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[54] **BONDED PIEZOELECTRIC BENDING TRANSDUCER AND PROCESS FOR PRODUCING THE SAME**

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[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **310/330;** 310/331; 310/363; 310/364

[58] **Field of Search** 310/330–332, 310/363–365

[56] **References Cited**

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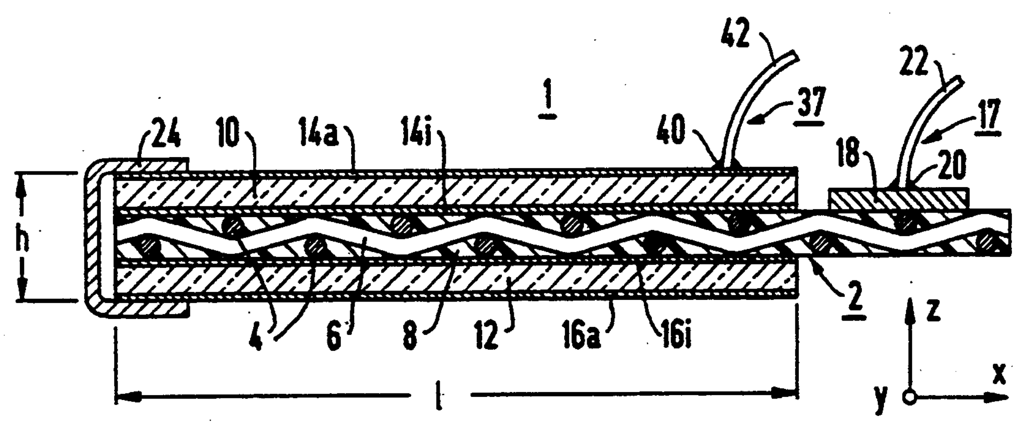
[57] **ABSTRACT**

A piezoelectric bending transducer includes two piezoceramic layers each having two sides and electrodes on both of the sides. A graphite fiber layer is glued between the piezoceramic layers with an epoxy resin. The graphite fiber layer has a greater length than the two piezoceramic layers defining an exposed part of the graphite fiber layer. A copper foil is glued to the exposed part. The copper foil has an area for disposition of a solder contact. A process for producing a bending transducer includes placing a graphite fiber layer impregnated with incompletely hardened epoxy resin between two polarized piezoceramic layers. The graphite fiber layer is glued between the piezoceramic layers upon hardening of the epoxy resin. A copper foil is glued onto the graphite fiber layer, preferably simultaneously with the gluing of the two piezoceramic layers.

4 Claims, 1 Drawing Sheet



BONDED PIEZOELECTRIC BENDING TRANSDUCER AND PROCESS FOR PRODUCING THE SAME

This application is a continuation of application Ser. No. 08/016,096, filed Feb. 10, 1993, now abandoned.

CROSS-REFERENCE TO RELATED APPLICATION

This application is a Continuation of International Application Ser. No. PCT/DE91/00616, filed Jul. 31, 1991.

SPECIFICATION

The invention relates to a piezoelectric bending transducer with a graphite fiber layer that is glued with an epoxy resin between two piezoceramic layers which are provided with electrodes on both sides. It also relates to a process for producing such a piezoelectric bending transducer.

If such an electromagnetic bending transducer is firmly fastened at one end and has a magnetic head at the other end, then when a voltage is applied to the bending transducer, the magnetic head will be deflected by a distance corresponding to the voltage. In that structure, the bending transducer can then be used in magnetic recording and reproducing equipment, such as in videocassette recorders. Another field of use for a bending transducer besides video technology is valve technology or Braille readers.

As a rule, piezoelectric bending transducers include two piezoceramic chips or layers that are glued to both sides of a metal or plastic foil, which may also be fabric-reinforced. The ceramic chips are provided with a metallization on both sides. Before or after being glued to the metal or plastic foil they are polarized to make a bimorph. In that process they are placed in an electrical field of 700 V/mm, for instance, and made piezoelectric in that way. If a potential of 170 V, for example, is then applied to the inner electrodes of the two piezoceramic chips and a potential of 0 V is applied to the two outer electrodes, then an electrical field is created which has opposite directions in the upper and lower ceramic chips. As a result of the piezoelectric effect, one piezoceramic chip will becomes longer and the other will become shorter. The bending transducer therefore bends. It can thus be used as an electromechanical adjusting element and its fields of application are, for example, those given above.

A piezoelectric bending transducer of the type referred to at the outset above is known from German Published, Non-Prosecuted Application DE 30 46 535 Al. In that bending transducer, it is not a layer of metal or plastic but rather a layer of graphite or carbon fiber that is disposed between the two piezoceramic layers. The individual carbon fibers are embedded in an epoxy resin. It is particularly significant that in that electromagnetic transducer, the carbon fibers extend in the same direction, or in other words are all disposed parallel to one another. The individual graphite fibers are placed in such a way that they extend parallel to the direction in which the electromechanical transducer is to expand or contract to generate the deflection. It is assumed that it is in that direction that the graphite fiber layer has its greatest modulus of elasticity. The modulus of elasticity is substantially less at right angles to that direction. The piezoelectric ceramic slabs may, for example, be made from a lead-zirconate-titanium ceramic. The bending transducer is dimensioned as being virtually square. Nothing is said in that disclosure about the bonding of the various electrodes.

The same piezoelectric bending transducer, with a carbon fiber layer placed between two piezoceramic layers, is known from U.S. Pat. No. 4,363,993 of Nishigaki et al. In that piezoelectric bending transducer, the operating voltage is applied only to the outer electrodes. The inner electrodes lack external terminals.

U.S. Pat. No. 4,363,993 and German Published, Non-Prosecuted Application DE 30 46 535 Al are both based on the same Japanese priority applications.

A piezoelectric bending transducer is known from Abstract JP 62-237780, in Patent Abstracts of Japan, Vol. 12, No. 108, E597, that has a conductive elastic intermediate layer which is provided with an electrical contact. However, nothing is known about the material of which that intermediate layer is made and in what way the bonding of the intermediate layer was achieved.

It is accordingly an object of the invention to provide a bonded piezoelectric bending transducer and a process for producing the same, which overcome the hereinafore-mentioned disadvantages of the heretofore-known products and processes of this general type, in which the bonding of the inner electrodes of the two piezoceramic layers can be carried out in a reliable and simple way, and accordingly in which providing the electrical connection does not entail an overly great effort or expense.

With the foregoing and other objects in view there is provided, in accordance with the invention, a piezoelectric bending transducer, comprising two piezoceramic layers each having two sides and electrodes on both of the sides; a graphite fiber layer being glued between the piezoceramic layers with an epoxy resin; the graphite fiber layer having a greater length than the two piezoceramic layers defining an exposed or free part of the graphite fiber layer; and a copper foil glued to the exposed part, the copper foil having an area for disposition of a solder contact.

Accordingly, the graphite fiber layer is used as a common electrode and is provided with an electrical terminal for the two electrodes located on the inside. This can be carried out relatively simply.

In accordance with another feature of the invention, the copper foil has a pretreated surface of rough structure, being oriented toward the graphite fiber layer, in order to make the contact between the copper foil and the graphite fiber layer particularly good.

In accordance with a further feature of the invention, the surface of the copper foil is covered with a rough layer of a material selected from the group consisting of tin, nickel and copper.

With the objects of the invention in view, there is also provided a process for producing a bending transducer, which comprises placing a graphite fiber layer impregnated or saturated with incompletely hardened epoxy resin between two polarized piezoceramic layers; gluing the graphite fiber layer between the piezoceramic layers upon hardening of the epoxy resin; and gluing a copper foil onto the graphite fiber layer, preferably simultaneously with the gluing of the two piezoceramic layers.

In accordance with another mode of the invention, there is provided a process which comprises pretreating the copper foil by covering the copper foil with a thin, rough metal layer before gluing the copper foil onto the graphite fiber layer.

In accordance with a further mode of the invention, there is provided a process which comprises pretreating the copper foil by covering the copper foil with a thin, rough metal layer selected from the group consisting of zinc and nickel applied by electrolytic deposition before gluing the copper foil onto the graphite fiber layer.

In accordance with a concomitant mode of the invention, there is provided a process which comprises pretreating the copper foil by covering the copper foil with a thin, rough copper layer applied by electrolytic deposition at high current density before gluing the copper foil onto the graphite fiber layer.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in a bonded piezoelectric bending transducer and a process for producing the same, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

FIG. **1** is a diagrammatic, longitudinal-sectional view of a piezoelectric bending transducer with a brass foil being used as an inner layer, for the sake of more clearly illustrating the problem presented;

FIG. **2** is a longitudinal-sectional view of a piezoelectric bending transducer with a plastic foil being used as the inner layer, again for more clearly illustrating the problem presented; and

FIG. **3** is a longitudinal-sectional view of a piezoelectric bending transducer according to the invention.

Referring now to the figures of the drawing in detail and first, particularly, to FIG. **1** thereof, there is seen a bending transducer **1** which includes a metal foil or metal layer **2M**, onto both sides of which piezoceramic chips or layers **10**, **12** are glued. The piezoceramic layers **10**, **12** are provided with metallizations or electrodes on both sides. Inner electrodes are marked with reference symbols **14*i***, **16*i*** and outer electrodes are marked with reference symbols **14*a***, **16*a***. Relatively thick layers **11** and **13**, which include an adhesive, are respectively located between the layer **2M** and the layers **10** and **12**. The metal foil **2M**, which in particular may be formed of brass, is somewhat longer toward the right end than the two piezoceramic layers **10**, **12**, defining an exposed region. Located in the exposed region is an electrical terminal **17** having a soldering point **20**, to which a connecting wire **22** leads. Correspondingly, an electrical connection **36** with a soldering point **40** and a connecting wire **42** is provided on the upper outer electrode **14*a***. On the left end, a metal bracket **24** assures contact of the two outer electrodes **14*a***, **16*a*** with one another.

Before or after being glued, the ceramic chips **10**, **12** are polarized, by being placed in an electrical field E of 700 V/mm, for instance, and thus made piezoelectric. Upon application of a voltage U to the connecting or feed wires **22**, **42**, the bending transducer **1** bends.

The structure shown in FIG. **1** with a brass foil **2M** as the inner layer has the advantage that the metallizations **14*i***, **16*i*** located on the inside of the piezoceramic layers **10**, **12** can be bonded in a simple manner. This is because the adhesive layers **11**, **13** can be selected to be so thin that points and bumps, which are always present because of the rough surface of the ceramic layers **10**, **12**, penetrate the adhesive **11**, **13** at many points, thus producing a reliable contact between the metal foil **2M** and the metallization layers **14*i***, **16*i*** on the inside. Additionally, the wires **22**, **42** can easily be soldered for purposes of further electrical wiring.

However, the structure with the brass foil **2M** has grave disadvantages as well. First, brass is difficult to glue and second, brass and piezoceramic have quite different coefficients of thermal expansion. As a result, tensile or compressive strains arise in the piezoceramic layers **10**, **12** as a function of the gluing temperature and the temperature of use. If gluing is carried out at room temperature and if the bending transducer **1** is heated in the equipment in which it is incorporated, then tensile strains arise in the piezoceramic layers **10**, **12**, and the ceramic will crack. On the other hand, if gluing is carried out at a higher temperature, such as 130° C., then even though one can be certain that the bending transducer is hardly likely to be exposed to higher temperatures during use, nevertheless the ceramic layers **10**, **12** will be under compressive strain. If a ceramic layer **10**, **12** that has already been prepolarized has been glued, then the mechanical strains cause depolarization and therefore an attenuation of the piezo effect. The bending will also be less.

Metal layers **2M** having a coefficient of thermal expansion that is adapted to the ceramic layers **10**, **12** are usually not usable, because of their vulnerability to corrosion. Moreover, they lend themselves poorly to soldering, so that attaching further wiring becomes difficult again.

In contrast, if the glued sandwich is polarized, then the ceramic layer **10**, **12** cracks. The polarization in fact involves an alignment of domains in the particles of the ceramic layers **10**, **12**. This produces a shape change, because of the crystallographic anisotropy of the piezoceramic layers **10**, **12**. The ceramic chip **10**, **12** that is affected becomes shorter and thicker. Since it is firmly glued to the brass sheet **2M**, it cannot contract and accordingly cracks.

FIG. **2** shows that in principle a plastic foil **2K** can also be used instead of a metal foil **2M**. In that case, bonding the inner electrodes **14*i***, **16*i*** becomes difficult, because they border a nonconductive plastic of the foil **2K**. In that case, the inner metallizations **14*i***, **16*i*** can be extended upward and downward over an edge (shown on the right in FIG. **2**) of the applicable piezoceramic layer **10**, **12**, to enable bonding. This then produces two bonding points **36**. This all involves major effort and expense technologically.

FIG. **3** shows a piezoelectric bending transducer in which the bonding problems discussed above are counteracted.

In FIG. **3**, the piezoelectric bending transducer **1** includes a graphite fiber layer **2** as its essential element, which includes carbon fibers **6** extending in a longitudinal direction x, carbon fibers **4** extending in a transverse direction y at right angles thereto, as well as epoxy resin **8**. The various carbon fibers **4** and **6**, which are woven together with one another, thus form a carbon fiber fabric, which is saturated with the epoxy resin **8**. Constructing the graphite fiber layer **2** as a fabric with crosswise fibers **4** and **6** lends the layer adequate stabil-