Aug. 5, 1958 R. I. HARRISON 2,845,690

ELECTRICAL COMPONENTS AND METHODS

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FIG. 1.

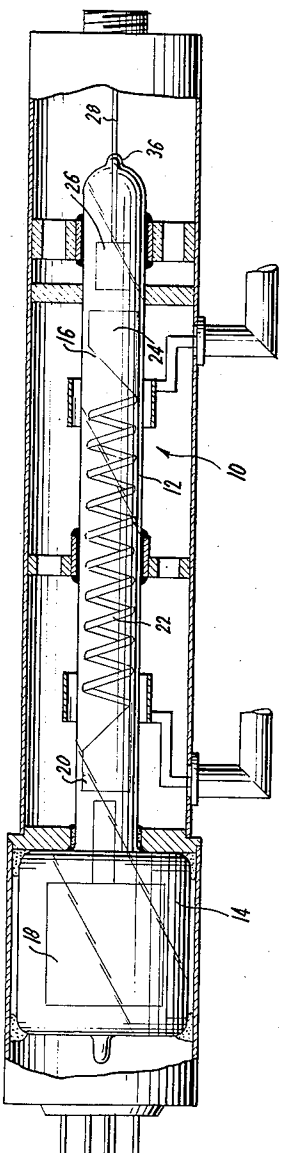


FIG. 4.

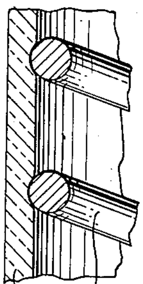


FIG. 2.

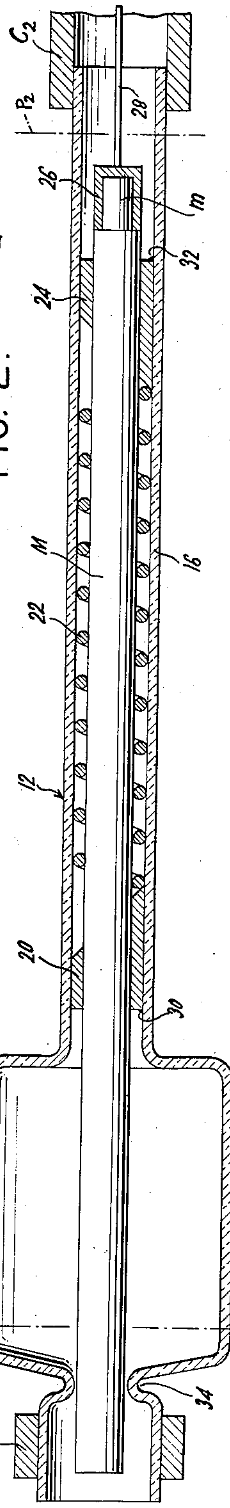
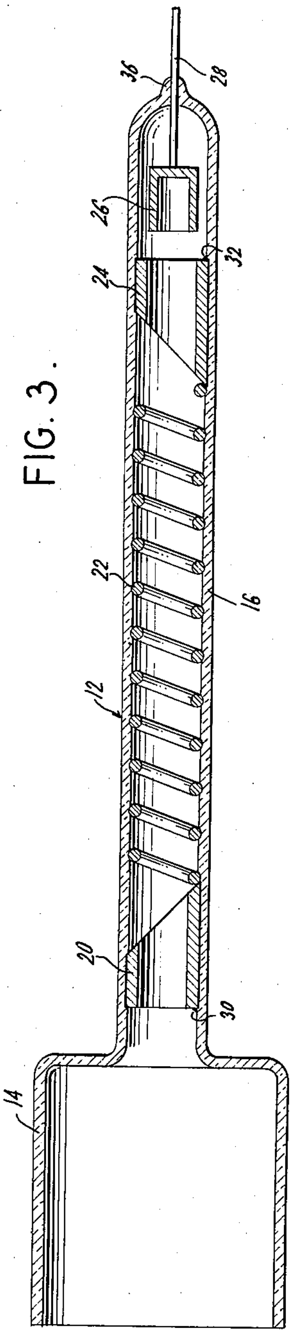


FIG. 3.



INVENTOR.
RICHARD I. HARRISON

Morton Amster
ATTORNEY

United States Patent Office

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ELECTRICAL COMPONENTS AND METHODS

Richard I. Harrison, New York, N. Y., assignor to Sylvania Electric Products Inc., a corporation of Massachusetts

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The present invention relates to electrical components, such as encased and supported impedance and signal-transmission elements, more particularly to an improved process for fabricating such components and to resultant electrical devices exhibiting enhanced mechanical and electrical properties. Specifically, the present invention is concerned with an improved method of manufacturing traveling wave tubes and like devices incorporating a helical wire conductor and with traveling wave devices having improved characteristics, prominently reliability and ruggedness.

The impedance and signal-transmission characteristics of coils, helices and the like, useful as circuit components and as parts of electrical and electronic devices, frequently depend upon turn distribution and/or the material surrounding and between turns. For example, the inductance of a coil and the signal-transmission properties of a helical conductor change with variations in inter-turn spacing and the proximity of dielectric material to the respective turns.

Accordingly, it is an object of the present invention to provide an improved method of fabricating electrical components. To advantage, encased and supported coils, helices and the like may be constructed having a fixed turn distribution and desirable electrical and mechanical properties.

In one form, the invention may be best demonstrated as applied to the well-known traveling wave tube which is essentially an electron beam tube employing an electron gun. The electron gun, similar to those commonly found in cathode ray tubes, forms and projects an electron beam axially within a surrounding wire helical conductor which is excited by a high frequency input signal at the input end thereof. During travel of the input signal along the helical conductor, there is interaction with the electron beam which results in amplification of a broad band of input frequencies available at the output end of the helical conductor.

Such known traveling wave tubes include an elongated wire helix, encased within a vitreous envelope or tube throughout its length and appropriately assembled with input and output coupling devices, as well as beam collecting and focusing electrodes. Such helix assemblies, usually of relatively small dimensions, are comparatively long and include many turns in relation to the diameter of the helix. The accomplishment of entry transfer between the beam and the helix often necessitates the use of 700 to 800 turns for a helix length of approximately 15 inches and helix diameters of the order of $\frac{1}{10}$ of an inch.

The support of such a helix within a vitreous sheath or envelope presents a rather troublesome problem, particularly since the assembly is rather small and has critical electrical properties which may vary greatly and in a random fashion depending upon the mounting of the helix. Of primary importance is the fixing of the respective turns of the helix in relation to each other in accordance with the established helix pitch, whether uniform or varied. Such fixing of the turn distribution of the helix should be accomplished without adversely affecting the electrical properties of the helix, as by establishing microwave mismatches or causing prohibitive standing wave ratios.

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Numerous approaches have been suggested in the manufacture of traveling wave devices for forming an encased helix having a fixed turn distribution and desirable electrical properties. Among these approaches has been the formation of an internal thread on a precisely bored tubing, followed by deposition of metallic material in the threads and the removal of any metallic material in the spaces between successive turns of the thread. The inherent complexity of such procedure is apparent, particularly when it is considered that the thread must be formed within a long tubing having a relatively small internal cross-section.

Accordingly, it is another object of the present invention to provide a novel method of fabricating traveling wave tubes which obviates one or more of the aforesaid difficulties. Specifically, it is within the contemplation of the invention to provide an improved process for mechanically supporting the helix of a traveling wave device with a particular turn distribution and without altering said turn distribution and/or adversely affecting the electrical properties of the final traveling wave tube assembly.

As applied to traveling wave tubes, the present invention employs the principle of assembling a helix within a closely conforming vitreous sheath or tubing, and heat softening and shrinking the vitreous sheath into supporting relation with the helix, thus fixing the distribution of the helix turns. A helix supported by heat shrinking of its vitreous sheathing into supporting relation with the helix turns has been found to be exceptionally rugged; further said helix exhibits electrical characteristics compatible with proper functioning of traveling wave devices.

In accordance with an illustrative process demonstrating features of the present invention, a wire helix is wound upon a mandrel and preferably assembled with devices for input and output coupling of wave energy to the helix. The subassembly of the wound helix and coupling devices is then placed within and axially of a glass tube having a bore diameter closely conforming to the outer diameter of the helix. The assembly of the helix and the sheathing or tube is elevated to a temperature appropriate to heat soften and shrink the glass into contact with the respective turns of the helix. By control over the shrinking rate, relatively rigid tolerances may be maintained for the degree of contact between the glass of the tube and the helix turns, as well as the penetration of glass between the respective turns of the helix.

Preferably the process is carried out with the mandrel substantially filling out the helix space and with the assembly continuously rotated about the common axis of the mandrel and the vitreous tube such that the tube does not bow throughout its length due to gravitational forces. Additionally, the heat shrinking is preferably carried out with the interior of the tube at a reduced pressure with respect to the exterior of the tube. This pressure differential lowers the shrinking temperature, thus providing high viscosity of the glass at relatively low control sensitivity of glass-sagging.

The above as well as still further objects, features and advantages of the present invention will be best appreciated by reference to the following detailed description of a presently preferred process and articles attainable thereby, when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is an elevational view with parts broken away, showing a traveling wave tube assembly processed in accordance with features of the present invention;

Figure 2 is a longitudinal sectional view, enlarged and foreshortened, showing the assembly of a mandrel having a helix and coupling probles with a vitreous sheathing assembled prior to a processing in accordance with the present invention;

Figure 3 is a sectional view, enlarged and foreshortened, of a sheathed helix and probe assembly processed in accordance with the present invention;

Figure 4 is a fragmentary sectional view on a greatly enlarged and exaggerated scale showing the contact region between the turns of the helix and the encasing vitreous sheath.

In Figure 1 there is shown an illustrative traveling wave tube **10** which includes a vitreous body **12** having an enlarged bulb **14** and an elongated sheath or tube **16**. Within the bulb **14** is the well-known electron gun assembly **18** which is arranged to produce a beam to be directed axially along the envelope or tube **16** and includes the usual filamentary heater, electron-emitting cathode and beam-forming elements. The electrode assembly within the elongated tube or sheath **16** includes an input probe **20**, a helix **22** of variable or uniform pitch having one end electrically connected to the input probe **20**, and an output probe **24** electrically connected to the other end of the helix. Beyond the output probe **24** is a collector **26** for the electron beam having an appropriate external terminal or connection. As is well understood appropriate connections are provided for establishing operating potentials and a magnetic field to focus the electron beam. In that the present invention is not concerned with this broadly old traveling wave tube, further description as to the details of the tube construction will be dispensed with except as is necessary for an understanding of the present improved method.

Referring now specifically to Figure 2, there is shown the helix **22** which is of tungsten wire wound on a mandrel M of a material having a coefficient of expansion selected to avoid indenting of the helix material. It has been found that a steel mandrel may be used successfully with a wire helix of either tungsten or molydenum having a copper coating. Preferably, the helix and its mandrel are fired at a temperature of approximately 900° C. for a period of three to four minutes in a protective atmosphere to set the helix turns. The input and output probes **20**, **24** are assembled with the helix **22**, as by spot welding or the like. The mandrel M with the assembled helix **22** and energy-coupling probes **20**, **24** is inserted within the vitreous bulb envelope or body **12** which may be of a glass, such as Corning 7052. Insofar as the rate of propagation of electromagnetic wave energy along the helix is critically dependent upon the dielectric medium in the immediate vicinity of the helix **22**, the glass of the envelope **12** is selected to have an appropriate dielectric constant for microwave applications. The envelope **12**, illustrated in incomplete state with its opposite ends open, includes the tubing **16** precisely bored in the region coextensive with the helix and probe assembly, the tubing **16** having an inside diameter approximately equal to the outside diameter of the helix and probe assembly. The envelope **12** may be preliminarily processed to form an attenuated coating thereon in selected regions, as by evaporating a nichrome film onto the inner walls of the tube **16** as shown in U. S. Patent No. 2,660,690.

Preliminary to processing in accordance with the present invention it may be further desirable to cold match the inserted helix and probes to obtain an appropriate radio frequency match and to determine whether the assembly meets other predetermined standards of electrical performance. The cold match is carried out by making appropriate connections to the input and output ends of the assembly and testing on a radio frequency bench. Acceptable assemblies are then completed by fitting the collector **26** on the reduced end *m* of the mandrel M, the mandrel M serving to align the respective probes **20**, **24**, the helix **22** and the collector **26**.

To preclude lengthening and foreshortening of the helix **22** during heat treatment, the probes **20**, **24** are secured to the vitreous sheath or tubing **16**. This may be accomplished by dimpling the tubing **16** or by application of a cold ceramic cement, such as Sauereisen #29 at the locations **30**, **32**. The mandrel M is fixed in relation to the envelope or bulb **12** by pinching down on the envelope or blank at its opposite ends, as illustrated at the left in Figure 2 and designated by the numeral **34**. The right end of the tube **12** beyond the collector **26** may likewise be secured in relation to the mandrel M by pinching down on the glass tubing. At points beyond the region of support of the tube **16** by the mandrel M, it may be desirable to provide extension tubings which have a sufficiently high melting and softening point as compared to the glass of the envelope for convenience in working and to preclude bowing of the assembly.

The assembly of the mandrel M and the envelope **12** is then supported between the chucks C_1, C_2. The chuck C_1 is a vacuum chuck connected to an appropriate exhaust pump, while the chuck C_2 is an ordinary mechanical chuck. The end of the envelope-mandrel assembly supported in chuck C_2, which may be an extension of a high melting and softening point glass, is appropriately sealed, as by a stopper (not shown). The use of the mandrel M for centering the probes **20**, **24**, the helix **22** and the collector **26** assures perfect coaxial relation between the respective components of the final tube assembly; while the use of the low-expansion cold cement having good electrical properties and capable of withstanding relatively high vacuum assures that the helix **22** will not change length.

The assembly of Figure 2, while under vacuum and rotating, is heated, as by application of a flame directly thereto or by placing the assembly within an oven. The heating, whether in a localized area or throughout the length of the assembly, is continued for a period and at a temperature to sofeten and shrink the tubing **16** onto the probe-helix assembly. The shrinking temperature is dependent upon the type of vitreous material used and on the pressure differential existing between the inner and outer walls of the sealed-off envelope **12**. Slow shrinkage is preferred to facilitate accurate control over the depth of sagging or penetration of the vitreous material between the respective turns of the helix **22**. To this end, the use of a relatively high vacuum and lower shrinking temperatures assures low flow rates of the vitreous material due to the high viscosity of the glass. The use of reduced temperatures besides providing for easier control over glass sagging, minimizes the risk of oxidizing the metal tube parts as well as fusing copper from the plating of the helix wire onto the adjacent vitreous walls. Such fusing of copper onto the glass walls increases the attenuation of microwave power and is appreciably reduced by lowering the shrinking temperature. By careful control of the shrinking temperature and by operating at vacuums on the order of one-tenth of an atmosphere or less, it has been found possible to obtain uniform shrinkage of the vitreous material between respective turns of the helix **22** to fix the preestablished turn distribution of the helix **22**. Although it is preferable to obtain the pressure differential between the inside and outside walls of the envelope **12** by drawing a vacuum therein, it is equally within the scope of the invention to apply pressure externally of the envelope **12**.

When the required glass sagging is obtained, the temperature of the assembly is reduced to stop the sagging action. During the reverse cycling of the heat-shrunken assembly, it is preferable to continue rotation and operation under vacuum. By slow cooling, it is possible to anneal the tubing with attendant advantages.

The helix and probe assembly within the envelope **12** is then prepared for incorporation into the final traveling wave tube by removing the extension portions of the envelope by cutting at the parting planes P_1, P_2, illustrated in Figure 2. The final helix and probe assembly with the mandrel removed is shown in Figure 3. Preliminary to removal of the mandrel M, the lead or extension **28** for the collector **26** is sealed to the envelope, as indicated at **36**.

Upon inspection of Figure 4, it will be appreciated that intermediate the respective turns of the helix **22**, there are integral portions of the tube **16** which provide peripherally-extending and circumferentially-extending area contact to the respective turns of the helix **22**. The area contact embraces the outer surface of the wire of the helix throughout the length of the wire. Such embracing arcuate contact, providing a helical groove mating with the outer surface of the wire of the helix, contrasts markedly to constructions in which the helix is snugly received in its supporting envelope. The showings of Figures 2 to 4 inclusive are exaggerated dimensionally such that the physical configurations attainable in accordance with the present invention may be fully appreciated. However, a typical traveling wave tube assembly includes a helix having an inside diameter of approximately .1 inch which helix is fabricated of a tungsten wire of 10 mils diameter and having an electroplated copper coating of approximately .5 mil. The outside diameter of the helix is approximately .11 inch, the helix being received within a precisely bored tubing having an inside diameter of .12 inch and an outside diameter of .210 inch. A typical assembly includes 770 turns in a length of approximately 15¾ inches. Approximately .2 mil of total sagging, that is .07% of the wire circumference, has been found to be sufficient to secure the turns of the helix in relation to each other without significant interference with the electrical characteristics of the tube due to the presence of prohibitive amounts of dielectric material between the respective turns. Traveling wave tubes with desirable characteristics have been constructed having 3% circumferential wetting of the helix turns by the dielectric material of the sheath. The aforesaid dimensions are purely illustrative and are set forth such that the relative proportions of one such typical structure may be more fully appreciated.

Following processing of the probe and helix assembly, the electron gun **18** is placed within the bulb **14** and the remaining electrodes and leads connected in accordance with techniques which are well understood. Thereafter the envelope **12** is evacuated and sealed.

The wide variety of modifications as well as further details will be apparent to those skilled in the art. For example, the helix **22** may be wound on a variable pitch throughout selected regions of its length, to advantage in certain types of microwave applications. Still further refinement may be made in control of the temperature throughout the various portions of the helix and probe assembly. For example, in the regions adjacent to the probes **20**, **24** more localized heating may be required in that a large area of heat conduction is provided to the vitreous wall or sheath **16**; while in the regions occupied by the helix **22**, such large areas of heat conduction are not present.

Although the invention has been described as applied to traveling wave amplifying devices, application of the principles herein to manufacture of precise inductance coils and tube electric components is likewise intended.

Further modifications and varied applications of the foregoing invention will occur to those skilled in the art. Accordingly, the appended claims should be construed broadly, consistent with the spirit and scope of the present invention.

What I claim is:

1. In the manufacture of traveling wave tubes, the steps including subassembling a helix and probes concentrically of a mandrel, placing said mandrel in a vitreous tube, fixing said probes to said vitreous tube to prevent elongation and foreshortening of said helix, drawing a vacuum in said vitreous tube, axially rotating the assembly of said mandrel and vitreous tube, and heating said assembly while rotating to shrink said vitreous tube onto said helix to permanently fix the helix turns in place.

2. In the manufacture of traveling wave tubes, the steps including subassembling a helix and probes concentrically of a mandrel, placing said mandrel in a vitreous tube, fixing said probes in relation to said vitreous tube to prevent elongation and foreshortening of said helix, and heating said assembly while rotating to shrink said vitreous tube onto said helix to permanently fix the helix turns in place.

3. In the manufacture of traveling wave tubes, the steps including subassembling a helix and probes concentrically of a mandrel, placing said mandrel in a vitreous tube, fixing said probes to said vitreous tube to prevent elongation and foreshortening of said helix, drawing a vacuum in said vitreous tube, axially rotating the assembly of said mandrel and vitreous tube, and heating said assembly while rotating to a temperature sufficient to shrink said vitreous tube at a low flow rate to uniformly engage the helix turns circumferentially and along their length.

4. In the manufacture of traveling wave tubes, the steps including subassembling a helix and probes concentrically of a mandrel, placing said mandrel in a vitreous tube, fixing said probes to said vitreous tube to prevent elongation and foreshortening of said helix, drawing a vacuum of the order of one-tenth of an atmosphere in said vitreous tube, axially rotating the assembly of said mandrel and vitreous tube, and heating said assembly while rotating to a temperature sufficient to shrink said vitreous tube at a low flow rate to uniformly engage the helix turns circumferentially and along their length.

5. A method of constructing a helix assembly for a traveling wave tube including an envelope of thermoplastic material having an enlarged bulb and an elongated tube including the steps of placing the assembly of a wire helix on a supporting mandrel within said tube with said helix in contact with the inner wall of said tube, creating a pressure differential between the inside and outside walls of said tube, heating said tube to shrinking temperature sufficient to soften said thermoplastic material, and correlating the relationship between said pressure differential and said shrinking temperature whereby said thermoplastic material sags into substantially continuous embracing contact both circumferentially and lengthwise of said wire and at a low flow rate allowing for accurate control over and the limited penetration of said thermoplastic material between the respective turns of said helix.

6. A method for constructing a helix assembly including the steps of winding wire in a helical configuration on a supporting mandrel, surrounding said wire by a snugly fitting vitreous envelope, creating a pressure differential between the inside and outside of said envelope, heating said envelope to a shrinking temperature sufficient only to soften said vitreous material, and correlating the relationship between said pressure differential and said shrinking temperature to cause said vitreous material to sag into substantially continuous circumferential embracing contact throughout the length of said wire and at a low flow rate assuring accurate control over and the limited penetration of said vitreous material between the respective turns of said wire.

7. A method for constructing a helix assembly including the steps of winding wire in a helical configuration on a supporting mandrel, heat treating said wire to set said wire in said helical configuration, surrounding said wire by a snugly fitting vitreous envelope, creating a pressure differential between the inside and outside of said envelope, heating said envelope to a shinking temperature

sufficient only to soften said vitreous material, and correlating the relationship between said pressure differential and said shrinking temperature to cause said vitreous material to sag into substantially continuous circumferential embracing contact with said wire throughout the length thereof and at a low flow rate assuring accurate control over and the limited penetration of said vitreous material between the respective turns of said wire.

8. A method for constructing a helix assembly including the steps of winding wire in a helical configuration on a supporting mandrel, surrounding said wire by a snugly fitting vitreous envelope, creating a pressure differential between the inside and outside of said envelope, axially rotating the assembly of said supporting mandrel and envelope, heating said envelope to a shrinking temperature sufficient only to soften said vitreous material, and correlating the relationship between said pressure differential and said shrinking temperature to cause said vitreous material to sag into substantially continuous circumferential contact with said wire throughout the length thereof and at a low flow rate assuring accurate control over and the limited penetration of said vitreous material between the respective turns of said wire.

9. A method for constructing a helix assembly for a traveling wave tube including an envelope having an enlarged bulb and an elongated tube including the steps of winding a wire helix on a supporting mandrel, heat treating said helix to fix the turn distribution thereof, assembling said mandrel within said elongated tube with said helix in contact with the inner wall of said elongated tube, creating a pressure differential between the inside and outside walls of said helix, heating said elongated tube to a shrinking temperature sufficient only to soften said vitreous material while rotating the assembly, and correlating and maintaining the relationship between said pressure differential and said shrinking temperature to cause said vitreous material to sag into substantially continuous embracing contact both circumferentially and axially of said helix and at a low flow rate assuring for accurate control over and the limited penetration of said vitreous material between the respective turns of said helix.

10. A method for constructing a helix assembly for a traveling wave tube including an envelope an enlarged bulb and an elongated tube including the steps of winding a wire helix on a supporting mandrel, heat treating said helix to fix the turn distribution thereof, assembling said mandrel within said elongated tube with said helix in contact with the inner wall of said elongated tube, fixing both said mandrel and said helix in relation to said elongated tube, creating a pressure differential between the inside and outside walls of said helix, heating said elongated tube to a shrinking temperature sufficient only to soften said vitreous material while rotating the assembly, and correlating and maintaining the relationship between said pressure differential and said shrinking temperature to cause said vitreous material to sag into substantially continuous embracing contact both circumferentially and axially of said helix at a low flow rate allowing for accurate control over and the limited penetration of said virteous material between the respective turns of said helix.

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