With the advent of new, exotic devices, the vacuum tube has been de-emphasized by many engineers. However, tube designers are continually striving to design better tubes. One area of their interest has been the heater. A significant number of improvements have been made in the heater over the last few years.

The Materials and Shapes of

Vacuum Tube Heaters

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IN vacuum receiving tubes, heat can be supplied to the cathode by either of two conventional methods: "Directly," by means of a current passed through a filament of base metal to which the emissive material has been applied; or "Indirectly," by means of a separate, insulated heating element which is mounted within the cathode structure. Because the directly heated cathode is rather simple in construction, we will discuss only the heating element in an indirectly heated cathode.

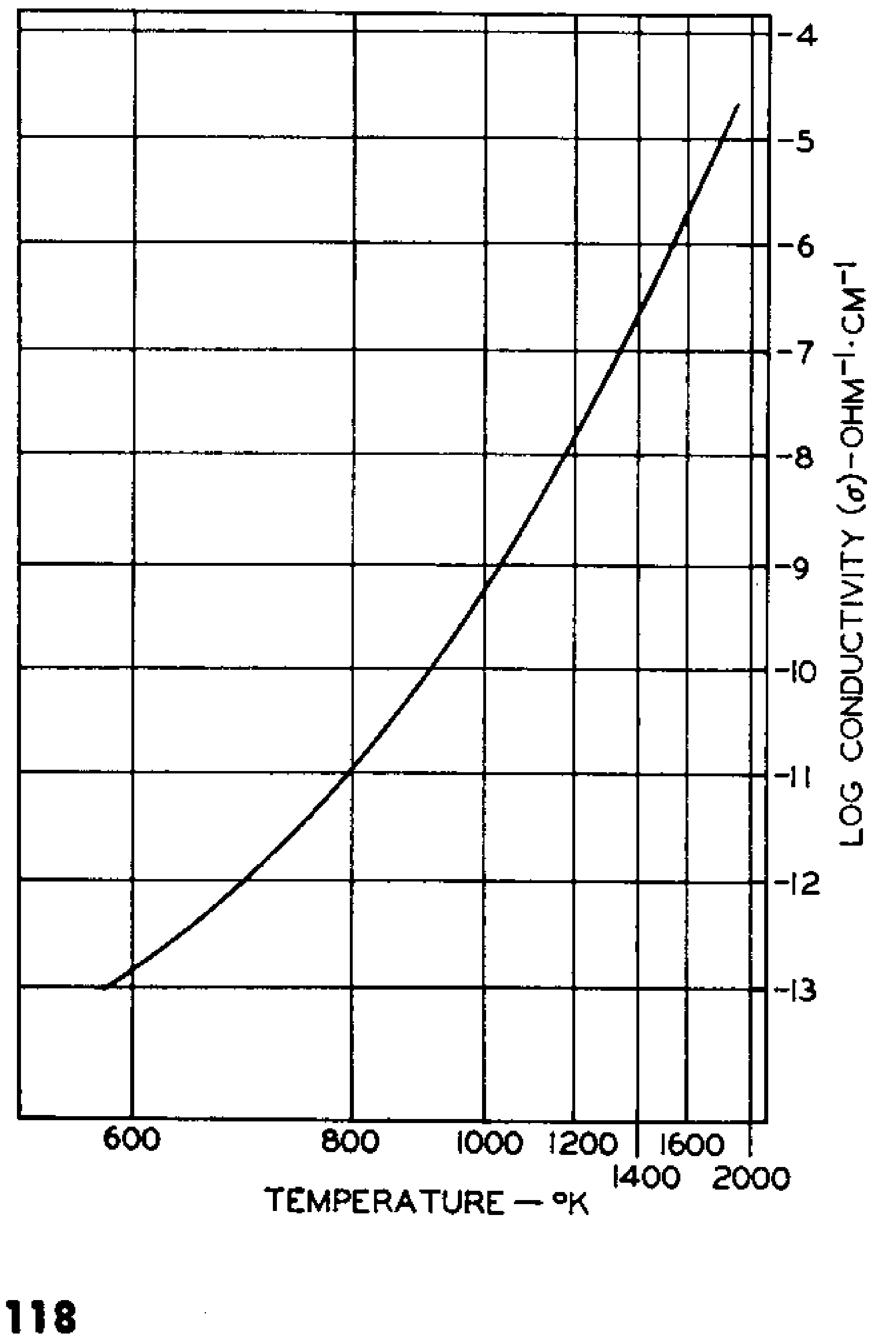

Fig. 1: Graph shows the effect of temperature on the electrical conductivity of alumina.

For proper cathode temperature, the heater normally operates at about 1100° to 1200° C. It may sometimes reach 1600° C in tube processing. Under these rigorous conditions, only the most carefully selected and controlled materials can be used. Therefore, the choice of heater materials is limited to those elements which are characterized by high melting point, low vapor pressure, chemical inertness and low cost. Of the available materials, tungsten, which is used as the heating element and alumina, which is used as the electrical insulating material, meet these requirements.

Heater Materials

In its natural form tungsten is usually obtained from the minerals wolframite (Fe, Mn) WO_4 and schoelite (Ca WO_4). Because 70% of our original tungsten resources have been depleted, methods have been found for purifying relatively poor-grade ores.

The quality of tungsten heater wire depends upon many factors, and the materials and manufacturing process are carefully controlled. The powder used to produce the ductile metal is initially of high purity. For the purpose of inhibiting grain growth, however, very small quantities of partly volatile alkali silicates and non-volatile oxides such as silica, alumina, thoria, or calcia are added to the tungsten powder.

After being mixed, the tungsten powder is pressed into bar ingots. Ingots are then sintered at a temperature of approximately 3000° C. The time-temperature relationship at which the ingots are sintered is carefully controlled to assure a dense bar which, in turn, determines many of the properties of the finished heater wire. At a temperature of about 1300° C, the sintered bar is worked into a rod by mechanical hammering or "swaging." During this process the cross-sectional area is reduced by 15% each time the rod is run through a successively smaller die. After the swaging process, the tungsten rods are drawn hot through a tungsten carbide die. The final, smaller wire sizes are drawn through highly polished diamond dies. As the wire is drawn and reduced in area, its tensile strength increases to as much as 500,000 lbs/sq. in.

The electrical, as well as the chemical and physical properties of tungsten have been intensively investigated. Although the resistivity of tungsten is not as high as that of some other materials, its high melting point of 3400° C makes it a desirable heater material.

At room temperature, small variations in resistivity are found among tungsten wires, depending upon their previous treatment. Despite these small variations, however, tungsten wires display similar electrical resistivities at high temperatures. This characteristic is important because it enables the mass production of reproducible heaters having a uniform current at operating voltages. No other material has such an outstanding combination of desirable properties at elevated temperatures in vacuum.

Alumina

Alumina, alone or associated with silica, is a major constituent of the earth's crust. The principal alumina ore is bauxite ($Al_2O_3 \cdot 2H_2O$).

The three principal crystalline forms of alumina are designated alpha, beta, and gamma. Alpha alumina is formed at high temperatures. It is found in the natural mineral corundum and in fused alumina formed from the solidification of a melt; beta alumina is a modification containing sodium in its crystal structure; and gamma alumina is encountered in the low-temperature calcination of aluminum compounds. The alumina used for heater coating is a very high-purity alpha form.

Large fragments of the fused alumina are reduced to very fine particles by grinding in an iron-ball-mill. After particle-size reduction, the material is cleaned in acid, washed, and heat-treated to remove any contaminants. This preparation results in the pure, carefully controlled alumina particles which are important in the deposition of the alumina on the heater.

An important property of alumina, which depends upon the crystal form and purity, is its extremely low electrical conductivity. Fig. 1 shows the effect of temperature on the electrical conductivity of alumina. Thus curve represents an average based upon the work of several investigators. The thickness of the alumina coating required on a heater is a function of its dielectric strength, and usually depends upon the bias to be applied between the heater and the cathode. It is generally agreed that one mil of the coating is required for each 75 volts.

Because heat energy is primarily transferred from the heater to the cathode by radiation, the thermal conductivity of alumina, although good, is not too important a factor. The chemical stability, high melting point, and electrical resistivity are the important properties that make alumina a dependable insulating coat for vacuum tube heaters.

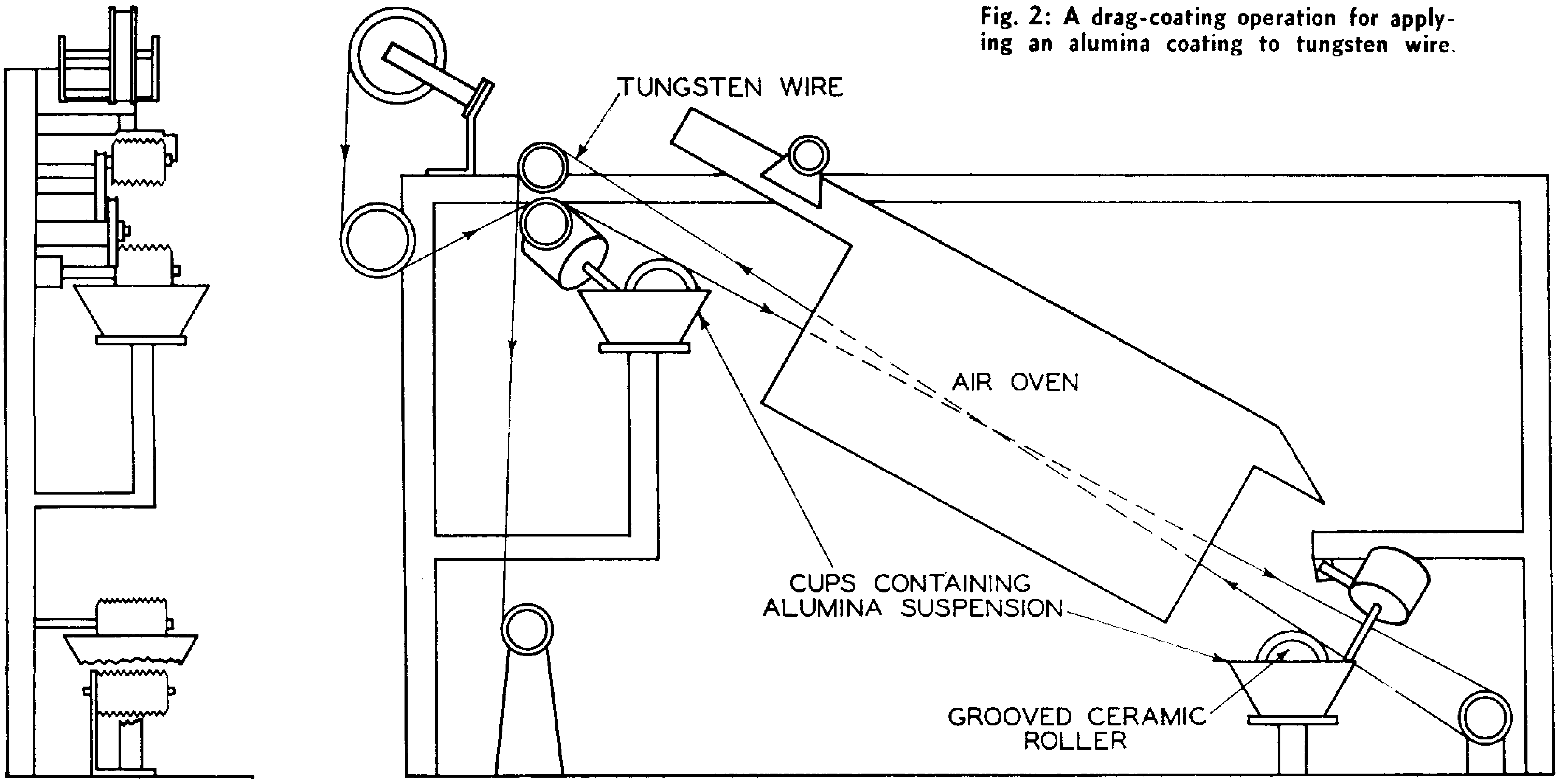

Fig. 2: A drag-coating operation for applying an alumina coating to tungsten wire.

Tube Heaters *(Continued)*

Methods of Alumina Deposition

One technique used for the application of the alumina insulating layer to the tungsten wire is the "drag"-coat method. As the name implies, the bare tungsten wire is passed or dragged through a specially prepared alumina suspension. This suspension is composed of a very pure, fused and milled alumina in a solution of methanol, aluminum nitrate salt, and distilled water. The alumina particle size usually ranges from 5 microns to 40 microns. The methanol acts as a suspending agent for the fine alumina particles and evaporates quickly as the wire passes from the suspension into an air furnace. The aluminum nitrate salt acts as a low-temperature binder. It cements the alumina particles together as each layer is built up during the "drag" operation.

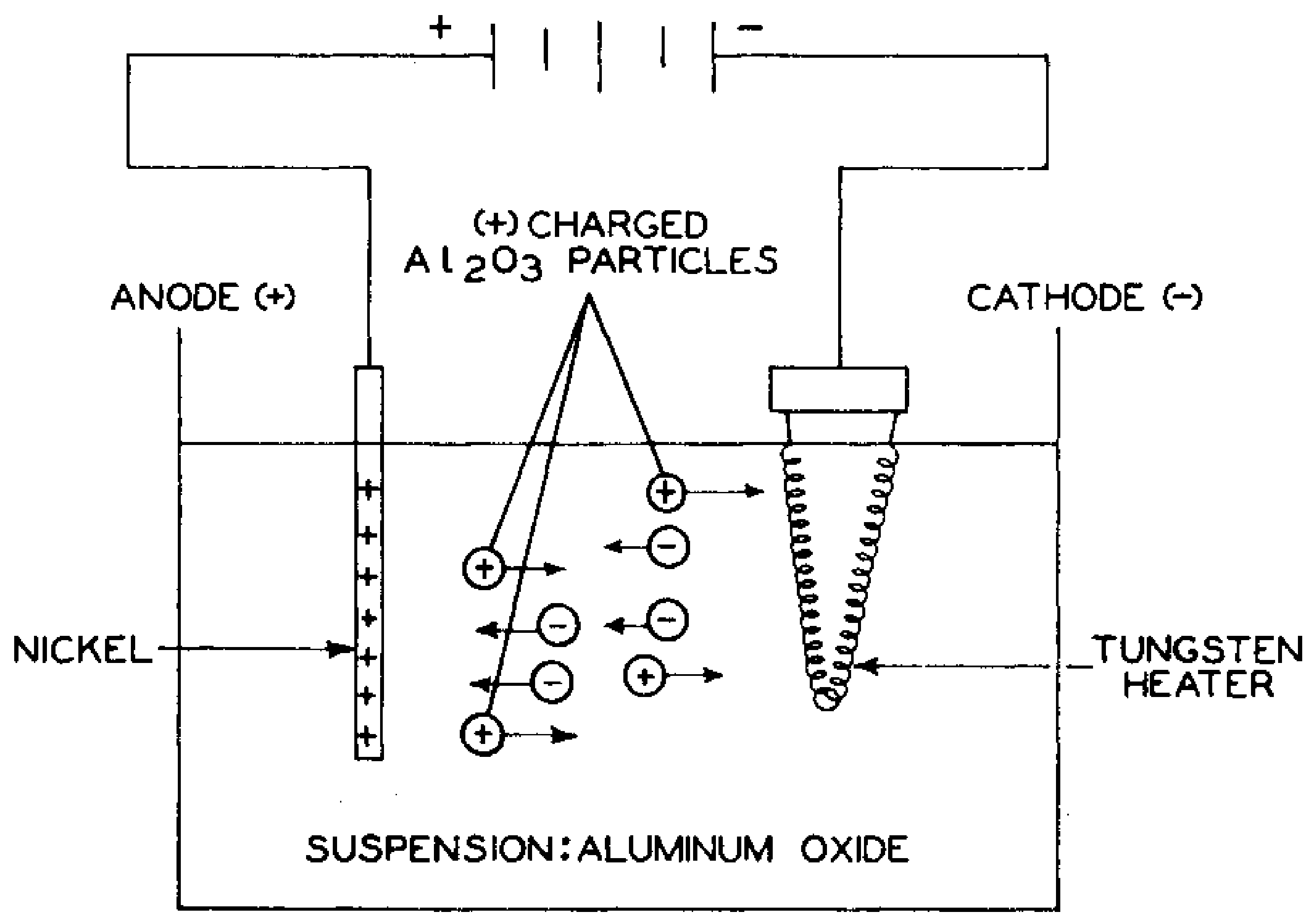

Fig. 3: Alumina coating is applied to tungsten filament wire by using an electrical potential to obtain charged particles.

Fig. 2 is a sketch of the "drag"-coating operation. The grooved ceramic roller rotates partially submerged in the alumina suspension, and applies a thin layer of coating to the tungsten wire passing over it. The specific gravity of the suspension and the speed of the machine are adjusted so that after 8 or 10 passes of the wire over the ceramic roller, the coating is built up to the desired diameter. As the wire leaves the ceramic roller, it enters an air oven. Oven temperature is between 600° and 800° C to dry and bake the coating. The coated wire is then passed through a hydrogen-atmosphere furnace. It operates at approximately 1200° C to chemically reduce any tungstic oxide which may have formed on the wire.

The coated diameter is controlled automatically by means of a photoelectric cell. The cell operates a solenoid valve to release a measured quantity of aluminum nitrate solution into the suspension, thus adjusting its specific gravity. The coated wire is carefully controlled for diameter, smoothness, concentricity, flexural strength, and weight.

Heaters are fabricated from the coated wire by spade-winding. In this operation, a length of wire is folded over razor-sharp edges set a predetermined distance apart, depending upon the linear dimension of each heater strand. After the proper number of strands are wound, the heater is automatically cut from the continuous length of spooled wire. Simultaneously, a small section of the coating is removed from the heater legs to expose the wire at the ends for welding to the tube stem leads.

Cataphoretic Coating

Cataphoresis or electrophoresis is defined as "the migration of coloidal particles under the influence of an electrical potential." Cataphoresis, as applied to heater coatings, is the process by which positively charged alumina particles are deposited on a negatively charged tungsten heater wire. The alumina used in the suspension consists of very fine particles, usually in the one-to-five-micron size range. An increased number of ionized groups on the alumina surface results when the particles are surface-charged by the addition of small amounts of selected soluble inorganic salts, such as aluminum nitrate.

The charge and stability of the alumina particle in the suspension is due to the preferential absorption of a particular ion. By the application of a potential, the positively charged alumina particles are deposited on the negatively charged tungsten heater, and a layer of alumina is built up to form the insulating coating. Fig. 3 illustrates the deposition of alumina on a heater. Generally, the amount of alumina deposited on the wire depends upon the mobility of the particles, the concentration of the particles in the suspension, and the potential between the anode and the cathode. In production, a clip holds a number of heaters, which are submerged in a suitable alumina suspension, while a fixed voltage is applied. The coating thickness depends upon the value and the duration of this voltage. After the heater is coated, it is sintered at 1600° C for a short time in a hydrogen-atmosphere furnace.

Spray Coating

Heater coatings are also applied by the spray technique. As in the drag and cataphoretic coat suspensions, the spray suspension is specially compounded for optimum results. High-quality spraying is obtained by control of the viscosity and the drying rate of the suspension. Organic solvents are added to aid dispersion and to prevent the settling of the fine-grained alumina. A nitrocellulose binder is used to produce a tough coating that can be handled easily. The desired coating texture is obtained by adjustment of the air pressure and of the area of the orifice of the spray gun. A smooth, dense coating is desired because it produces a strong coating which facilitates insertion of the heater into the cathode during tube mounting.

REFERENCE PAGES

The pages in this section are perforated for easy removal and retention as valuable reference material.

SOMETHING NEW HAS BEEN ADDED

An extra-wide margin is now provided to permit them to be punched with a standard three-hole-punch without obliterating any of the text. They can be filed in standard three-hole notebooks or folders.

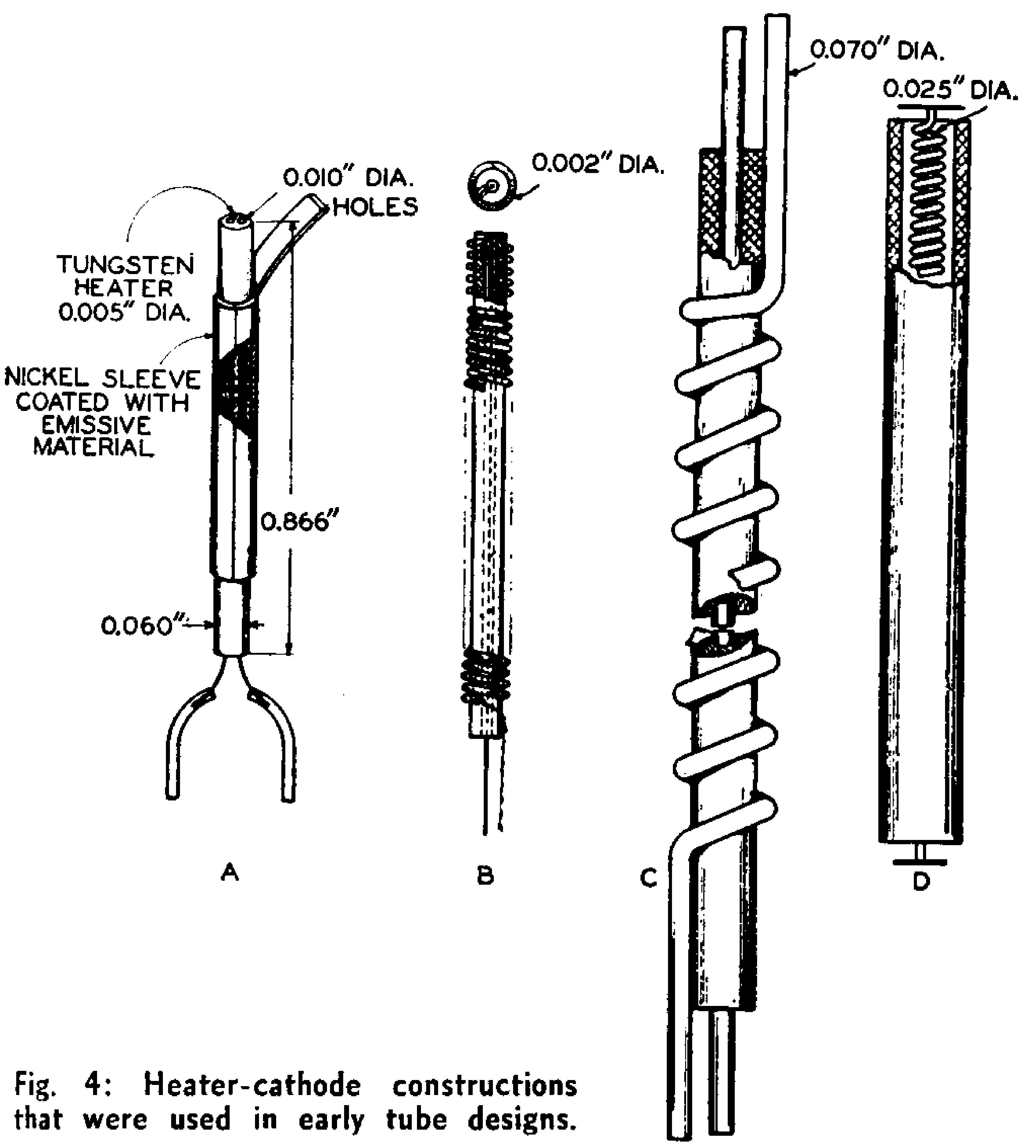

Fig. 4: Heater-cathode constructions that were used in early tube designs.

The heaters are mounted into a clip. The clip is placed in a rotary spraying machine having spray guns positioned at selected points. At each revolution, the sprayed alumina is deposited in thin layers which are dried by infrared lamps. The desired coating weight and thickness are obtained after several revolutions of the coating machine. For sintering of alumina, the heater is fired at 1600° C in a hydrogen atmosphere furnace.

Heater Configurations

Heater designs have varied considerably since 1927 when the first indirectly heated cathodes were introduced. At that time, a hairpin tungsten heater was supported by an extruded ceramic insulator, surrounded by a nickel sleeve. Fig. 4a shows a heater common to the early detector- and amplifier-type tubes. This heater operated from a 2.5 volt supply. It had a warm-up time of 20 to 30 seconds. Fig. 4b shows a 2 mil wire spirally wound on an alumina insulating tube. The return lead passed through the center of the insulating rod. Usually the wire was covered with an outside alumina coating.

Fig. 4c illustrates a 70 mil diameter tungsten wire wound around an alumina insulator. A molybdenum rod passing through the center of the tube acts as a support rod. Such heaters were designed to operate at 5 volts and 60 amperes. Fig. 4d shows a 25 mil diameter spiral heater wire supported inside an extruded insulating tube.

All of these heaters were made in various sizes to meet different heater-power requirements. The ceramic insulating sleeves were usually made of alumina, magnesia, thoria, beryllia, or electrical porcelain. Many factors, such as high cost, contaminants in the ceramics, and slow warm-up time, resulted in the decline of these heaters.

A few of the heater designs now in use are briefly described in the following section. The basic designs fall into the following three groups: the spade-wound folded heater, the single helical heater, and the double helical heater.

Folded Heater

The folded heater, made from drag-coated wire, is simple and easily manufactured. There are many design modifications in this type of heater. However, three principal forms are the staggered apex, the straight apex, and the sloped apex. The staggered-apex type is designed so that each succeeding fold is shorter than the other; the straight-apex type has each apex opposite another; and the sloped-apex type has the top and bottom apices sloped parallel to each other.

The staggered-apex heater, shown in Fig. 5a, is mostly used in round cathodes requiring a closely-packed heater. In such an arrangement, the shorter apices nest between the strands of the longer apices, thus preventing their direct contact. The straight-apex heater is best suited for a flat cathode whose cross-sectional area permits a certain amount of alignment of the heater strands, and permits the apices to spread. Because the folded heater is versatile, it is used in either round or flat cathodes. The choice of strands is determined primarily by the fit of the heater within the cathode. In practice, the folded heater is commonly used in octal tubes of the rectifier type and the power amplifiers. The heaters used in these tubes are of extremely rugged construction, and they typify the design of most of the spade-wound heaters.

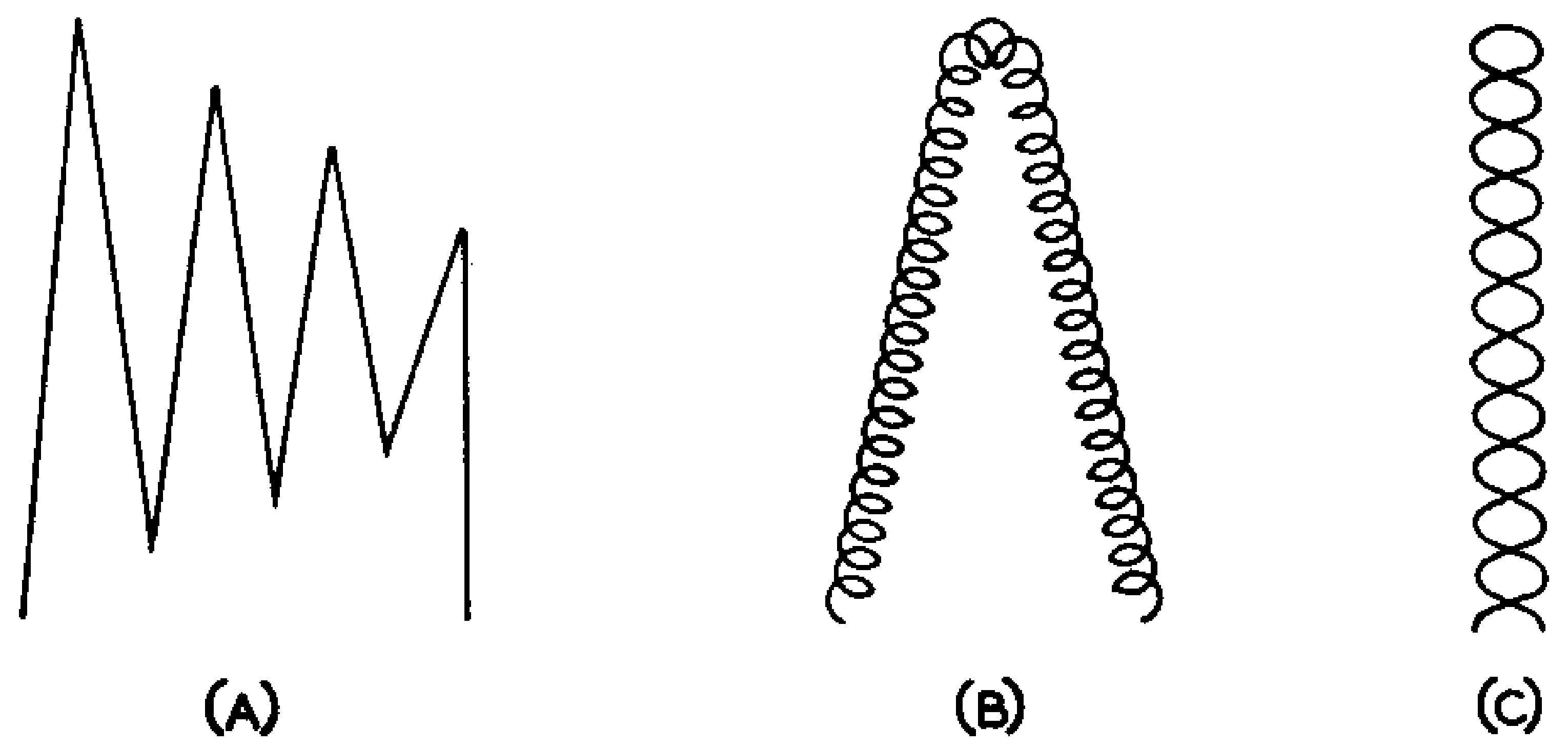

Fig. 5: Three types of heaters that are used in today's tubes.

Single Helical Heaters

The three single-helical shapes commonly employed in vacuum tubes are the inverted "V," or hairpin, the inverted "U," and the "M" shape. The "V," or hairpin shape, is used to accommodate single cathodes, whereas the inverted "U" or "M" shapes are used to accommodate 2 cathodes, depending upon whether the heater bridge between the cathodes is at the top or bottom of the tube cage construction. These heaters are made by winding tungsten wire around a metal mandrel to form a helix. Helix is cut to the acquired length and bent into the desired shape. Because the heater current depends upon

Tube Heaters *(Concluded)*

the total wire length rather than the helix length, the turns of wire are precisely spaced so that each heater is accurately reproduced. After the heater is formed, it is cataphoretically coated with alumina and sintered at a high temperature in a hydrogen atmosphere. The core, usually molybdenum, is removed by an acid-dissolving process.

Because the extremely high number of turns per inch obtainable with this heater permits more wire per unit length, it is possible to use a single helical heater in thirty-mil-or-less flat or round cathodes which normally would require tightly packed folded heaters. Fig. 5b illustrates a single helical hairpin heater, the most popular shape of the helical heaters. It is used extensively for minature tubes in which power requirements dictate heater designs involving long wire lengths.

Double-Helical Heaters

Use of the double-helical heater is usually restricted to round cathodes having diameters of 30 mils or larger because the mechanical forming techniques make it difficult to make smaller sizes. The heater wire is cut to the desired length, fed into a coil-winding machine, and wound around a mandrel. After the coil is removed from the mandrel, the alumina insulating layer is applied by spray or cataphoretic coating techniques. To increase the amount or wire in a double-helical heater, a single helix wire is frequently shaped into a double-helical heater by winding on a mandrel. This modified design not only permits a greater length of wire to be placed in the cathode, but also takes advantage of low hum characteristics of the double-helical heater. Fig. 5c shows a double-helical heater used in octal or miniature tubes requiring low hum characteristics.

Of the many complicating factors that enter into the design of a heater, such as the relative emissivities of the heater and inner surfaces of the cathode. the thickness of the heater coating, and the heater fit within the cathode, the dimension of the cathode sleeve is of prime importance. This dimension determines the heat that the heater must furnish to maintain the proper cathode temperature. The heater design temperature is calculated from the appropriate tungsten resistivity formulas or determined from nomographs specially constructed for the purpose.

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