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Majkrzak et al.

[11] **3,831,399**

[45] **Aug. 27, 1974**

[54] **DRIVE SHAFT CONFIGURATION FOR A HIGH VOLTAGE ANTENNA TUNING MECHANISM**

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[52] **U.S. Cl.** ..... **64/1 R,** 64/2 R, 174/DIG. 1, 343/895

[51] **Int. Cl.** **F16c 1/00**

[58] **Field of Search** ..... 64/1 R, 1 S, 2 R, 23; 174/DIG. 1, DIG. 4; 343/895

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[57] **ABSTRACT**

There is disclosed dielectric material drive shaft constructions designed for use particularly in high electric-field potential environments such as in driven tuning mechanism of a high voltage helical transmitting antenna, which shaft constructions are capable of maintaining operation under unusually high mechanical loads requiring both rotational and axial movement. A plurality of elongated common-stock pieces of layered epoxy or silicon-bonded fiberglass are shaped cross-sectionally to be united predeterminably into a unitary form via longitudinally running bonds of epoxy adhesive. The unitary form cross-section is a "soft" polygon, for example a rounded-off triangle or square, wherein the individual pieces are so arranged as to have the interlaminar shear planes of the layered dielectric material substantially perpendicular to the direction of the force of the applied loads. To provide a shaft surface which resists wear, prevents surface contamination, and has nontracking properties most beneficial in preventing arcing and creepage in extremely high potential electric gradient environments, a sleeve or jacket of teflon is provided about the shaft's outer surface. In cases where shafts loads are excessive, the shaft construction may include a multiplicity of strong dielectric pins driven thru the unitary structure, each across a successive interfacing epoxy bond, to form a helical pin configuration which resist interlaminar shear loads and provides additional strength to these bonds.

13 Claims, 10 Drawing Figures

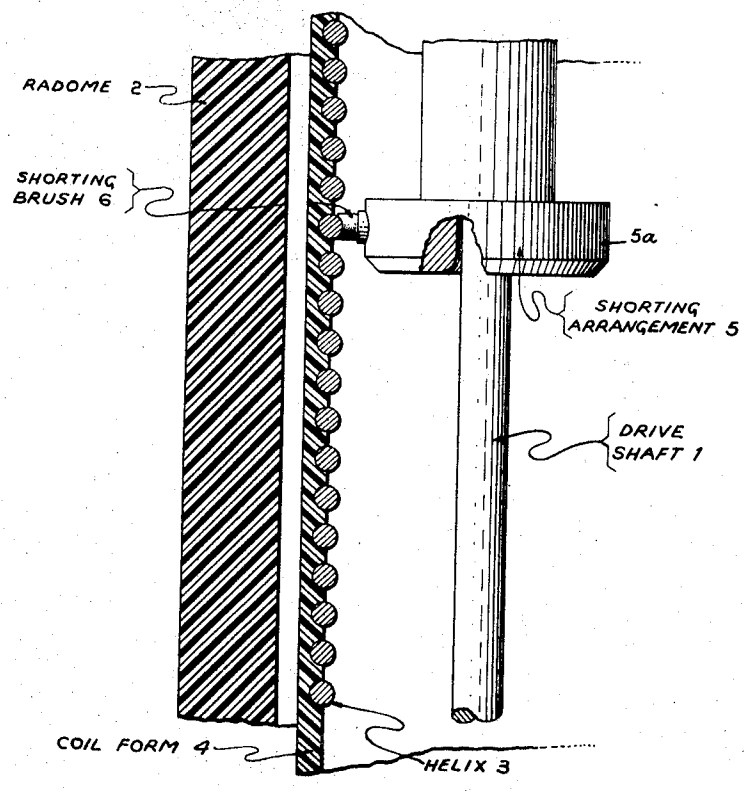


Fig. 1

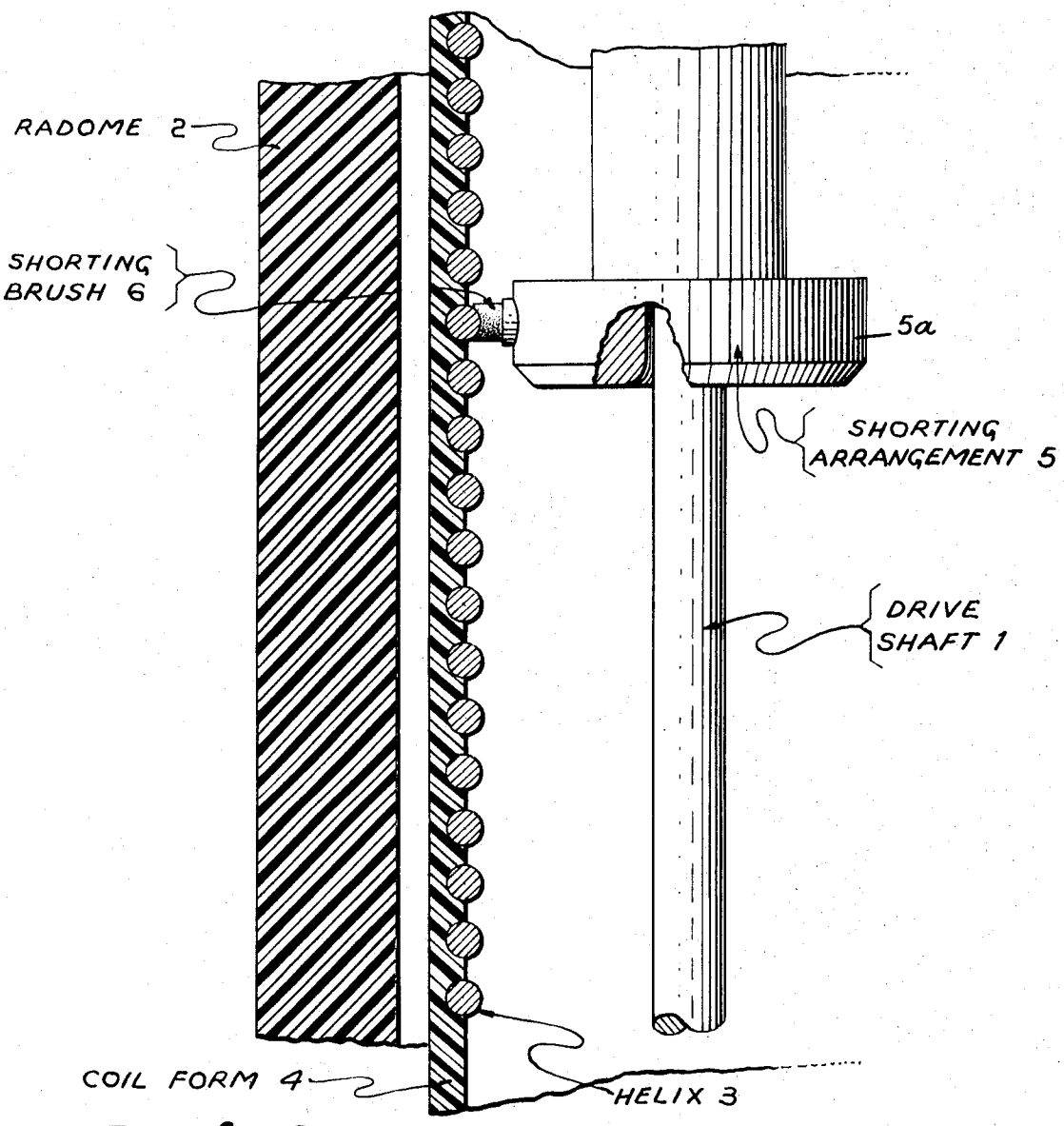


Fig. 2A

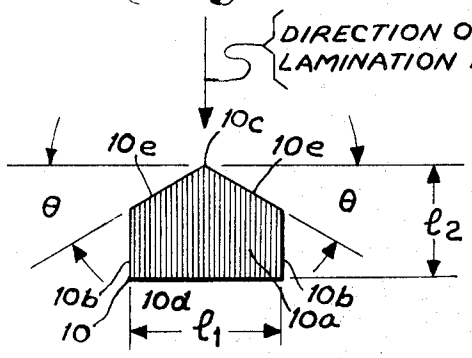


Fig. 2B

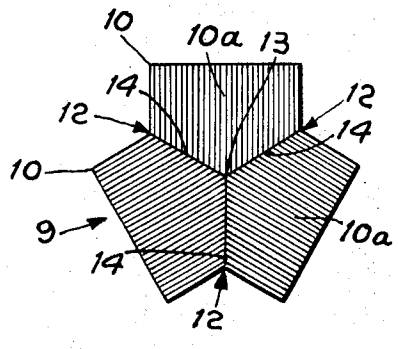


Fig. 3A

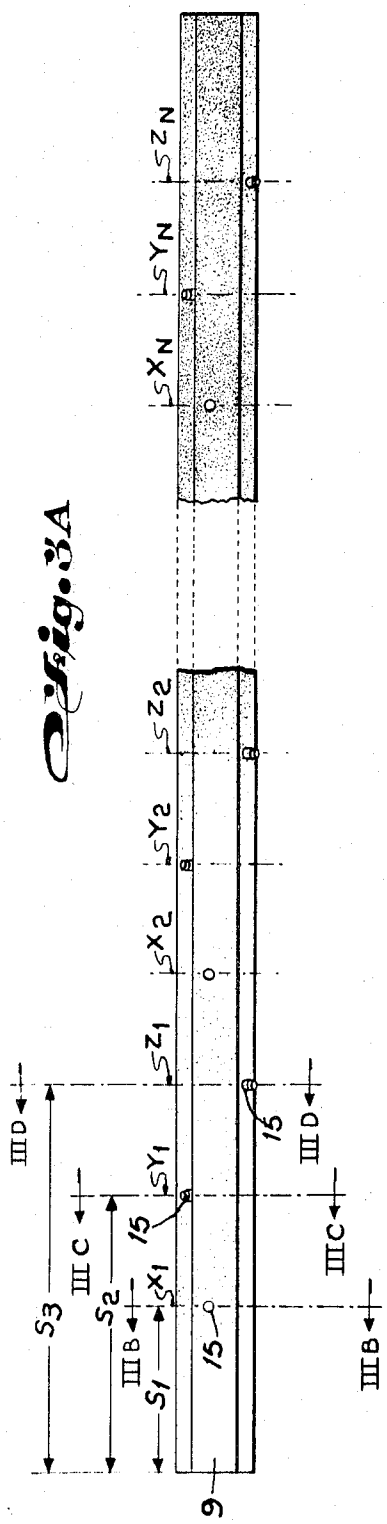


Fig. 3B

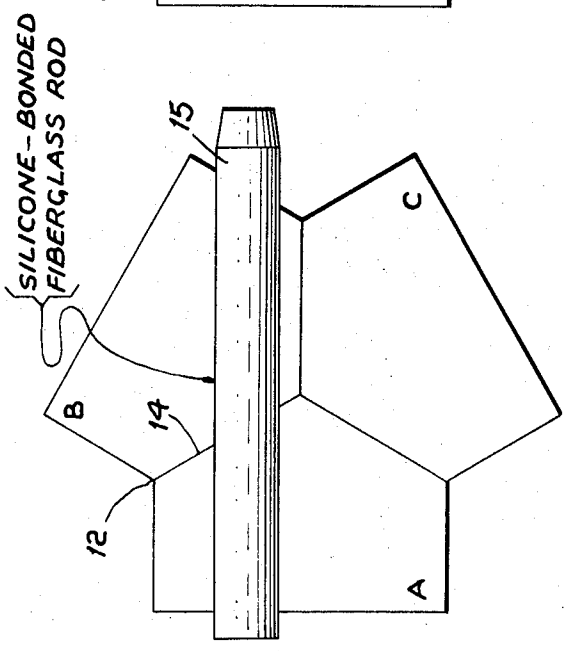


Fig. 3C

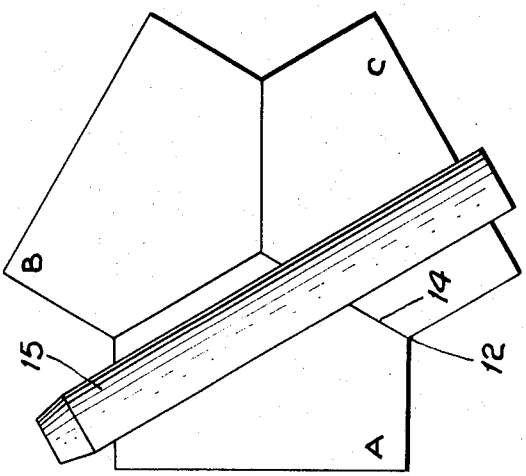


Fig. 3D

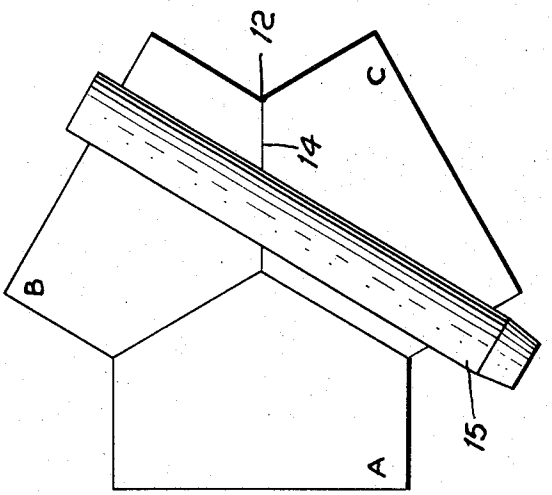


Fig. 4B

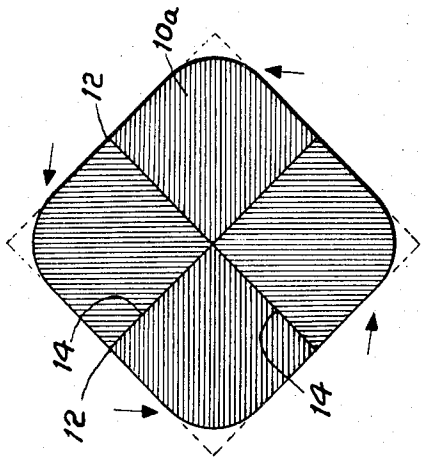


Fig. 4A

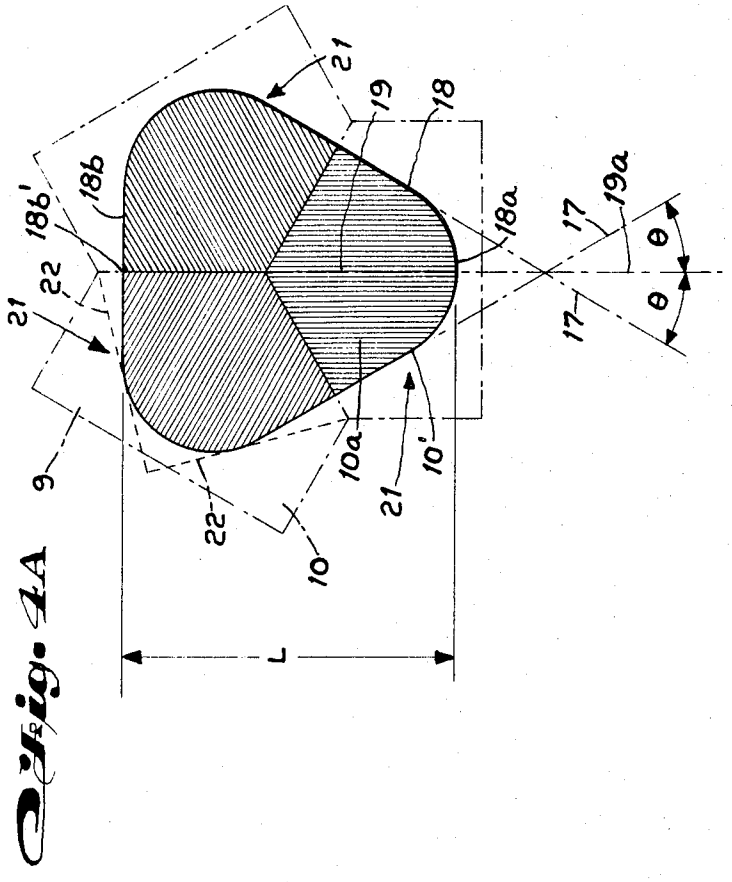
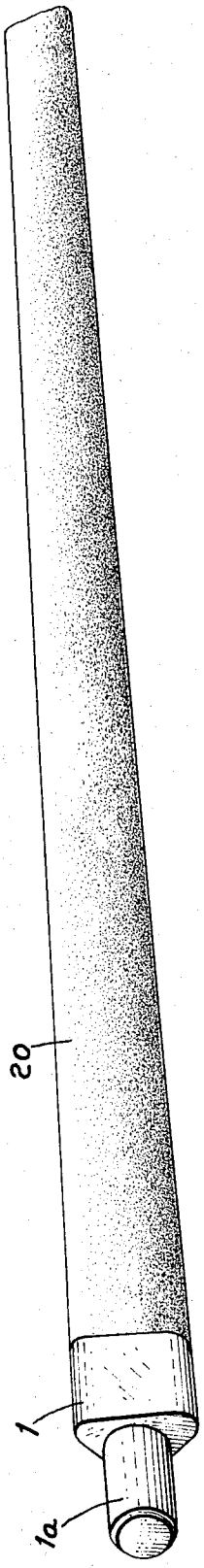


Fig. 5



DRIVE SHAFT CONFIGURATION FOR A HIGH VOLTAGE ANTENNA TUNING MECHANISM

BACKGROUND OF THE INVENTION

This invention relates to high voltage antenna tuning arrangements, and more particularly to the drive shaft construction and arrangement for tuning apparatus in high voltage antenna environments.

Antennas requiring a special drive shaft construction for tuning purposes may be of the high power transmitting type in the 2 to 30 mhz range for shipboard and submarine use and comprised primarily of the tunable inductive/capacitive type; that is, an inductive helix in series with and physically arranged end-to-end with a capacitive cylinder. Such antennas are disclosed in copending U.S. applications Ser. No. 324,607 filed Jan. 18, 1973 and Ser. No. 329,792 filed Feb. 5, 1973, the disclosures of which applications, in so far as they are pertinent to the present disclosure and invention, are incorporated herein by reference.

The tuning arrangement is, by design, a driven metal tube with one end contacting the helix internally through an assembly of graphite brushes, the other end similarly contacting the cylinder internally, and a multiplicity of predeterminably spaced graphite brushes alternately contacting both the helix and the cylinder as required in its travel over the tuning range. This tuning element is motor-driven by a "spline" shaft that not only imparts rotation to the tuning element so that the brushes slide along a helix turn but also permits an axial movement of the tuning element within the helix so as to permit the brushes to follow the pitch of the helix turn. A series of grooved rollers engaged onto the helix and mounted upon the tuning element imparts the proper axial movement to the tuning element. It is this "spline" shaft that is the object of this disclosure.

Since the "spline" shaft is rotated axially within the helix, it is subject to intense r.f. electric fields, which precludes the use of metallic drive shafts. The drive shaft must, therefore, be of dielectric material, and of course, with acceptable physical properties to transmit the imposed rotation loads within its environment.

It is, therefore, an object of this invention to provide a novel driven shaft of construction capable of satisfactorily performing under the environmental conditions above-mentioned, and particularly the conditions wherein exceptionally short radiators are employed within transmitting antenna configurations of very high power rating. In transmitting antennas of lower power rating or of reasonably tall radiators where the potential gradient along the helix is mild, the use of epoxy-bonded fiberglass is permitted. In transmitting antennas of higher power rating and/or of exceptionally short radiators where the potential gradient along the helix is steep, the use of silicone-bonded fiberglass is necessary. The dielectric properties that determine the choice of material are its dielectric constant and its power factor, the product of which is its loss factor; this latter factor is a measure of the power loss within the substance. This loss of power, of course, decreases the antennas's efficiency and shows up as heat in the driven shaft, which can destroy it. It can be shown that the epoxy-bonded fiberglass will absorb ten times the electrical energy as will silicone-bonded fiberglass under the same conditions.

Since the drive shaft is one that imparts axial movement to the tuning (shorting tube) assembly as well as rotation, sliding necessarily occurs at the interface. The choice and configuration of material at this interface becomes extremely important for controlling the distribution of electrical stress to prevent concentrations and their associated steep voltage gradients, and to minimize the transfer of harmful contaminants onto the face of the shaft, which contaminants lower the shaft's creepage resistance.

It is, therefore, another object of this invention to provide a drive shaft construction and arrangement for minimizing electrical stress concentration and associated steep voltage gradients particularly in an antenna tuning arrangement of the type described above.

It is a further object to provide a drive shaft construction and arrangement which minimizes the transfer of potentially harmful contaminants onto the shaft face.

It is another object of this invention to provide such a drive shaft construction which even if creepage should occur along its face due to outside considerations, the surface material is of the type which is capable of repairing itself and thus in effect erase the creepage path immediately following a discharge.

In the practical sense, creepage resistance of various materials is determined by standard test procedures that measure surface resistance to electrical flow and the time for complete surface breakdown of the substances under predetermined conditions. By way of example:

Material	Surface Resistivity	Surface Arc Resistance
Epoxy-Bonded Fiberglass	1×10^{12}ohms	100 secs
Silicone-Bonded Fiberglass	1×10^{13}ohms	190 secs
Teflon (Fluorocarbon Resin)	1×10^{16}ohms	over 300 secs

Finally, to completely grasp the significance of this disclosure, it is important also to compare certain important physical properties of the laminated materials concerned herein, namely directional strength and interlaminar strength.

Material	Flexural Strength	Bonding Strength
Epoxy-Bonded Fiberglass	60,000 psi	2600 lb
Silicone-Bonded Fiberglass	27,000 psi	900 lb

In the past, where silicone-bonded fiberglass was necessary for electrical reasons, the required shaft strength was obtained by orienting the glass fibers to adequately accept loads through fiber orientation. Here, resin-saturated woven fiberglass cloth was wound to produce a shaft of convolutely-wound cross-section. Under high pressure and temperature in a forming mold, the silicone resin was cured to produce a shaft wherein applied loads always occurred in the desirable mode, i.e. across glass fibers.

As a result of the present general trend of economic reorganization within industry and in further view of the special requirements for costly high-temperature, high-pressure tooling and equipment for the processing

of silicones, a source of supply for such a shaft construction no longer is available.

It is, therefore, still another object to provide an improved drive shaft construction and arrangement which fulfills this industry need and which is superior to the prior art designs in strength, cost and effectiveness.

SUMMARY OF THE INVENTION

According to the broader aspects of this invention there is provided a drive shaft comprising a rod-like structure having a rounded polygonal cross-section and composed of a material from the class of epoxy-bonded fiberglass or silicone-bonded fiberglass, and having disposed about the exterior thereof a layer of teflon.

Also there is provided a drive shaft comprising a unitary structure made up of a plurality of elongated members mounted together in symmetrical arrangement about a longitudinal center axis, said members being composed of layered dielectric material from the class of dielectric materials which include epoxy-bonded fiberglass and silicone-bonded fiberglass, wherein each member has a longitudinally running principal plane of symmetry parallelly running with the layers thereof and is arranged such that said principal plane of symmetry includes said longitudinal center axis.

A major aspect of this invention is the unitary polygonal cross-sectional construction from elongated longitudinally-bonded pieces of layered silicone or epoxy-bonded fiberglass, in which the unitary arrangement of the pieces is such that the loads on the drive shaft are directed across rather than along the interlaminar shear planes.

Another major feature of the invention is a staggered arrangement of pins of strong dielectric material driven successively in helical formation through the epoxy bonds securing the three-piece construction.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other objects and features of this invention will be more clearly understood from the following description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a fragmentary, partial-sectional side view schematically illustrating the novel drive shaft in an example antenna environment;

FIG. 2A is a schematic end view of one of three elongated, pentagonally-shaped sections longitudinally bonded together to form the shaft according to the invention;

FIG. 2B is a schematic end view of three of the shaped sections of FIG. 2A bonded together to form the drive shaft and illustrating the orientation of the shear planes of each section according to the invention;

FIG. 3A schematicallly illustrates the staggered arrangement of pins incorporated in the shaft according to the invention for combating shear forces;

FIGS. 3B-3D illustrate in enlarged cross-sectional views the drive shaft according to the invention taken at IIB, IIC and IID respectively of FIG. 3A, and showing the helical sequential arrangement formed by the pins in the triangular bonded shaft structure;

FIG. 4A schematically illustrates in end view the cross-section of the drive shaft in finished form as milled from the arrangement according to FIG. 2B;

FIG. 4B schematically illustrates in end view the cross section of another embodiment of the drive shaft according to the invention; and

FIG. 5 is a perspective view of the drive shaft complete with a teflon sleeve according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a drive shaft 1 constructed in accordance with this invention is shown situate in a contemplated very high voltage and space restricted environment. This contemplated environment comprises the mast of a submarine having a radome 2 of dielectric material enclosing among other things a transmitting antenna. The antenna as hereinbefore described is of the tunable inductance/capacitance type, wherein the helix (inductive) portion 3 is provided within a dielectric coilform structure 4.

Riding the shaft 1 is a tunable short arrangement 5 of which only the lower half is shown. By the tuning of drive shaft 1, the short 5 revolvingly remains in contact with a particular turn of the helix 3 via a shorting brush 6, while simultaneously also being displaced vertically within the helix. The other end of short 5 (not shown) is in contact with the cylindrical (capacitive) portion of the antenna, via another shorting brush, thus providing a variable inductance/capacitance ratio relative to the position of the shorting arrangement.

The lower or drive portion 5a of shorting arrangement 5 is provided with a "soft" or rounded-off triangular aperture which corresponds to the rounded triangular cross-section of shaft 1, as may be better seen in FIGS. 4A and 5. It is to be noted that the shorting brushes 6 used in the arrangement 5 may conventionally be constructed of graphite. Moreover, the "fit" of end 5a of shorting arrangement 5 is intended to be close enough with shaft 1 so as to provide efficient operation, and which, therefore, results in more or less continual circumferential contact with the latter as the short moves vertically up or down. In view of this rubbing contact, together with the normal wearing of the graphite brushes, there tends to occur a buildup of graphite particles and other impurities on the surface of the shaft 1 which creates potential flash or creepage paths along the surface thereof which could result in the destruction of the equipment. A solution for this problem is provided by surrounding the shaft in a teflon sleeve or coating, which will be more clearly disclosed hereinafter.

As the splined shaft 1 is axially arranged within the helix according the the example arrangement of FIG. 1, it experiences intense RF fields, thus making it impractical to use metallic drive shafts. Therefore, faced with the condition that drive shaft construction must be of dielectric material, the choice thereof together with shaft design must provide sufficiently acceptable physical properties to enable a continual transmission of imposed rotation loads within its environment.

Lower power antennas or antennas having tall radiators have comparatively mild potential gradients to contend with. In these instances epoxy-bonded fiberglass may be used as the dielectric drive shaft material. However, in instances where the drive shaft will be subjected to much steeper potential gradients, such as would be the case in transmitting antennas of much higher power rating and/or exceptionally short radiators, silicone-bonded fiberglass material is required, the

justification for which may be seen from differences in properties of the two materials as indicated in the tables given hereinbefore. Another comparison between the two materials may be derived from the following table:

Material	Dielectric Constant	Power Factor	Loss Factor
Epoxy-Bonded Fiberglass	5.0	.020	.100
Silicone-Bonded Fiberglass	4.0	.003	.012

Referring now to FIG. 2A, there is illustrated in end view an elongated piece **10** of silicone-bonded fiberglass taken from commercially available stock. This piece has been cut so as to possess in cross-section substantially the pentagonal shape of "home plate" in baseball. The fiberglass stock is layered or laminated, with the parallel layers or laminations **10***a* of the stock **10** being themselves parallel to the pair of parallel sides **10***b* of the pentagon, and also parallel to the bisector of the obtuse angle vertex **10***c* of the pentagon. A line drawn parallel to the base side **10***d* of piece **10** and tangent to the vertex **10***c* forms with the two angled equal-length sides **10***e* angles θ, preferably 30°. The length of side **10***d* is l_1, preferably one inch stock and the distance between vertex **10***c* and base side **10***d* is l_2. The shape of the elongated piece **10** defines a principal axis of symmetry which from a cross-sectional point of view bisects base side **10***d* and obtuse angle **10***c*.

Three pieces of the type shown in FIG. 2A are placed together longitudinally to form an unitary piece **9**, as shown in FIG. 2B, by way of firm bonds **12** of epoxy adhesive, running the entire length of the pieces **10**. The union of the three pieces **10** is accomplished by placing the respective vertices **10***c* thereof together at **13**, wherein by virtue of the angular shape of sides **10***e* of each of the pieces **10** as defined by θ, these sides match up to each other to form three basic interfaces **14** running the entire length of the elongated pieces **10**. To be noted is the fact that each one of the bonded interfaces **14** is parallel to the laminations of a respective oppositely arranged one of the pieces **10**.

FIG. 3A is illustrative of a schematic side view of the unitary structure **9** depicted in end view in FIG. 2A, wherein a series of pins **15** composed of dielectric material such as silicone-bonded fiberglass are driven through the unitary structure **9** at spaced intervals and in a simulated "helical" orientation as may be better seen in FIGS. 3B–3D. FIGS. 3B–3D are enlarged cross-sectional views of the unitary structure **9** in FIG. 3A taken respectively at IIB, IIC and IID thereof. As such, the pins **15** in FIGS. 3B–3D relate to successive pin positions X_1, Y_1 and Z_1 of FIG. 3A.

For convenience and clarity the three pieces **10** forming the unitary structure **9** are labeled A, B and C in FIGS. 3B–3D to demonstrate the successive helical staggering of the pins **15** around and along the structure **9**. As shown, pin position X_1, which is depicted in FIG. 3B, relates to a pin **15** being driven across the epoxy bond **12** at the interface **14** between pieces A and B. Likewise FIG. 3C depicts the pin position Y_1 wherein a pin **15** is driven through the epoxy bond **12** at the interface **14** between pieces A and C. Similarly, FIG. 3D demonstrates the pin position Z_1, wherein a pin **15** is driven through the bond between pieces B and C.

The X_2 position is a repeat of FIG. 3B, the Y_2 position a repeat of FIG. 3C, and so on, thus forming a "helical" orientation of pins. It is to be understood that this "pinned" version of drive shaft disclosed in FIGS. 3A–3D is not required in all uses, the epoxy bonds **12** at the various interfaces **14** themselves being sufficiently strong for normal contemplated shear loads. The "pinned" version represents a drive shaft construction for use with abnormally high torque loads.

The description thus far has indicated that in the "pinned" embodiment the pins were "driven" through the bonds. However, any suitable means of providing the pins **15** in their intended orientation may be used; for example drilling holes having the proper orientation may be drilled through the shaft and the pins **15** placed therein, preferably maintained via epoxy adhesive. It is preferable also, though not intended to be a limit to this invention, to assemble the pins **15** into the structure before final milling to achieve the rounded triangular cross-sectional shape depicted in FIG. **4**.

Referring to FIG. **4**, there is depicted in dashed lines the outline of unitary structure **9**, having been milled down to the desired final "soft" triangular shape **18** according to the invention. This final shape is defined in part by a predetermined length L of a line **19** running between any one of the rounded vertices **18***a* and the center **18***b*′ of the side **18***b* opposite that vertex. Further definition may be derived via the combination of an extension **19***a* of this line **19** beyond the vertex **18***a*, together with extensions **17** of the sides of triangle **18** that make up the vertex **18***a*, forming a pair of angles θ, also in this case 30°.

To be particularly noted in FIG. **4** is the fact that the loads to be placed on the shaft, as represented by arrows **21**, are, by way of the orientation of the individual pieces **10**′ making up the triangular cross-sectional shape of the shaft, oriented at almost right angles with the lamination planes **10***a* of the individual pieces **10**′. Because of this the possibility of delamination due to shaft loading is virtually nil. Moreover, by the orientation of the pieces **10** and their respective laminations, delamination as a result of the milling operation to achieve the final rounded-off triangular shape cross-section will not occur.

It is to be understood that this invention is not to be limited in any way by the fact that the pieces **10** in the example description above are pentagonal in shape. These pieces **10** could for example be originally four-sided as evidenced by the dotted lines **22** in FIG. **4**. The most important consideration is that the individual pieces **10** be shaped to form close interfaces with each other to permit a uniform bond to be created therebetween.

In accordance with this, the arrangement of FIG. **4B** is possible, wherein a substantially rectangular (square) construction is depicted. The basic orientation and construction method of the individual elongated pieces, relative to each other and relative to their respective laminations, is the same as for the triangular shaft construction described above. In this case, however, the individual elongated pieces are substantially square in cross-section and together form a composite or unitary square construction. Here, as is the case with the triangular construction, the shaft loads are substantially perpendicular (applied across) the laminations as indicated by the arrows in FIG. **4B**. A sequential helical pin arrangement may also be incorporated into the

square construction. As indicated hereinbefore, however, by virtue of the fact that the orientation of glass fibers of the individual pieces making up the composite structure is such as to prevent applied loads from coinciding directly with weak shear planes, there is permitted the fabrication of a drive shaft with relatively common techniques from readily available stocked materials without the need for the pin arrangements in all cases of normal loads.

Since the trend in more recent developments has been towards physically shorter antennas, which, in turn, entails steeper voltage gradients, the reliability of the drive shaft should then be, at least, maintained, if not increased. The means for maintaining and increasing performance in this regard according to the invention is to apply a nonporous jacket or coating of teflon on the shaft to increase its surface resistivity and its surface arc resistance. We have experimentally accomplished this for example by applying an "off-the-shelf" shrinkable teflon tubing over the shaft. Teflon has a dielectric constant of 2.1 and a dissipation factor of .0004 which produces a loss factor of .0008 (negligible power adsorption in this application). It displays a very acceptable static-friction coefficient of .08 and dynamic-friction coefficient of .10 at a PV of 8,000. Its surface not only helps prevent the formation of surface contamination, but also provides a non-tracking property (alluded to hereinbefore) since carbonized conducting paths are not generated during arcing with teflon.

The drive shaft has to be low loss to prevent adsorption of the energy from the field of the helix. This is one major reason why silicone-bonded fiberglass is chosen as the basic shaft material in high power rated or shortened radiator antenna arrangements. Teflon, as indicated above, also has very favorable properties in this regard. However, the silicone tends to pick up impurities from the constant sliding contact with the tuning element, which impurities contribute to tracking and creepage. With a teflon sleeve, however, there is presented a surface more slippery than silicone which tends to prevent clinging by impurities. Moreover, even if sufficient particles become collected onto teflon sleeve to give rise to an arcing condition, teflon confines an arc to a track on the outer surface thereof, thus avoiding camage to the shaft itself. By its self-healing property, teflon successfully resists surface damage from the continual sliding contact with the tuning element and robs possible secondary arcs of any less-resistive surface tracks which in the case of other materials would have resulted from carbonization from the initial arcing condition. Thus, in the unlikely case that creepage does occur along the teflon sleeve **20** due to outside considerations, there results no permanent damage to the shaft.

To be noted in FIG. **5** is a metallic end member **1a** mounted to the shaft **1.** It is permissible to use a metallic member here inasmuch as it is positioned at all times well away from the steep gradients and high fields associative to the radiating portion of the antenna arrangements.

There has been disclosed herein dielectric material drive shaft constructions designed for use particularly in high field potential environments such as a helically driven tuning mechanism of a high voltage transmitting antenna, which shaft constructions are capable of maintaining operation under unusually high mechanical loads requiring both rotational and axial movement. A plurality of elongated common-stock pieces of layered epoxy or silicone-bonded fiberglass are shaped cross-sectionally to be united predeterminably into a unitary form via longitudinally running bonds of epoxy adhesive. The unitary form cross-section is a "soft" polygon, for example a rounded-off triangle or square, wherein the individual pieces are so arranged as to have the shear planes of the layered dielectric material substantially perpendicular to the direction of the force of the applied loads. To provide a shaft surface which resists wear, prevents surface contamination, and has nontracking properties most beneficial in preventing arcing and creepage in extremely high potential gradient environments, a sleeve or jacket of teflon is provided about the shaft's outer surface. In cases where shafts loads are excessive, the shaft construction may include a multiplicity of strong dielectric pins driven thru the unitary structure, each across a successive interfacing epoxy bond, to form a helical pin configuration which provides additional strength to these bonds.

It is to be understood that the foregoing description of specific examples of this invention is made by way of example only and is not to be considered as limiting on the scope of this invention as set forth in the objects and features thereof and in the accompanying claims.

What is claimed is:

1. A drive shaft comprising a rodlike structure having a rounded polygonal cross-section and composed of a material selected from the group consisting of epoxy-bonded fiberglass and silicone-bonded fiberglass, and having disposed about the exterior thereof a layer of fluorocarbon resin; and wherein the drive shaft is a unitary structure comprised of a plurality of elongated members bonded together and symmetrically arranged about a longitudinal center axis, each of said members being of layered construction, and wherein each member has a longitudinally running principal plane of symmetry in parallel with the layers thereof and is arranged such that said principal plane of symmetry includes said longitudinal center axis.

2. The arrangement of claim **1** further including a plurality of predeterminably spaced apart dielectric pins arranged to extend through the drive shaft, each pin extending across at least one of the bonded interfaces between said members which is different from the respective interfaces associated with the adjacent pins, wherein the arrangement of said pins taken together simulates a helical form.

3. The arrangement of claim **2** wherein said pins extend through the drive shaft in substantially perpendicular orientation relative to the center axis.

4. The arrangement of claim **1** wherein the drive shaft is substantially triangular in cross-section.

5. The arrangement of claim **1** wherein the drive shaft is substantially square in cross-section.

6. The arrangement of claim **2** wherein said layer of fluorocarbon resin is a sleeve of fluorocarbon resin shrink tubing.

7. A drive shaft comprising a unitary structure made up of a plurality of elongated members mounted together in symmetrical arrangement about a longitudinal center axis, said members being composed of layered dielectric material from the class of dielectric materials which include epoxy-bonded fiberglass and sili-

cone-bonded fiberglass, wherein each member has a longitudinally running principal plane of symmetry parallelly running with the layers thereof and is arranged such that said principal plate of symmetry includes said longitudinal center axis.

8. The arrangement of claim **8** further including a layer of fluorocarbon resin disposed about the exterior of the drive shaft.

9. The arrangement of claim **7** wherein the drive shaft has a substantially triangular cross-section and each said member interfaces with and is bonded to each of the other members.

10. The arrangement of claim **7** wherein the drive shaft has a substantially square cross-section in which each member is also substantially square shaped in cross-section.

11. The arrangement of claim **7** wherein the longitudinally running edges of the drive shaft are rounded for minimizing potential gradients in a field of high electric potential.

12. The arrangement of claim **7** further including a plurality of predeterminably spaced apart dielectric pins arranged to extend through the drive shaft, each pin extending across at least one of the bonded interfaces between said members which is different from the respective interfaces associated with the adjacent pins, wherein the arrangement of said pins taken together simulates a helical form.

13. A drive shaft comprising a plurality of elongated members arranged to be symmetrically mounted in side-to-side communication with each other about a longitudinal center axis to form a unitary rod-like configuration of rounded polygonal cross-section, each of said plurality of members being composed of a plurality of longitudinally running planar layers of one of the materials selected from the group consisting of epoxy-gonded fiberglass and silicone-bonded fiberglass, wherein the arrangement of said members is such that the planar layers thereof extend substantially perpendicular to the direction of the force loads applied to the drive shaft.

* * * * *