SUPPORTING MEANS FOR PIEZOELECTRIC TRANSFORMERS

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ABSTRACT

In a piezoelectric transformer comprising a ceramic body in the form of an elongate plate of piezoelectric material with one half polarized in the direction of thickness and the remaining half in the longitudinal direction, a pair of input electrodes secured to the opposite sides of said one half and an output electrode secured to the end surface of the remaining half, there is provided supporting means including means for mechanically clamping and supporting the piezoelectric transformer at at least one of the transverse line nodes of the longitudinal mechanical vibrational movement thereof which support permits free longitudinal vibrations while suppressing undesirable vibrating modes.

5 Claims, 15 Drawing Figures
SUPPORTING MEANS FOR PIEZOELECTRIC TRANSFORMERS

BACKGROUND OF THE INVENTION

This invention relates to means for supporting a piezoelectric transformer. As is well known in the art the piezoelectric transformer generally comprises an elongated rectangular ceramic body made of piezoelectric material such as barium titanate (BaTiO$_3$) or lead zirconate titanate by powder metallurgy. One half the length of the ceramic body is polarized in the direction of thickness while the remaining half is polarized in the longitudinal direction. Input electrodes are applied on the opposite sides of the first half polarized in the direction of thickness and an output electrode is applied to the end surface of the latter half by firing. When an AC signal having a frequency corresponding to the natural frequency of the ceramic body is applied across the input electrodes the piezoelectric transformer undergoes a mechanical vibration to produce a stepped up output voltage at the output electrode. The construction of the prior supporting device of such a piezoelectric transformer is typically as follows. Thus for example, the ceramic body is sandwiched between a plurality of sets of spaced apart supports or totally encased by a covering of pliable insulating material, foam or the like, for example. However, such supporting means have been designed without due consideration of dissipation of heat generated in the ceramic body during operation. More particularly, the temperature of the ceramic body rises due to heat generated by the polarization hysteresis and the mechanical vibration according to the Hooke's law with the result that the frequency of natural vibration of the ceramic body is increased to higher ones to decrease the output voltage. Further excessive heating of the ceramic body results in the creep phenomenon to crack and damage the ceramic body.

Further inasmuch as the ceramic body vibrates not only in the longitudinal direction but also in the direction of its thickness and width or in the direction of the resultant of these different directions, these complicated vibrational movements cause supports to shift from their normal positions so that the ceramic body is no more supported as required. Although the piezoelectric transformer is designed to vibrate in the longitudinal direction at the $\lambda/2$ mode or $\lambda$ mode we have found that the ceramic body also vibrates concurrently at higher harmonics at these operational modes or in the direction of width or thickness. Since these vibrations at higher harmonics increase heating of the ceramic body and hence decrease the output voltage it is necessary to suppress vibrations at these undesirable modes.

SUMMARY OF THE INVENTION

It is therefore the principal object of this invention to provide a new and improved device for supporting a piezoelectric transformer which can efficiently dissipate heat from the ceramic body and does not restrain the desired vibration thereof.

Another object of this invention is to provide a novel device for supporting a piezoelectric transformer which can position the supporting device at a prescribed position and can prevent the supporting device from shifting away from the prescribed position.

Further object of this invention is to provide a novel supporting device for a piezoelectric transformer which can effectively suppress vibrations of undesired modes thus increasing the output voltage without increasing heating.

To accomplish these and other objects in accordance with this invention the nodal point of the mechanical vibration along the length of the ceramic body is supported at the point or along a transverse line including the nodal point to substantially increase the area of heat dissipation thus decreasing the temperature rise of the ceramic body. According to one aspect of this invention, where the piezoelectric transformer is supported at the nodal point by a band in the form of a narrow rectangular rod of insulating elastic material, there is provided means to position the band at the prescribed position. The positioning means may be comprised by grooves or projections on the opposite surfaces of the ceramic body. The band is accommodated in the groove or provided with openings to receive the projections whereby to secure the band to the ceramic body. Further, the supporting means provided at the nodal point may be comprised by a pair of rigid insulating members adapted to clamp the ceramic body therebetween and clamping screws extending through opposite ends of the rigid members. These supporting means function to effectively suppress undesired vibration and heating of the ceramic body thus increasing output voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of this invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagram to explain the $\lambda/2$ mode vibration of a piezoelectric transformer;

FIG. 2 is a similar view to explain the $\lambda$ mode vibration of the piezoelectric transformer;

FIG. 3 shows a perspective view of a piezoelectric transformer supported by a supporting leg embodying the invention;

FIG. 4 shows a perspective view of the supporting leg;

FIG. 5 shows the relationship between supporting positions of a piezoelectric transformer and the quantity of heat generated;

FIG. 6 shows a perspective view, partly in section, of a piezoelectric transformer employing an elastic band;

FIG. 7 shows a perspective view of the supporting band;

FIG. 8 shows a perspective view of the piezoelectric transformer shown in FIG. 6;

FIG. 9 shows a perspective view of a modified piezoelectric transformer;

FIGS. 10, 11 and 12 show perspective views of still other modifications of the piezoelectric transformer and

FIGS. 13, 14 and 15 show piezoelectric transformers with modified supporting devices.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the accompanying drawings, the piezoelectric transformer, generally designated by a reference numeral 20 comprises a ceramic body 22 in the form of a rectangular plate made of barium titanate or lead zirconate and the like piezoelectric material by the powder metallurgy technique with its lefthand half 24 along the length thereof polarized in the direction of thickness A—A while the remaining or righthand half 26 is polarized in the direction of length B—B'. The piezoelectric transformer 20 is provided with a pair of input electrodes 28 applied by firing to the opposite surfaces of the lefthand half 24 and an output electrode 30 similarly attached to the end surface of the righthand half 26. Upon application of an AC input signal of a frequency corresponding to the natural frequency of the ceramic body across input electrodes 28, the piezoelectric transformer 20 undergoes mechanical vibrations to produce a stepped-up output voltage at the output electrode 30. Theoretically, the piezoelectric transformer 20 vibrates at a $(n/2)\lambda$ mode (where $n$ is an integer) but from the standpoint of voltage transformation ratio and heating, it is designed to operate at the $\lambda/2$ mode or $\lambda$ mode. As a result, the vibrational motions of the piezoelectric transformer operating at the $\lambda/2$ and $\lambda$ modes are shown by FIGS. 1 and 2 respectively. When operating at the $\lambda/2$ mode the nodal point of the mechanical vibration is at the center along the length of the ceramic body or at a point 1/2 spaced apart from either end, where 1 represents the total length of the ceramic body. Whereas when operating at the $\lambda$ mode the nodal points are at two points each spaced apart from the respective ends by 1/4. In other words, these
nodal points are spatially fixed points it is clear that even when these nodal points are mechanically fixed by supporting means, the waveform of the vibration of the piezoelectric transformer and hence the operating characteristics thereof would never be affected.

As above described, this invention contemplates the provision of a novel supporting device which supports the piezoelectric transformer at the nodal point or points or along transverse line or lines including such nodal point or points.

FIGS. 3 and 4 illustrate one embodiment of this invention comprising a supporting leg of an inverted T shape cross-sectional configuration and made of insulating material such as polypropylene. The vertical leg or wall 34 is provided with an elongated slot 36 corresponding to the cross-sectional configuration of the ceramic body. As shown in FIG. 3, the ceramic body is supported by the leg 32 at the middle or the nodal point of the vibration by extending through slot 36. Preferably, the vertical leg should be rigid and thin as far as possible. When operating at the λ mode, two supporting legs are provided at respective nodal points 1/4 spaced apart from opposite ends of the piezoelectric transformer.

FIG. 5 shows the relationship between the output voltage, quantity of heat generated and the positions of supporting means where the supporting legs of the construction shown in FIG. 3 are utilized. The percentage of the reduction in output voltage $\delta V_o$ and the percentage of the reduction in the temperature $\delta T_o$ were determined by the following equations

$$\delta V_o = \frac{V_a - V_x}{V_a} \times 100\% \quad (1)$$

$$\delta T_o = \frac{T_a - T_x}{T_a} \times 100\% \quad (2)$$

where $V_a$ represents the output voltage of an unsupported piezoelectric transformer, $V_x$ that of a supported piezoelectric transformer, $T_a$ the temperature of the unsupported piezoelectric transformer and $T_x$ that of the supported piezoelectric transformer. Supporting positions of the piezoelectric transformer are shown on the abscissa wherein a shows unsupported case, b the case wherein the piezoelectric transformer is supported at the middle, c the case wherein the piezoelectric transformer operating at the λ mode is supported at a point 1/4 spaced apart from the lefthand end, d the case where the piezoelectric transformer operating at the λ mode is supported at a point 1/4 spaced apart from the righthand end and e the case wherein the piezoelectric transformer operating at the λ mode is supported at two points respectively 1/4 spaced apart from opposite ends.

As can be clearly noted from FIG. 5, by supporting the piezoelectric transformers at points c, d and e the nodal points thereof the percentage of reduction of temperature $\delta T_o$ can be reduced by 15 percent and yet the decrease in the output voltage $\delta V_o$ is only 5 percent which means that by supporting the piezoelectric transformer at its nodal point or points it is not only possible to effectively dissipate the heat but also to decrease the reduction in the output voltage. It is considered that this is caused not only by the improved heat dissipation but also by the suppression of the undesirable vibrational modes which occur when the piezoelectric transformer is not supported at the nodal point, thus decreasing heat loss.

FIGS. 6 to 12 inclusive show another embodiments of this invention. The piezoelectric transformer has opposed notches 38 on the opposite sides of the nodal point as shown in FIG. 8.

The portion of the piezoelectric transformer 20 between these notches 38 is received in an opening 42 of a rectangular frame shaped resilient band 40 of insulating material such as rubber, shown in FIG. 7, and both sides of band 40 are received in guide slots 44 of a supporting member 43 as shown in FIG. 6. Instead of providing notches 38 on the opposite sides of the ceramic body 22 transverse grooves 46 may be formed on the upper and lower surfaces of the ceramic body at the nodal point as shown in FIG. 9. Further, as shown in FIG. 12, to operate the piezoelectric transformer 20 at the λ mode two pairs of opposing notches 48 and 50 may be formed on both sides of the ceramic body at the nodal points. In the embodiment shown in FIG. 10 a pair of projections or pins 52 are provided on both sides of the ceramic body 22 to project in the opposite direction and to be received in corresponding openings in resilient band 40. Further a pair of opposing pins 53 may be formed on the upper and lower surfaces of the ceramic body 22 for the same purpose as shown in FIG. 11. With these modified embodiments the resilient band 40 is positively secured at the nodal point of the piezoelectric transformer by the provision of grooves or pins.

The ceramic body formed with grooves 38, 46, 48 or 50 or pins 52 or 53 can also be supported by supporting devices shown in FIGS. 13 to 15.

In the example shown in FIG. 13, the piezoelectric transformer 20 is supported by a supporting device 54 provided at the nodal point and comprising a pair of rigid insulator strips 56 made of phenolic resin, epoxide resin, acrylic resin and the like and extending transversely along the upper and lower surfaces of the ceramic body 22, a pair of screws 58 extending through openings at the opposite ends of the rigid strips 56 and nuts 60 engaging screws 58. Thus, by clamping the supporting device 54 to the nodal point of the piezoelectric transformer 20 it is possible to suppress the vibration of the ceramic body 22 in the direction of thickness thereof to decrease heat loss due to such vibration. As shown in FIG. 14 it is also possible to clamp both sides of the ceramic body 22 with the supporting device 54 shown in FIG. 13 so as to suppress the vibration of the piezoelectric transformer in the direction of the width thereof. Further, as shown in FIG. 15, two supporting devices similar to that shown in FIG. 13 may be used at two nodal points of a piezoelectric transformer operating at the λ mode.

As can be clearly noted from the foregoing description use of one or two supporting devices is effective to suppress the vibration in the direction of thickness or width and to promote the vibration of the longitudinal direction of the piezoelectric transformer. Further this arrangement greatly decreases undesirable vibrations other than the natural vibration and permits the longitudinal vibration alone so that it is possible to present heating as well as noise which result in the loss of energy. The result of experiment shows that when the supporting device 54 is used, the shift in the resonance frequency of the piezoelectric transformer can be limited to only ±100 Hz and the quantity of heat can be reduced by about 30 percent when compared with a piezoelectric transformer not supported by the supporting device.

While the invention has been shown and described in terms of its preferred embodiments it will be clear that many changes and modifications may be made without departing from the true spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A piezoelectric power transformer comprising:

a ceramic body in the form of an elongated rectangular plate of piezoelectric material, one half of the length of said ceramic body being polarized in the direction of thickness of said ceramic body, the remaining half being polarized in the longitudinal direction,

a pair of constraint-free input electrodes substantially coextensive with and secured to the opposite sides of said one half of said ceramic body,

an output electrode secured to the end surface of said remaining half, and supporting means including only a constraining transverse linear mechanical support at least one of the transverse nodal lines of the longitudinal mechanical vibrational movement of said piezoelectric transformer, said transverse linear mechanical support applying transverse constraining forces to opposite surfaces of said ceramic body at said nodal lines sufficient to suppress undesirable transverse vibration modes without interfering with said longitudinal mechanical vibrational movement.
2. The transformer according to claim 1 in which said supporting means comprises at least one rigid insulator frame fitted about said piezoelectric transformer at said transverse nodal line and with minimal width in the direction of the longitudinal vibrational movement of said piezoelectric transformer, and means adjustably connecting opposite sides of said frame for applying said constraining forces.

3. The transformer according to claim 1 in which said supporting means comprises at least one insulative elastic band fitted about said ceramic body at said transverse nodal line of the longitudinal mechanical vibrational movement of said piezoelectric transformer and stationary means for mechanically supporting opposite sides of said elastic band.

4. Apparatus according to claim 3 wherein said ceramic body is formed with a pair of projections projecting from opposite surfaces thereof on said nodal line and said projections are received within said insulative elastic band extending transversely of said ceramic body.

5. Apparatus according to claim 2 in which said rigid frame comprises a pair of insulative rigid members extending transversely of said ceramic body at the nodal line of the longitudinal mechanical vibrational movement of said piezoelectric transformer and clamping screw means for clamping opposite ends of said pair of insulative rigid members.

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