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METHOD OF WINDING HELICES

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This invention relates to helix fabrication techniques, and, more particularly, to the fabrication of helical transmission lines for use in electron discharge devices of the traveling wave tube type.

In devices of the traveling wave tube type, broad band amplification at exceedingly high frequencies is achieved through the interaction of an electron beam and an electromagnetic wave traveling in synchronism along an extended path. Inasmuch as the normal velocity of an electromagnetic wave is of the order of the speed of light, while that of an electron beam is of the order of one-tenth to one-fifteenth of that speed, to achieve synchronism it is necessary that the velocity of the electromagnetic wave be decreased to that of the beam. One of the most useful arrangements for achieving this slowing down of the wave is a helical transmission line which surrounds the electron beam and along which the wave propagates. Usually a plurality of cylindrical support rods of any suitable insulator material which will not introduce excessive loss or capacitance to the helix are used to position the helix within the envelope, usually glass, of the tube.

For maximum gain, the pitch of the helix must be chosen so that the electromagnetic field of the wave from turn to turn will add in phase along the helical path. It thus becomes necessary not only to wind the helix with the proper pitch, but also to minimize the possibility of pitch variations during and after the winding process. Pitch variations, in addition to reducing the amount of gain obtainable, also give rise to reflections which, in turn, produce signal distortion, and in more serious cases, self oscillation.

Heretofore, it has been the practice to wind a helix of a material such as molybdenum tightly on a mandrel of a rigid material such as tungsten and then to normalize the helix. The normalizing serves to relieve the stresses in the helix wire which were created during the winding, and, when these stresses are relieved, the helix wire "relaxes," thereby providing sufficient clearance between the helix and the mandrel to permit withdrawing the mandrel. Prior to withdrawing the mandrel, but subsequent to the normalizing, the dielectric support rods are glazed to the helix in the manner, for example, taught in U.S. Patent 2,790,926 to J. A. Morton. While such a method produces helices of sufficient uniformity for low frequency applications, it has been found that for the very high frequency applications, where the helix size is quite small, there are non-uniformities in pitch produced which materially degrade tube performance. The non-uniformities arise in the normalizing step, when the helix wire relaxes or springs back, since it is no longer tightly bound to the mandrel. On the other hand, this helix "spring back" has heretofore been necessary to provide the clearance needed for withdrawing the mandrel.

Accordingly, it is an object of this invention to produce helices for use in traveling wave tubes of sufficient uniformity for use at very high frequencies.

It is another object of this invention to wind helices in a manner which eliminates any steps giving rise to non-uniformities.

It is still another object of this invention to eliminate the necessity of utilizing helix "spring back" to provide clearance between the mandrel and the helix.

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It is a further object of this invention to produce a rigidly mounted, uniform helix which retains its uniformity throughout its useful life.

These and other objects are accomplished by the method of the present invention which comprises the steps of coating the winding mandrel with a material which preferably hardens in air, winding the helix on the mandrel thus coated with sufficient tension to imbed the helix wire in the coating material, placing dielectric support rods priorly coated with a glazing material in contact with the helix, and introducing the assembly into a furnace for glazing the rods to the helix.

In accordance with the present invention, as the helix is wound the material with which the mandrel is coated acts to grip the helix wire so that there is no slippage. This material is chosen from materials which will volatilize or, more specifically, burn off under proper furnace conditions of heat and atmosphere. The glazing material is chosen to have a melting point slightly higher than the burning or oxidizing point of the mandrel coating. Under these conditions, as the mandrel coating material commences to burn off, a temperature has been reached where the glazing material has commenced to grip the helix. Thus there is a smooth transition from the helix being held by the coating material to the helix being held by the glazing material, and helix "spring back" is avoided. In addition, after the coating material has burned off, there is then sufficient clearance for the mandrel to be withdrawn.

Accordingly, it is a feature of this invention that the process of winding a helix include the initial step of coating the mandrel with a thin layer of volatilizable or oxidizable material.

It is another feature of the present invention that the material burns or oxidizes at a temperature near the melting temperature of the glazing material on the dielectric rods.

It is still another feature of the present invention that the furnace atmosphere be such as to insure substantially complete burning off of the material with which the helix is coated.

It is a further feature of the invention that the thickness of the layer on the mandrel be sufficient to insure clearance between the helix and mandrel after the material has burned off.

These and other features of the present invention will be more readily appreciated from the following description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view of an arrangement for accomplishing the first step of the invention;

FIG. 2 is a cross-sectional view of a helix mandrel after spraying;

FIG. 3 is a partially sectional view of the assembly of elements prior to introduction into a furnace; and

FIG. 4 is a partially sectional view of the elements after removal from the furnace.

Turning now to the drawings, there is disclosed in FIG. 1 a perspective view of one specific arrangement for accomplishing the first step of the process of the present invention. A plurality of mandrels 11 upon which the helices are to be wound are mounted between a first support member 12 and a second support member 13. Advantageously, one of the support members such as member 12 contains a drive unit for rotating each of the mandrels 11 about the mandrel axis. Support member 13 is so designed to permit the mandrels to turn about their axis while affording support for them. Mounted adjacent the supporting arrangement for the mandrels is a spray gun 14 of any suitable, commercially available

type. Gun 14 is preferably mounted on a carriage 16 which is adapted to move longitudinally and parallel to the mandrels from support member 12 to support member 13, being guided by guide members 17 with the rate of motion being determined by the rotation of a lead screw 18. Spray gun 14 is supplied with a suitable material for spraying the mandrels, the composition of which will be discussed more fully hereinafter, through a supply conduit 19. In addition, the gun is supplied with compressed air for accomplishing the spraying function through a suitable supply conduit 21. Advantageously, spray gun 14 has an adjustable nozzle 22 for controlling the rate of spraying and consequently the rate of deposition of material on the mandrels 11. In operation, the mandrels 11 are caused to rotate about their axes by means of the drive mechanism in support member 12. Initially the spray gun is at the limit of its travel in the direction of support member 12. The spray gun 14 is actuated and concurrently therewith lead screw 18 starts to rotate, causing gun 14 to move along mandrels 11 toward support member 13. In this manner a uniform coating is supplied to the mandrels 11, and any desired thickness of coating, the significance of which will be discussed more fully hereinafter, may be attained by adjusting the rate of spray, the rate of translational movement of the gun 14 and the rate of rotation of mandrels 11.

In FIG. 2 there is shown a cross-sectional view of a mandrel 11 after spraying, having a layer 22 of sprayed material thereon. As was pointed out in the foregoing, the sprayed material which is necessarily in suspension to permit spraying, is such that it preferably air-hardens after the spraying process, and the layer 22 on mandrel 11 is a substantially solid, hard coating.

Turning now to FIG. 3, there is shown partially in cross section the assembly of elements as exists after the second and third steps of the process have been performed. Mandrel 11 with its coating 22 has wound thereon under tension a helix 23. During the winding process the tension of the helix is maintained such that the helix wire imbeds itself into the coating material 22, as best seen in the cross-sectional portion of FIG. 3. Under ideal conditions, it is preferred that the helix wire imbed itself approximately half way into the thickness of the coating material, as is shown in FIG. 3. In order that the helix 23 will be securely held in place on the mandrel, mandrel 11 is supplied with flat portions 24 over which the helix is wound. The flat portions act to distort the helix and, as a consequence, prevent any rotational movement of the helix after winding. Preferably although not necessarily, the distance between the flat portions 24 on the mandrel 11 is slightly greater than the desired length of helix, and there may be several flat portions with, in effect, several helices of the desired length being wound in one winding operation.

After the helix has been wound on the mandrel and firmly gripped in place by the action of the flats 24 and the material 22, preglazed dielectric support rods 26 are placed in contact with the outside of the turns of the helix. In general, there will be three such support rods so placed; however for simplicity only one has been shown in FIG. 3. Any suitable means may be used for holding the support rods in place against the helix turns.

With the elements thus assembled, the assembly is introduced into a controlled atmosphere furnace, not shown. In a preferred embodiment of the invention the coating material 22 initially comprised a solution of colloidal graphite in water, which on air-hardening became a layer of graphite 22 on the mandrel 11. I have found that if the atmosphere of the furnace comprises a wet forming gas, such as 85 percent nitrogen and 15 percent hydrogen, bubbled or passed through distilled water, the graphite coating 22 will burn off at approximately 1000 degrees C. By properly choosing the glazing material with which

the dielectric rods 26 are preglazed, such as an alsmag glaze having a melting temperature in the order of 1100 degrees to 1200 degrees C., the glazing material will have become tacky at 1000 degrees C. and will grip the helix. As a consequence, when the assembly of elements as depicted in FIG. 3 is introduced into the furnace and the temperature of the furnace is raised, the coating 22 does not commence to burn off until the glazing material on the rods 26 has commenced to grip and adhere to the turns of the helix 23. As 1000 degrees C. is reached the coating 22 completely burns off while the helix is prevented from moving or shifting by virtue of the gripping action of the glazing material.

In FIG. 4 the assembly of FIG. 3 is depicted after the coating 22 is burned off. It can be seen from FIG. 4 that the glazing material on the rods 26 has melted sufficiently to form fillets 27, which adhere firmly to the turns of the helix thereby rigidly joining the helix to the rods. In addition, it can be seen from FIG. 4 that with the removal of the coating 22 there is left a clearance between the mandrel 11 and the helix 23, which clearance is sufficient to permit withdrawal of the mandrel after the helix has been cut to proper length. From the foregoing, it can readily be seen that from the time the helix was first wound upon the mandrel until the completion of the heating process the helix was held firmly and constrained against any movement whatsoever, first by the gripping action afforded by the coating 22 with the helix turns imbedded therein and finally by the gripping action of the glazing material on the rods 26. The transition from the gripping action of the coating 22 to the gripping action of the glazing material is made smoothly with no possible movement of the helix being permitted. As a consequence, the uniformity of the helix is limited only by the uniformity of the winding mechanism and there are no non-uniformities introduced subsequent to the winding step. An additional advantage of the method of the present invention is the fact that the furnace temperatures may be such as to normalize the helix, thereby relieving stresses without permitting "spring back" of the helix.

In one helix winding operation embodying the principles of the present invention, a tungsten winding mandrel of approximately .0375 inch diameter had applied thereto a coating of aquadag which was approximately .00035 inch thick. The helix was then wound on the mandrel, the helix wire diameter being approximately .005 inch, and the wire was imbedded in the aquadag coating to a depth of approximately .00015 inch, leaving a thickness of coating between the surface of the mandrel and the wire of approximately .0002 inch. The assembly was introduced into a furnace having an atmosphere of wet forming gas of 85 percent nitrogen and 15 percent hydrogen and heated for thirty minutes in the furnace, with the maximum temperature thereof being 1185 degrees C. When the helix was withdrawn from the furnace the coating material was completely burned off or volatilized and the helix was firmly glazed to the support rods 26. With the coating material eliminated, the inner diameter of the helix was approximately .0004 inch greater than the outer diameter of the mandrel, giving sufficient clearance for withdrawal of the helix from the mandrel.

While the particular materials and temperatures herein disclosed have been found to work quite well in practice, it is to be understood that they are given here by way of illustration of the principles of the invention. Numerous other materials and temperatures might be used by persons skilled in the art without departing from the spirit and scope of the present invention. For example, materials other than aquadag may be used for coating the mandrel, in which case the furnace atmosphere may be different in order to assure complete volatilization of the coating material, and the furnace temperatures may be somewhat different.

In addition, while dielectric support rods have been

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shown, other types of support members may be used, even in some cases, the glass envelope of the tube itself.

What is claimed is:

1. A process for winding a wire helix comprising the steps of spraying a mandrel upon which the helix is to be wound with a colloidal suspension of graphite in water, letting the coating thus sprayed harden, winding the helix under tension on said mandrel whereby the turns of the helix become imbedded in said coating to a depth of approximately half the thickness of said coating, placing preglazed support rods in contact with the helix thus wound the glaze material on said support rods having a melting point such that it becomes tacky at the temperature at which the graphite coating burns off, and introducing the mandrel, the helix and the support rods thus assembled into a furnace having an atmosphere of wet forming gas and heating the assembly until the coating on said mandrel substantially completely burns off and the glazing material on the support rods adheres to the helix, cooling the assembly, and withdrawing the mandrel from the helix.

2. The method of fabricating helical slow wave circuits for traveling wave tubes comprising the steps of winding a wire helix under tension around a mandrel having a coating thereon so as partially to imbed the wire helix into the coating, placing a preglazed support member adjacent the helix, and then heating the mandrel, helix and support member in an oxidizing inhibiting atmosphere to a temperature so that the coating on said mandrel burns off substantially simultaneously with the glaze becoming at least tacky enough to grip the helix and prevent changes in the helix position.

3. The method of fabricating helical slow wave circuits for traveling wave tubes comprising the steps of winding a wire helix under tension around a mandrel having a colloidal graphite coating thereon so as partially to imbed the wire helix into the coating, placing a plurality of preglazed support rods adjacent the helix, and then heating the mandrel, helix and support member in a furnace having an oxidizing inhibiting atmosphere to a temperature and under such atmospheric conditions that there is a smooth transition between the helix being held by the coating and being held by the glaze as the coating substantially completely burns off and the glaze melts around the turns of the helix.

4. A process for winding helices for traveling wave tubes comprising the steps of spraying the mandrel upon which the helix is to be wound with a coating of air-hardening, thermally oxidizable material, winding the helix

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under tension on said mandrel whereby the turns of the helix become partially imbedded in said coating, placing a support member having glazable material in contact with the helix thus wound, said glazable material having a melting point such that it becomes tacky at the temperature at which said oxidizable material burns off, said temperature being substantially higher than the operating temperature of the traveling wave tube, introducing the mandrel, the helix and the support member thus assembled in a controlled atmosphere furnace and heating the assembly until the coating on said mandrel substantially completely burns off and the glazing material of the support member grips the helix, cooling the assembly, and withdrawing the mandrel from the helix.

5. A process for winding a wire helix comprising the steps of spraying a mandrel upon which the helix is to be wound with a colloidal suspension of graphite in water, letting the coating thus sprayed harden, winding the helix under tension on said mandrel whereby the turns of the helix become partially imbedded in the coating, placing preglazed support rods in contact with the helix thus wound, the glaze material on said support rods having a melting point such that it becomes tacky at the temperature at which the graphite coating burns off, introducing the mandrel, the helix and the support rods thus assembled into a furnace having an atmosphere of wet forming gas comprising a mixture of hydrogen and oxygen, heating the assembly until the coating on the mandrel substantially completely burns off and the glazing material on the support rods adheres to the helix, cooling the assembly, and withdrawing the mandrel from the helix.

6. A process in accordance with claim 5 wherein the helix support rods and mandrel are heated to a temperature of between 1100 degrees and 1200 degrees C.

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