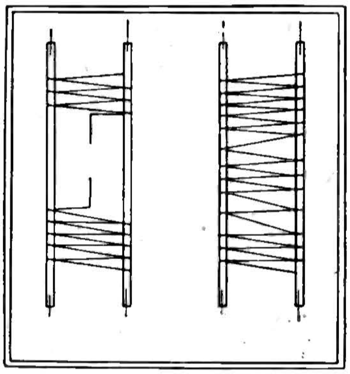

Fig. 4. Grids wound with constant and variable pitch.

The projecting ends of the grid support wires which are required for location and connexion, are obtained either by switching off the welding current or by lifting the swaging roller, depending on the process employed, the loose turns being removed in a subsequent operation.

The finishing processes commence with the length of wound grids as removed from the machine and are very important in view of the accuracy required. In the case of notched grids, the lengths are first stretched longitudinally to remove a slight distortion imparted by the swaging process. The grids are separated in a cutting-tool and then normalised in a high temperature hydrogen furnace. This treatment also releases some of the surface gas, which would be harmful to the vacuum in the finished valve. The grids are then, if the cross section permits, internally stretched in order to size them to the correct dimensions.

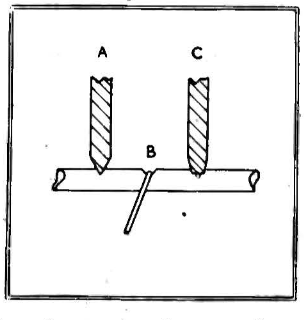

Fig. 6. Stages in the manufacture of notched grids.

All grids have to be gauged across the minor axis in "Go" and "Not Go" gauges. The normal limits imposed for the most critical grids are of the order of ±0.3 mm. (±.0012 in.) and in certain cases the limits may be even smaller. As previously pointed out these limits are large in comparison with accepted standards of precision engineering, but it is necessary to bear in mind the fact that, in the known art of wire drawing, variations in the temper of various successive batches exist, and these affect grid making considerably. When one considers that grids may be made in batches of say 10,000, and that anything up to 15 or 20 spools of wire may be required for this quantity, the possibility of variation is very apparent and frequent adjustments are necessary to maintain uniformity in the product.

Fig. 8. Photograph of a barrel jig used in electrode assembly.

Cathodes and Heaters

The cathode, of which there are two distinct types, namely, directly and indirectly heated, is coated with electron emitting chemicals which only become active when raised to a temperature of the order of 700/800° C.

The first consists of a length of wire or strip usually formed into one or more "vees" (See Fig. 7/1 and 7/3), the ends of which are clamped or welded to two lead wires in the pinch, the bottoms of the intermediate loops, if any, are secured to dummy lead wires while the tops are supported by helical or cantilever springs to hold the system taut and to compensate for expansion and contraction. The emissive coating is applied to the wire or strip by passing it at a steady rate through a series of baths with intermediate drying ovens; the coating thickness, which is critical, being maintained by careful control of the viscosity of the chemical suspensions in the baths.

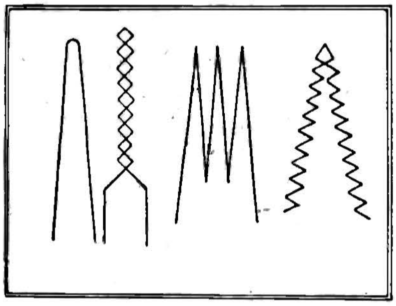

Fig. 7. Types of filaments and heaters.

In the indirectly heated type the cathode consists of a thin wall seamless or lock-seam folded cylindrical or elliptical nickel tube, whilst rectangular cathodes are usually formed up from thin strips of metal. The emissive coating is applied in the form of a fine spray directed on to a row of cathodes mounted in a jig, specially designed to control the length of the coated portion. The thickness is controlled by weighing samples in the coated and uncoated state. In order to activate the cathode coating, an insulated heater of tungsten or molybdenum-tungsten alloy wire is inserted into the interior. The transfer of heat is relatively slow, hence the time lag which is encountered in starting up with valves of this type. The insulating medium in this case is pure alumina, which is likewise applied by a spray gun to batches of heaters mounted in special jigs.

The coated heaters, which may assume any of the shapes shown in Fig. 7 are inserted into small bore alumina tubes and sintered at a high temperature (1,450-1,750° C.) in an atmosphere of hydrogen to remove impurities and to consolidate or sinter the coating.

The Mounting of the Electrode on to the Stem

The assembly of the various components on to the supporting stem or pinch is an operation calling for extreme care in order to ensure that the relative clearances between the various electrodes are maintained within the desired limits set to ensure that the required electrical characteristics of the finished valve are obtained. On this account it is usual to anchor the various grids, anodes and cathode systems in accurately pierced mica spacers before completing the operation of welding the electrode supports to the respective lead wires on the pinch.

In the more complicated types of valves the use of assembly aids or jigs is often resorted to. As previously mentioned, in the more complicated types assembly jigs are used and the barrel jig shown in Fig. 8 is probably the best example of this type. The various electrodes are

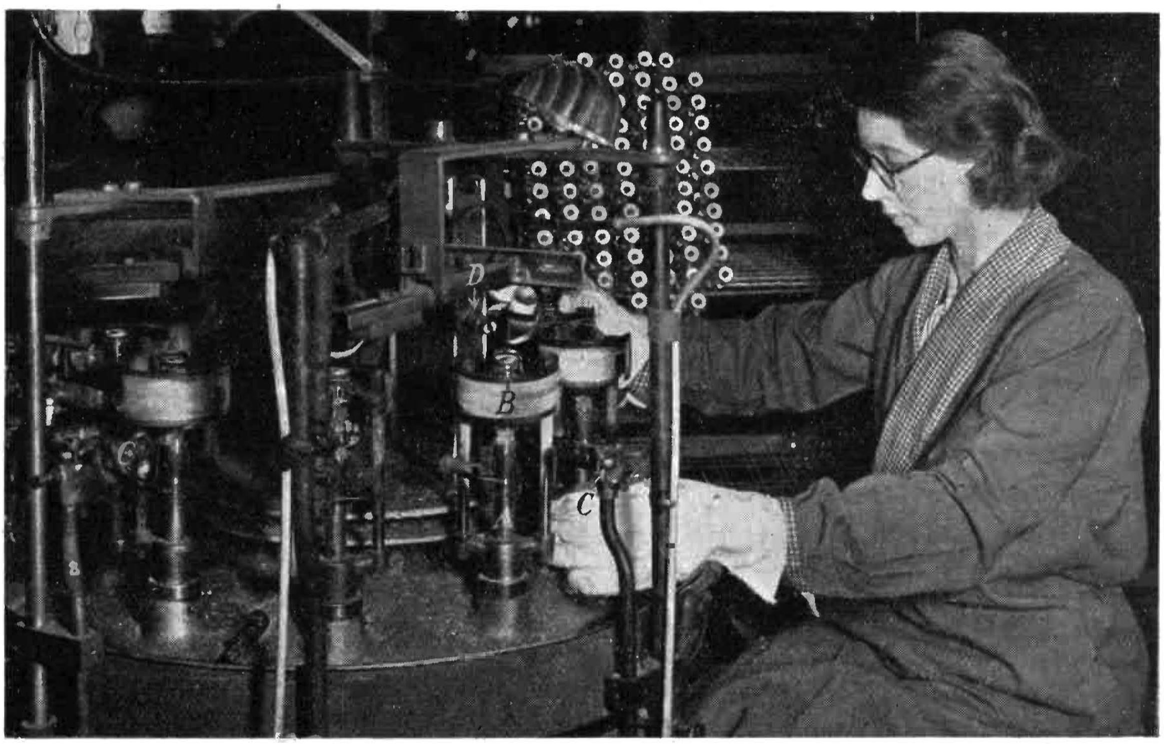

Fig. 9. A view of the automatic sealing-in machine.

loaded into the respective slots or grooves in the jig and the pinch, complete with the bottom mica assembled, is now offered up to the jig and the respective electrode leads fed through the holes in the bottom mica. The electrodes are now welded to the respective pinch supporting wires and the barrel jig withdrawn.

The welding operation itself calls for little comment. The spot welders are usually fitted with 1 kVA or 2 kVA step-down transformers and are of light construction, fitted with a spring-controlled make and break mechanism. In some cases special current controlling devices are fitted where extra delicate work is called for. The accurate use of these small welders is well within the capacity of the average woman worker and most of them are able to carry out this operation with a high degree of efficiency. Naturally, the avoidance of damage or distortion to the various electrodes during assembly is one of the things which call for most attention during this operation, particularly as much time and money has been spent in previous operations in making these electrodes to accurate sizes. Other allied problems have to be dealt with, such as the avoidance of contamination of the material surface by greasy hands, and the associated difficulty of avoidance or at any rate dispersal of small particles of fluff or lint, which ultimately give rise to extraneous noises in the finished valve.

Sealing-In

The electrode system, when mounted on the glass stem, is now ready for enclosing in the surrounding glass envelope or bulb. This operation, known as sealing-in, is carried out on the machine shown in Fig. 9. This consists of a number of rotating heads each having a central pin (A) into which the exhaust tube of the mounted seal is inserted. The bulb (B) is now fed into position open end downwards over the mounted seal. It is held in position by a chuck, in such a manner that it completely covers the mounted seal and the lower or open end extends for some distance below the opened out or flanged part of the seal. The machine which is power indexed now starts to rotate and in the first position "soft" fires impinge on the neck or lower part of the bulb at a point almost opposite the flanged out part of the seal. The machine continues to index through other positions, where other "harder" fires are brought into play at the same point. It is perhaps necessary to give an explanation of the term "soft" and "hard" fires. It is essential in working glass to raise the temperature slowly till the plastic stage is reached, in order to avoid thermal shock and the resultant cracking. Correspondingly the glass must not be allowed to cool suddenly after the operation is completed. In order to ensure that there is no sudden increase or decrease in the temperature gradient curve, the fires used are arranged so that in the initial stages they give a low heat output (usually by limiting the amount of gas flow and at the same time cutting down the air supply to a very low figure—this gives a "soft" flame). Correspondingly the latter stages consist of fiercer or hotter fires with a greatly increased air pressure, resulting in a "hard" fire. After the completion of the sealing-in operation the temperatures are again slowly lowered. With the increase of temperature the neck of the bulb starts to melt and in so doing the glass shrinks on to the flange at the bottom of the pinch and a lip near the top of the seal support pin, as the lower part of the bulb drops down under its own weight. An airtight joint is thus made between the bulb and the pinch, and the only connexion between the interior of the bulb and the atmosphere is now via the exhaust or stem tube. The sealing-in operation can perhaps be more readily followed by examination of Fig. 10 where view (1) shows the bulb prior to the application of heat, (2) after the bulb has shrunk on to the glass flange and pin and (3) where the neck has been separated from the bulb. This is accomplished by blowing a jet of air from a series of small holes in the pin above the lip which punctures the hot glass between the flange and the lip so that it is quickly melted away.

Pumping

The basic principle underlying the pumping operation is to drive out the occluded gases from the electrodes of the valve and also from the glass bulb in the shortest possible time. The gases occluded in the electrodes have been previously reduced to a minimum by cooking, either in a vacuum or in an atmosphere of hydrogen. Certain precautions are also taken in the smelting stage of the metals used to reduce the gas content. Very low pressures, by ordinary standards of comparison, are obtained by means of microscopic mechanical clearances in the rotary exhaust pumps sealed by oil, which has been treated under vacuum to remove the more volatile components. A good double stage oil pump, one stage of which is shown diagrammatically in Fig. 12, is capable of reaching a pressure of 1/10 of a micron (0.0001 mm. of mercury). Actually, the pressure in the exhausted valve is considerably above this figure, owing to unavoidable losses due to the multiplicity of rubber joints, leakage across the lapped surfaces of the machine valve, the restriction imposed by the small bore exhaust tube and the progressively slower rate of exhausting, which takes place as the lower pressures are reached. Some manufacturers prefer mercury vapour diffusion pumps backed by a single stage oil pump. This arrangement has a higher rate of exhausting but requires more maintenance.

In actual practice a pump machine shown diagrammatically in Fig. 11 consists of a number of such units, coupled by a multipoint central rotary valve to the various positions in a circular manifold, which support the valves to be exhausted. The exhausting process consists of inserting the glass exhaust stem of the valve into one of the rubber connecting tubes of the pump manifold and opening up the control tap to the pump system. The machine indexes and the valves being pumped then move forward under the pump oven which is heated at an average temperature of 450° C. By this means the bulk of the occluded gas is driven from the glass bulb—water vapour is readily removed by this treatment in considerable quantity. The electrodes of the valve are then heated up by a current induced from a high frequency source. This liberates gas from the electrodes and heats the cathode to decompose the carbonates in its sprayed coating. At this stage it is usual to reheat the electrodes to disperse any gas which they may have absorbed during the heating of the cathode. The final vacuum on the pump is usually obtained by liberating a "getter" or chemical composition to effect the final clean up of the remaining residual gases. The "getter" employed varies, but usually consists of barium or magnesium or a varying percentage of each.

With the completion of the pumping schedule the valve is sealed off by melting the exhaust stem to a small pip.

A typical pumping machine is shown in Fig. 13, which shows (A) one of the rubber valve connexion housings built into the circular water cooled manifold (B), (C) the oven for baking the bulbs, (D) one of the high frequency coils, (E) the sealing off device, and (F) the delivery chute to the capping machine.

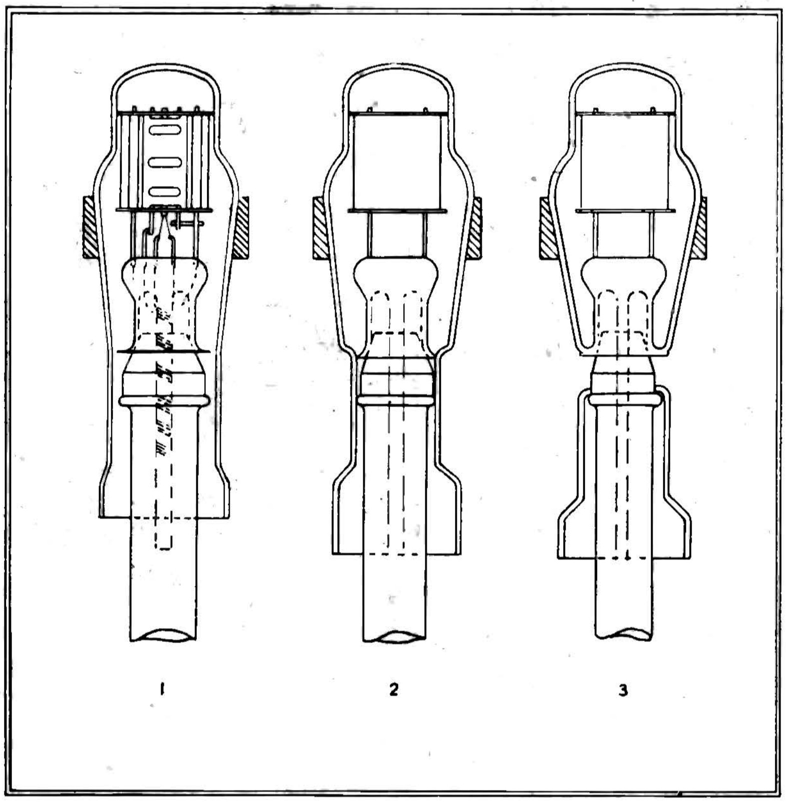

Fig. 10. Showing the stages in the sealing-in operation.

Capping

The fixing of the cap to the glass bulb is by no means such a simple operation as it appears at first sight. It is an unfortunate fact that most of the quick hot treatment cements available require a heat treatment temperature, which is very close to the blistering point of the bakelite material of the cap and great care has to be taken in selecting a suitable capping cement, which usually consists of a bakelite or shellac base with a suitable filler. The cement is fed into the cap in a semi-plastic state, and the copper leads from the valve are threaded into the respective pins in the cap, the lower part of the bulb is then introduced into the cap and is now in contact with the cement. The valve, complete with cap, is then inserted into a rotary machine and passes through an oven, thus drying out the carrier in the cement and forming the bond between the glass and the cap. Modern practice usually includes the use of centring devices, for ensuring that the cap and bulb are reasonably aligned. After the capping operation the surplus copper wires are cut off and the leads soldered to the pins in the cap.

Activation and Ageing

The full emission of the valve is not developed directly it comes off the pump, but by running the cathode at a temperature which requires careful control, with suitable potentials on the other electrodes for a specified time, further activation takes place, and the valve is stabilised from the point of view of the remaining small quantities of gas left behind.

Testing

The final operation in the manufacture of a valve is testing. The number of tests to be applied is governed by the type of valve being tested, but all valves have some tests in common.

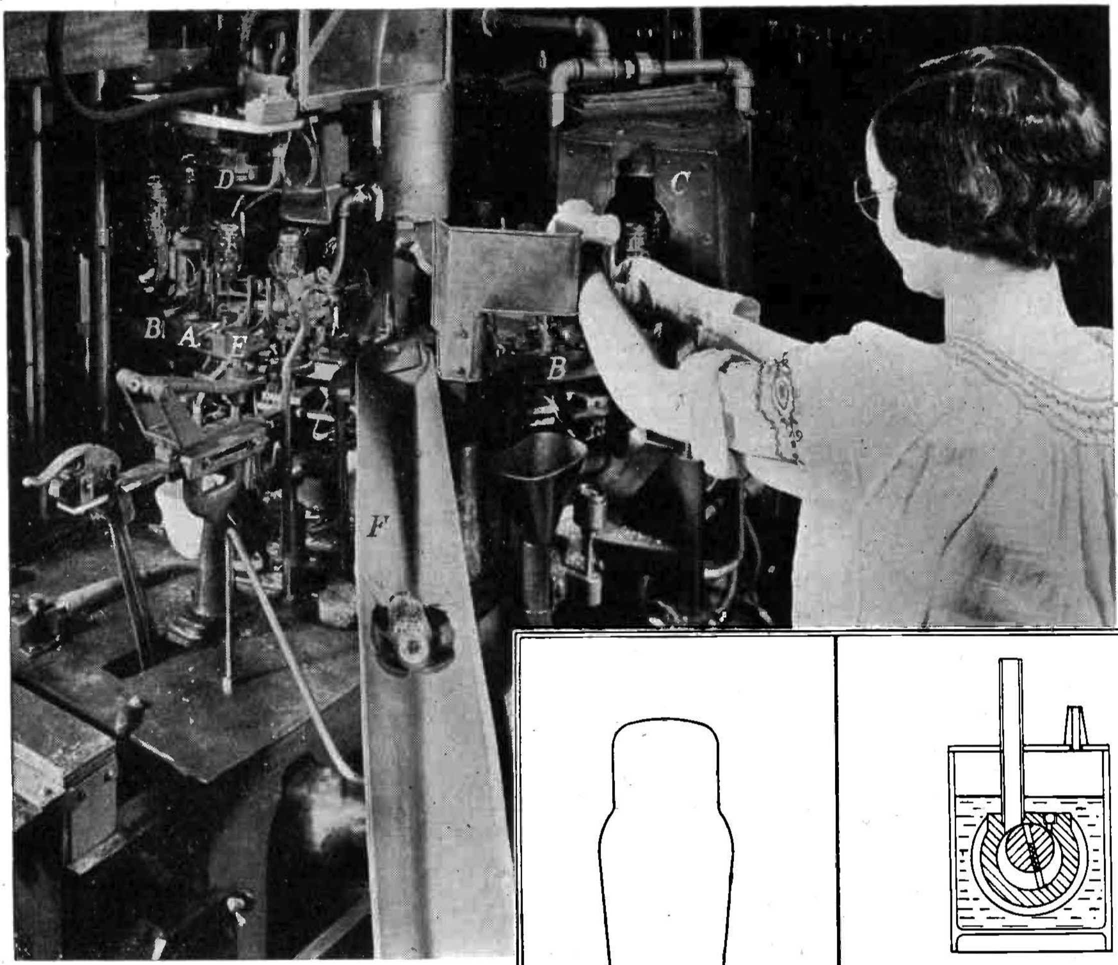

Fig. 13. Automatic rotary exhausting machine.

The ones usually applied are :—

(1) *Filament Rating.*

Either the filament voltage is fixed and the filament current read, or vice versa.

(2) *Anode Current.*

The anode current is recorded, with a fixed potential on the anode and grid, usually at the working point.

(3) *Negative Grid Current or "Backlash."*

A potential is applied to the anode and the heater/cathode or filament circuit run under normal conditions, and with a low negative potential applied to the grid the negative grid current is recorded. This reading will give an indication of the gas pressure of the valve under test.

(4) *Other Applied Tests.*

According to the type of valve and its particular application to circuit use, other tests are made such as power output in the case of the output valve, and conversion conductance in the case of frequency changers. In addition to these tests it is usual to test each valve for microphonic properties, or other noises which may be indicative of loose fitting or badly joined electrodes.

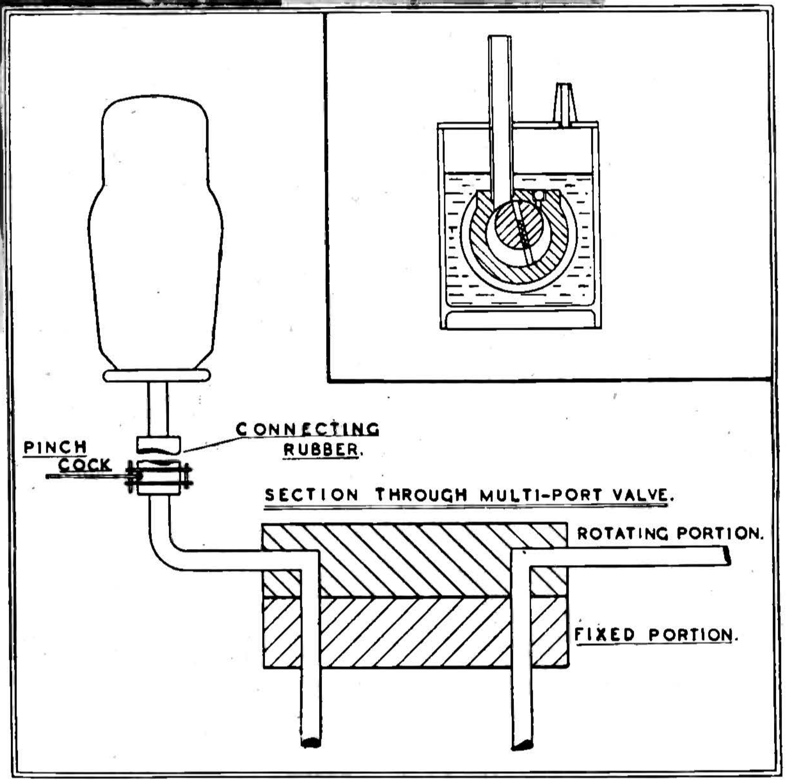

Fig. 11. Diagrammatic layout of exhausting machine.
Fig. 12. (Inset) Section through rotary oil pump.

Conclusion

From the foregoing it can be gathered that although valve manufacture has now developed on an extensive scale, the maintenance of characteristics, and satisfactory life performance, are problems which call for very close inspection of the electrode construction and all the subsequent valve manufacturing processes right up to the final testing.