Fine Wires in the Electron-Tube Industry*

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Summary—**This article discusses primarily the application of fine wires in the electron-tube industry. Some fundamental basic properties which confront the wire manufacturer are briefly discussed. Design formulas, including a nomograph, are given for electron-tube filaments. The use of platings of gold, platinum, and zirconium on metals of the refractory group have assisted in the reduction of grid emission. A unique method of utilizing zirconium, both to accelerate the vacuum exhaust process and to serve as a continuous "getter," is described. A novel method of securing a uniform rate of evaporation of thin films of metals is discussed.**

METHODS OF SPECIFYING CHARACTERISTICS

FINE WIRES such as nickel, nickel alloys, tungsten, thoriated tungsten, molybdenum, and tantalum have been used by the electron-tube industry from the date of its inception. The practices set up for manufacturing incandescent-lamp filaments were readily applied to filaments, heaters, and grids for electron tubes. Through a period of years, various standards for wire quality and characteristics have been established independently by individual electron-tube manufacturing companies. These standards in most cases are practically identical, with minor deviations occurring where certain other fabricating processes are to be considered.

The basic properties which have been considered are: (1) finish; (2) weight; (3) diameter; (4) elongation; (5) tensile strength; (6) straightness; (7) electrical resistance; (8) chemical composition; (9) brittleness.

The finish of a wire may vary from a clean, shiny surface to a dark matt surface. Manufacturing specifications may also include such statements as freedom from kinks, waves, cracks, slivers, seams, burrs, roughness, soap drawing compounds, oil, foreign matter, and oxides.

The weight of the fine wires is usually expressed in milligrams per 200 millimeters. Tolerances on weight usually vary from plus or minus 2 per cent for filaments to plus or minus 4 per cent for grid wires, these values depending upon the degree of control required to maintain the specified characteristic tolerances.

The diameter of the wire is usually specified as a nominal value for fine wires, and it can readily be computed by using either of the following formulas:

$$D = K_1\sqrt{W} \tag{1}$$

$$W = K_2D^2 \tag{2}$$

where D = the mean diameter of the wire in mils
W = the weight of the wire in milligrams per 200 millimeters of length
K_1 and K_2 = constants depending upon the densities of the wire.

Table I indicates values for K_1 and K_2 for the materials named.

TABLE I

Material	K_1	K_2
Molybdenum	0.989	1.022
Tungsten	0.717	1.950
Tantalum	0.771	1.682
Thoriated Tungsten	0.725	1.903
Nickel	1.055	0.898
Magno Nickel	1.064	0.883

The diameter of a wire is usually checked by the wire manufacturer for any out-of-round tendencies, which usually indicate excessive die wear and serve as a warning to change defective dies. Lack of uniform diameter may cause localized bright spots, if the wire is used as a filament, which would tend to shorten its useful life; if utilized as a grid, no detrimental effects should be observed providing the specified weight tolerance is maintained.

Out-of-roundness is usually expressed as a percentage equal to

$$\frac{A - B}{A} \times 100$$

where A = the maximum diameter of the cross section in inches, and
B = the minimum diameter of the cross section in inches.

The elongation of fine wires is usually specified if this material is to be used for grid material, in particular for grids requiring stretching of the laterals to maintain a specified shape. Typical values of elongation range from 17 to 22 per cent.

The straightness is usually specified for grid lateral material and tungsten heaters of the spiral type. This quality indicates the relative freedom from strain resulting from proper annealing of the wire. No standard method of testing this characteristic has been established in the electron-tube industry.[1] The usual crude test is to suspend a three-foot length at the ends in a horizontal plane approximately twenty inches apart and observe that the sample assumes the shape of a catenary free from bulges or irregular rises or twists.

Brittleness tests are specified for tungsten wire, which is used either as direct or indirect heaters. Stringent

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[1] See "American Society for Testing Materials Standards Handbook," 1944, p. 1794.

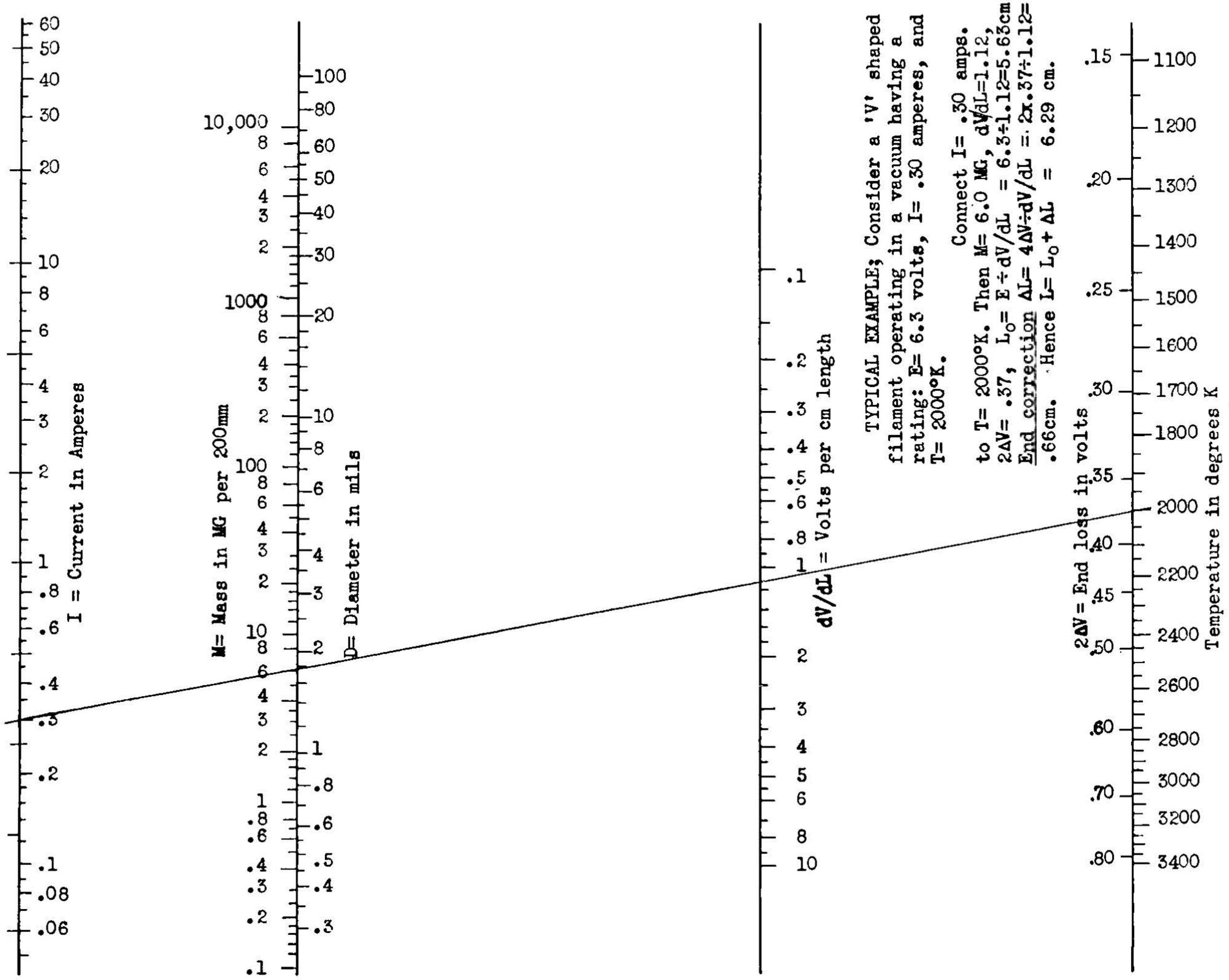
vibration testing of tubes has made such tests imperative. Manufacturers of electron tubes differ only in detail as to how this quality is measured. The usual procedure consists of supporting one end horizontally by clamping and bending the wire downward to a specified angle at which value the specimen shall not break or show a tendency towards splitting.

Electrical-resistance and chemical-composition tests are usually established only as additional tests. These properties have usually been well adhered to by most wire manufacturers, since it is very difficult to have any undue quantities of volatile impurities at the temperatures at which wires of the refractory group are sintered. Manufacturers who make alloys consisting of two or more metals of the refractory group conduct thorough tests on electrical conductivity as well as the chemical composition. In cases where the heaters or filaments are formed in the shape of coils, either inductive, noninductive, flat pancake, or spiral, nonsag material is usually specified.

It is clear that if the tube engineer puts such rigid quality requirements on his wires, the wire manufacturers can supply a satisfactory product only if they are equipped with up-to-date wire-drawing and wire-plating machinery.

In addition, a scientific control system, using the latest apparatus handled by a skilled staff to check the finished product is necessary. These features can be provided only by wire manufacturers in intimate contact with the electron-tube manufacturers.

Fine wires employed as a base metal for emitters usually consist of pure nickel, aluminum nickel, cobalt nickel, silicon nickel, tungsten, thoriated tungsten, and nickel-plated tungsten. Wires containing nickel are base metals for oxide-coated filaments of the alkaline earth group, usually barium, strontium, and calcium. Tungsten wires have been utilized either as a base metal for indirectly heated cathode-type tubes or as a direct emitter for high-power water-cooled copper-anode tubes. Thoriated-tungsten wire has been successfully employed as a direct emitter for power-transmitter tubes where the maximum plate dissipation does not exceed 1000 watts or the maximum plate voltage does not exceed 4000 volts. Nickel-plated tungsten wires having



TYPICAL EXAMPLE; Consider a 'V' shaped filament operating in a vacuum having a rating: E= 6.3 volts, I= .30 amperes, and T= 2000°K.

Connect I= .30 amps. to T= 2000°K. Then M= 6.0 MG, dV/dL=1.12, 2ΔV= .37, L_0= E ÷ dV/dL = 6.3÷1.12=5.63cm. <u>End correction</u> ΔL= 4ΔV÷dV/dL = 2x.37÷1.12= .66cm. Hence L= L_0 + ΔL = 6.29 cm.

Fig. 1—Nomograph for design of tungsten filaments. (See footnote reference 2.)

diameters of less than 0.001 inch are suitable as a base metal for oxide-coated filaments of the alkaline earth group on minature and hearing-aid-type tubes.

DESIGN FUNDAMENTALS

The following formula is generally employed by electron-tube engineers in the design of filaments. (End losses are not considered.)

$$R_h = \frac{2\rho L_h d}{W_h}$$

where R_h = heater resistance at operating temperature expressed in ohms
ρ = specific resistance in ohms at the operating diameter
d = density of the heater material in milligrams per cubic centimeter
W_h = heater-wire weight in milligrams per 200 millimeters of length
L_h = heater-wire length in millimeters.

Fig. 1 takes into consideration the correction factor for end losses due to conduction to the leads to which the filament is welded and the contact with the filament tension hook.[2]

GRID EMISSION

Grids on most receiving tubes and a number of transmitting types use lateral wires having diameters of less than 0.010 inch. The most common materials being used are manganese-nickel, nickel-chromium-iron alloys, tantalum, molybdenum, molybdenum-iron alloys, zirconium-clad molybdenum, platinum-clad molybdenum, and gold-plated molybdenum.

To reduce grid emission, manganese-nickel material has been utilized on most receiving-type tubes while zirconium-clad molybdenum, platinum-clad molybdenum, and gold-plated molybdenum have been used on most transmitter-type tubes.

To date, a controversy still exists as to whether platinum-clad molybdenum is superior to gold-plated molybdenum for the prevention of grid emission. Both materials are being used successfully, and data should be available in the near future as to which displays superior qualities. However, the use of platinum is recommended when either the degassing or operating temperature during processing is above or dangerously close to the melting point of gold. The gold-plating of molybdenum wire in a continuous process to provide a well-adherent nonporous coating offers certain fabricating difficulties which have now been overcome.

To date, it has been virtually impossible for the wire manufacturer to obtain the same results with plating of platinum as with gold, hence we must resort to a mechanical cladding process to produce platinum-clad molybdenum. From the stand of the wire manufacturer, plating is a simpler process than applying a platinum tube to a molybdenum core prior to the drawing operation.

The application of grid-emission inhibiting wires has found usage in grids (Fig. 2) of close-spaced triodes, pentodes, and velocity-modulated tubes where spacings from the cathode to the grid may range from 0.004 inch to 0.015 inch. The relative merits of zirconium-clad molybdenum for the prevention of grid emission has been explored on a number of medium-power high-frequency pentodes.

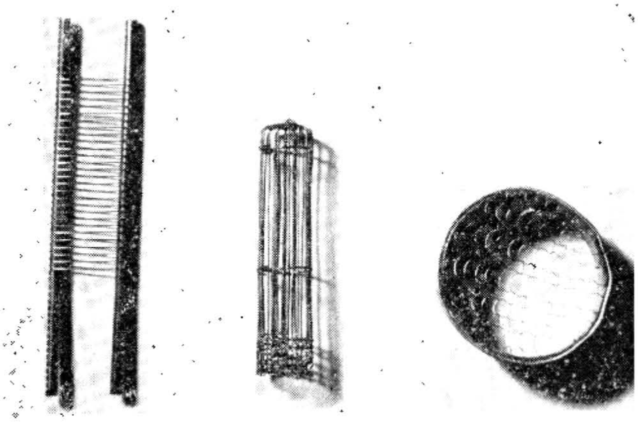


Fig. 2—Grid assemblies of various designs.

Electron-tube manufacturers who specialize in miniature or acorn-type tubes have usually had difficulties with molybdenum wire on grids due to heavy oxidation resulting from the heat generated during the sealing operations. Where possible, inert gases have been introduced into the envelope to reduce the degree of oxidation, but this method has not been entirely satisfactory. Molybdenum oxide on the grid laterals has a tendency to poison the emitting cathode, particularly if it consists of the alkaline earth type. Gold and silver plating of the molybdenum wire, prior to grid making, has offered considerable relief in reducing the degree of oxidation. Platinum and zirconium cladding have also been highly successful in this respect.

GETTER WIRES OF ZIRCONIUM

The use of fine zirconium wire as a getter material has had numerous applications in X-ray tubes where the barium getter has proven to be unsatisfactory due to its higher vapor pressure at the operating temperature of the tube. Zirconium has the peculiar property of absorption of hydrogen at temperatures ranging from 300 to 400 degrees centigrade, and absorption of all other gases (excepting rare gases) at temperatures ranging from 1000 to 1600 degrees centigrade.

Zirconium wire which is unsupported is not sufficiently strong to maintain its preformed shape at a

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[2] W. E. Forsythe and A. G. Worthing, "The properties of tungsten and the characteristics of tungsten lamps," *Astrophys. Jour.*, vol. 61, pp. 146–185; 1925.

temperature of 1600 degrees centigrade.[3] It has been found desirable to support it by winding zirconium wire (0.005 inch in diameter) alongside a tungsten wire (0.007 inch in diameter) on a tungsten or molybdenum core that is 0.008 inch in diameter. Zirconium wire exposed to the atmosphere has a tendency to oxidize slightly on the surface. This oxidation does not seriously impair the gettering qualities since it can be removed by glowing at 1600 degrees centigrade in a vacuum of approximately 1×10^{-6} millimeter of mercury. The combination zirconium-tungsten assembly wound on a molybdenum core has the advantage of serving as a support for the rather weak zirconium and also makes possible glowing of the assembly at a temperature slightly higher than the melting point of zirconium, so a zirconium mirror can be formed on the glass retainer envelope.

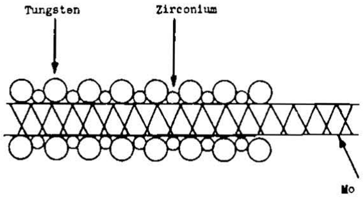

Fig. 3—Sketch showing cross section of a zirconium getter assembly.

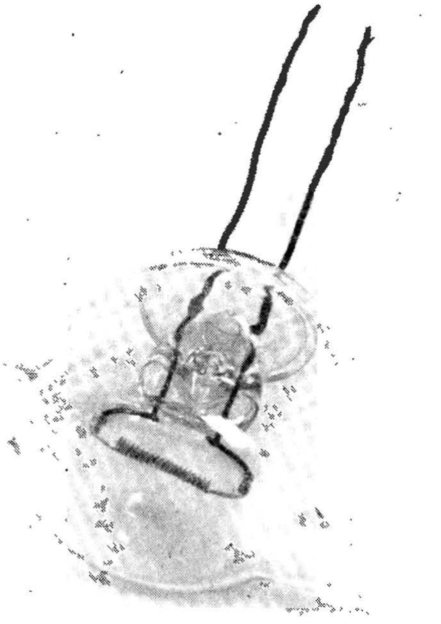

Fig. 4—View of helical coil sealed in glass envelope.

This assembly has the advantage that it prevents the liquid zirconium from forming globules about the core wire, since it is retained between two tungsten wires which serve as a trough preventing the zirconium from flowing along the length of the wire.

Fig. 3 shows a cross section of a zirconium getter assembly. To obtain continuous gettering action in a tube, it is suggested that the getter assembly be assembled either in series or parallel with the tube filaments.

Test runs using assemblies as indicated in Fig. 4 were employed to accelerate the vacuum exhausting process. This assembly is inserted between the diffusion pump and the tube to be exhausted. Prior to exhausting a given tube, the getter coil is glowed at 1650 to 1700 degrees centigrade for approximately one minute. The tube is exhausted in a normal manner, out-gassing the metal parts at a high frequency and internally bombarding the elements as required. When the vacuum approaches 1.0×10^{-3} millimeter of mercury, the getter coils are heated slowly to a temperature of 1650 degrees centigrade and maintained at this temperature for approximately five minutes. At the end of this period the vacuum pressure ranged from 1.0×10^{-5} to 1.0×10^{-6} millimeter of mercury. The time of pumping schedule of electron tubes exhausted with the use of zirconium getter coils was reduced approximately 25 per cent depending upon the type of tube (Fig. 5).

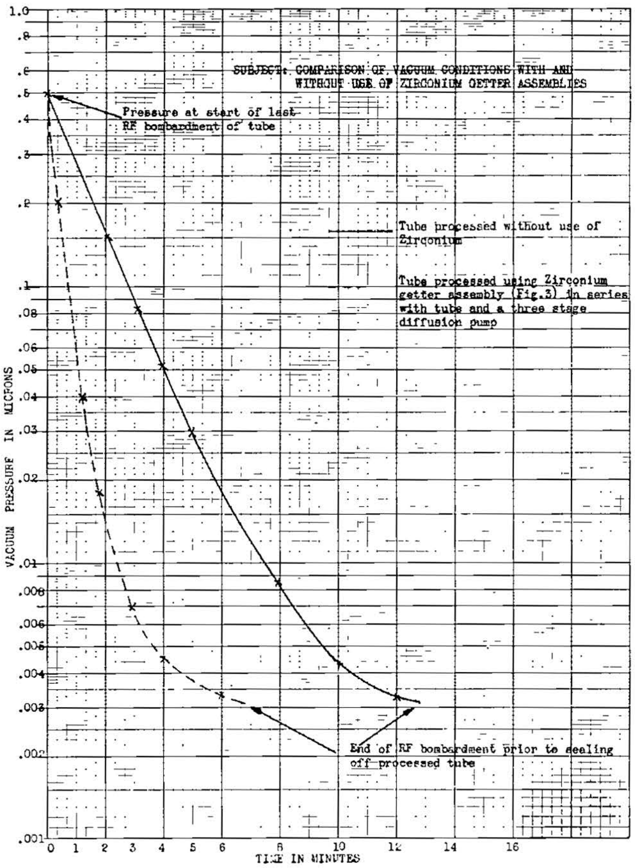

Fig. 5—Curves showing comparison of vacuum conditions with and without the use of zirconium getter assemblies.

The zirconium getter coil can be used repeatedly for gettering until the coil fails mechanically. The author has utilized a single coil as many as fifty times without noticing any impairment of the gettering qualities.

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[3] See United States Patent No. 2,336,138. A. J. van Hoorn and G. Thurmer, "Vaporization of metals," December 7, 1943.

WIRES FOR EVAPORATING METALS IN VACUUMS

The evaporation of metals has been successfully effected through a design of coil similar to the one shown in Fig. 6. Evaporation of thin films of silver, copper, gold, aluminum, etc., on glass, quartz, mica, etc. has been accomplished by replacing the zirconium (Fig. 3) with the metal to be evaporated. This type of assembly insures a uniform rate of evaporation and reduces the tendency of the evaporating metal towards forming globules, which result in an uneven diameter causing localized spheres of evaporation. Evaporation of silver, aluminum, copper, gold, etc., with the pancake-type coil (Fig. 6) which had a center-core rod of molybdenum was carried out at a pressure of 10^{-3} millimeter of mercury.

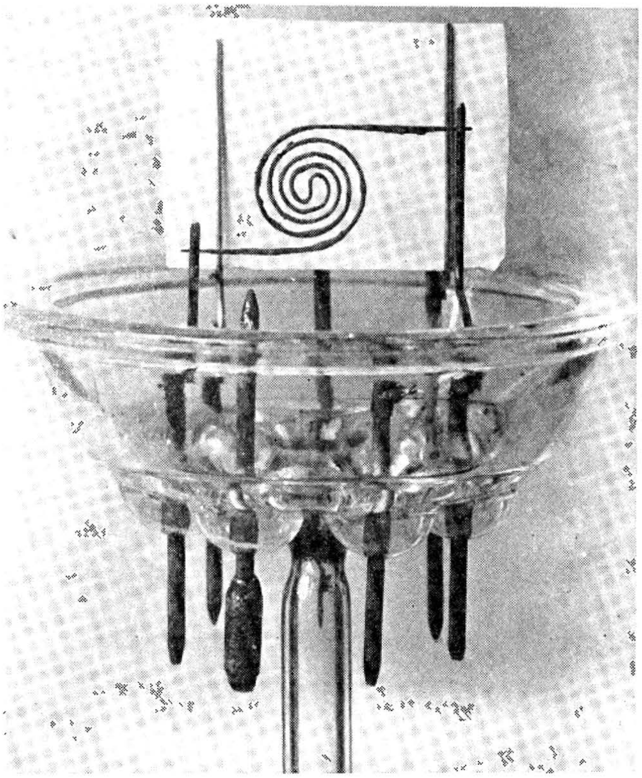

Fig. 6—View of evaporating coil.

The intimate contact of the plating wire in the coiled coil assembly made possible uniformity of control of evaporation. All assemblies using the same type of plating wire evaporated at approximately the same glow current would plate at the same rate. Measurements on a number of mica plates indicated that the weight of the evaporated material did not deviate by more than five per cent on approximately 100 specimens. Using fine wires rather than heavy wires in the order of 0.025 inch in diameter insured a minimum heating of the specimen to be plated, thus preventing a chemical breakdown of the sample as well as insuring a cool surface for the sample, which also resulted in a plating free from oxides, bubbles, and peeling. It was observed that the more rapid the plating process the better was the quality of the plating.

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