United States Patent

Inoue

[15] **3,707,636**

[45] **Dec. 26, 1972**

[54] **HIGH VOLTAGE GENERATING APPARATUS UTILIZING PIEZOELECTRIC TRANSFORMERS**

[72] Inventor: **Keiji Inoue,** Yokohama, Japan

[73] Assignee: **Denki Onkyo Company Limited,** Tokyo, Japan

[22] Filed: **Sept. 23, 1970**

[21] Appl. No.: **74,808**

[30] **Foreign Application Priority Data**

Sept. 30, 1969 Japan .....44/92792 (utility model)

[52] **U.S. Cl.** **310/8.1,** 310/8.2, 310/9.8

[51] **Int. Cl.** **H01v 7/00**

[58] **Field of Search**.....310/8.1, 8.7, 8.3, 8.2, 9.5, 310/9.6, 9.7, 9.8

[56] **References Cited**

UNITED STATES PATENTS

1,863,345	6/1932	Nicolson	310/8.1 UX
2,975,354	3/1961	Rosen	310/8.1 X
2,271,200	1/1942	Mason	310/8.2 X
3,562,792	6/1968	Berlincourt et al.	310/9.8 X
3,516,645	6/1970	Arndt	310/8.1 X
3,487,237	12/1969	Kreuke	310/8.1

Primary Examiner—J. V. Truhe

Assistant Examiner—B. A. Reynolds

Attorney—Chittick, Pfund, Birch, Samuels & Gauthier

[57] **ABSTRACT**

In a high voltage generating apparatus, there are provided a plurality of piezoelectric transformers which are connected in parallel and a driving voltage of the same frequency as the natural frequency or its higher harmonic is applied across the parallel connected driving electrodes of the piezoelectric transformers to polarize them in the same direction relative to their residual polarization.

4 Claims, 4 Drawing Figures

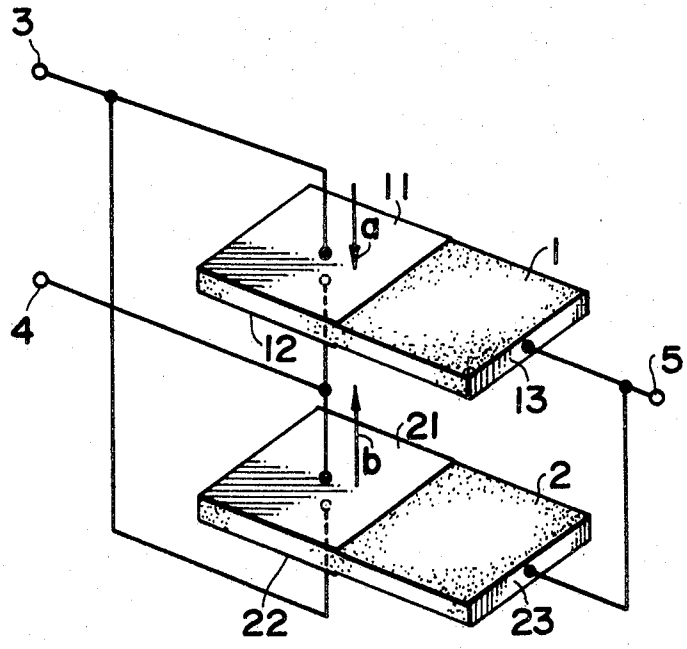


FIG. 1

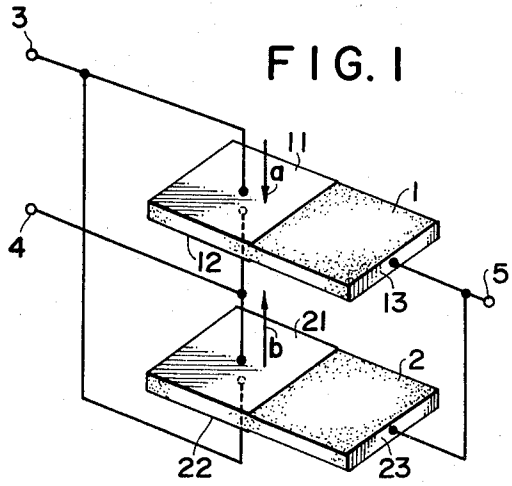


FIG. 3

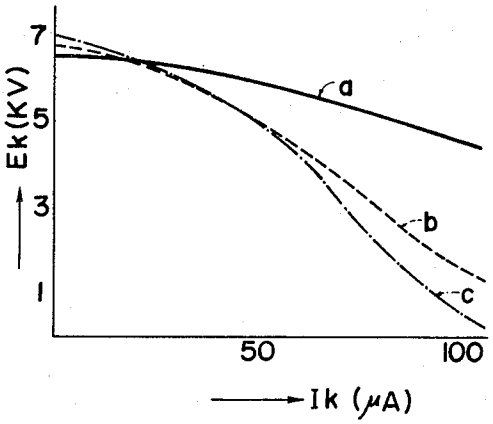


FIG. 4

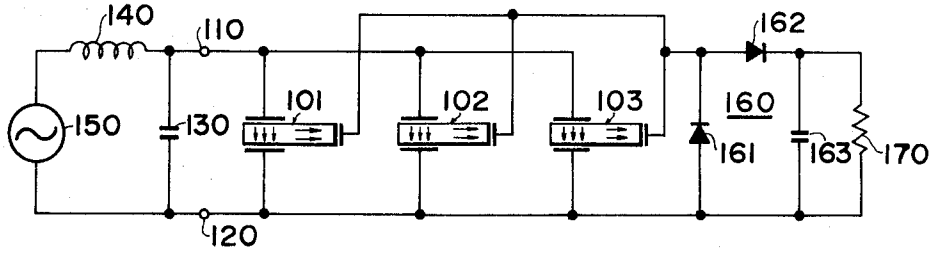
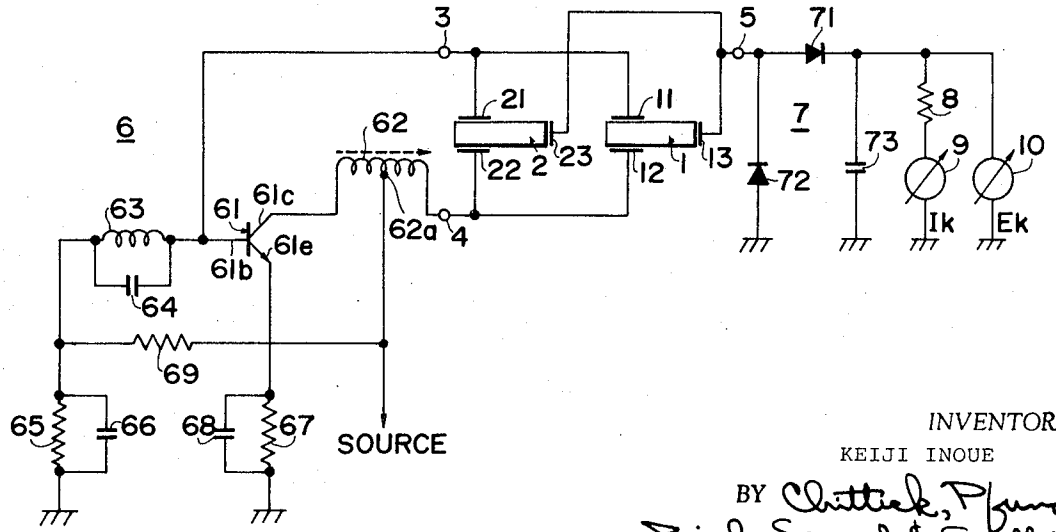


FIG. 2



INVENTOR.
KEIJI INOUE
BY Cushman, Darby & Cushman
Birch, Samuels & Gauthier

HIGH VOLTAGE GENERATING APPARATUS UTILIZING PIEZOELECTRIC TRANSFORMERS

BACKGROUND OF THE INVENTION

This invention relates to high voltage generating apparatus utilizing a piezoelectric transformer.

A piezoelectric transformer generally comprises a substrate of a fired ceramic of piezoelectric material, a pair of driving electrodes applied on the opposite surfaces of one end of the substrate, and an output electrode applied to the opposite end surface. Portions of the substrate between driving electrodes are polarized in the direction of thickness of the substrate while portions near the output electrode are polarized in the longitudinal direction. An AC driving voltage is impressed across the driving electrodes to cause the substrate to resonate or vibrate mechanically at its natural frequency whereby to derive a high voltage from the output electrode.

During operation, heat is generated in the substrate due to the polarization and the friction caused by the mechanical vibration and this heating has a tendency to shift or vary the natural frequency of the substrate to the higher side. For this reason, it is usual to decrease temperature rise and hence to prevent increase in the natural frequency either by decreasing the driving voltage or by increasing the length and thickness of the substrate so as to increase the output capacity of the piezoelectric transformer.

Due to unequal characteristics of piezoelectric transducers of the same design, it has been the practice to measure natural frequencies or resonance frequencies of respective elements and to prepare driving sources having frequencies equal to respective resonance frequencies or to adjust the frequencies of respective driving sources to be equal to the measured resonance frequencies.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide an improved high voltage generating apparatus utilizing a piezoelectric transducer having increased and stabilized output power with decreased heating.

According to this invention, a plurality of piezoelectric transformers which are polarized in the same direction are connected in parallel to decrease heating and increase output power.

According to this invention these and other objects can be accomplished by providing a plurality of piezoelectric transformers which are connected in parallel and are polarized in the same direction. This arrangement increases the output capacity and minimizes heating of the transducer element thus stabilizing the output thereof.

Further, a coil is connected in series with one terminal of the driving electrodes which are connected in parallel in a self-excitation type driving source so as to determine the frequency of the driving source by the capacitance between driving electrodes and the inductance of the coil, whereby it is possible to obtain driving sources which can be readily used for piezoelectric transformers of different characteristics.

A fixed driving source is utilized and a series resonance circuit is connected between the driving source and the plurality of parallel connected piezoelectric transformers. Again the piezoelectric transformers are disposed with their direction of polarization extended in the opposite directions, and the resonance frequencies of respective piezoelectric transformers are determined to coincide with the frequency of the driving source.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 shows a connection diagram of two parallel connected piezoelectric elements shown in a perspective view;

FIG. 2 shows a connection diagram of a self-excitation type high voltage generating apparatus embodying this invention;

FIG. 3 is a plot showing output voltage-current characteristic curves of the apparatus shown in FIG. 2 and of apparatus wherein two piezoelectric transducers are used independently and

FIG. 4 is a connection diagram of a modified embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. 1 which shows the basic principle of the invention, a pair of piezoelectric transformers 1 and 2 having substantially the same resonance frequencies are electrically connected in parallel with their driving portions polarized in the same direction relative to the electric driving voltage. More particularly, the piezoelectric transformer 1 is polarized in the direction from one driving electrode 11 to the other 12 as shown by arrow *a* while the other piezoelectric transformer 2 in the direction from one driving electrode 22 to the other 21 as shown by arrow *b*. Driving electrodes 12 and 21 are connected to one driving terminal 4 while remaining driving electrodes 11 and 22 are connected to another common driving terminal 3. Thus each piezoelectric transformer has the same polarization relative to the energization applied. Output electrodes 13 and 23 of piezoelectric transformers 1 and 2 are connected to a common output terminal 5.

With this arrangement, it is possible to increase the overall output capacity of the piezoelectric transformers. Since two piezoelectric transformers have substantially the same resonance frequencies and since the directions of their polarization are in such direction as to produce the outputs in the same direction, it is possible to increase the output voltage by about 20 percent with the same resonance frequency. Moreover, it is possible to decrease the driving voltage as well as the driving current. This decreases heating of the piezoelectric transformers and hence decreases shift in the resonance frequency.

When the directions of polarization of respective piezoelectric transformers are made opposite to those shown in FIG. 1, then the output voltage of the piezoelectric transformers will be decreased by approximately 50 percent. It is pressumed that this is caused by the fact that stresses created by mechanical vibrations at the driving portions of respective piezoelectric transformers and acting to produce outputs which are dephased by 180° so that one of the piezoelectric transformers undergoing a small vibration acts as a dummy element. In other words, when an electric field is applied across the driving electrodes of a piezoelectric

transformer with its driving portion polarized in the same direction as the applied field, a stress is created in the same direction as the polarization whereas upon application of a field in the opposite direction the direction of the stress will be reversed. Theoretically, when two piezoelectric transformers having the same characteristics are connected in parallel, with the directions of polarization the same as shown in FIG. 1, a double output voltage will be obtained for a given input power, but when the directions of the polarization are opposite each other, the output will be zero with the same input power.

FIG. 2 shows one example of a self-excitation type high voltage generating apparatus embodying this invention. As shown, a driving source, generally designated by a reference numeral 6, for the piezoelectric transformers 1 and 2 comprises a NPN-type transistor 61, the collector electrode 61*c* thereof being connected to the driving terminal 4 through a high frequency transformer (coil) 62 having an intermediate tap 62*a*. The base electrode 61 of the transistor is connected directly to the other driving terminal 3. The base electrode 61 is also connected to a parallel circuit comprised by a coil 63 and a capacitor 64 and the opposite terminal of the parallel circuit is grounded through a parallel circuit of a resistor 65 and a capacitor 66. The emitter electrode 61*e* of transistor 61 is grounded through a parallel circuit of a resistor 67 and a capacitor 68. One terminal of a bias resistor 69 for determining the oscillating point of the transistor 61 is connected to the juncture between two parallel circuits 63, 64 and 65, 66. A source not shown for energizing the driving source 6 is connected to the juncture between the other terminal of the bias resistor 69 and the intermediate point 62*a* of the coil 62.

In operation, the series resonance circuit comprised by the capacitances between the driving electrodes 11, 12 and 21, 22 and the coil 62 resonates to the natural frequency of the piezoelectric transformers or to a higher harmonic of the natural frequency to apply an AC voltage across the driving electrodes 11, 12 and 21, 22, whereby the respective piezoelectric transformers begin to vibrate. The high voltage AC signal produced at the output electrodes 13 and 23 is supplied to a voltage step-up rectifier circuit 7 comprised by diodes 71 and 72 and a capacitor 73 and is then supplied to a load.

The output voltage (E*k*) — output current (I*k*) characteristic of the circuit shown in FIG. 2 is shown by a curve *a* in FIG. 3. Curve *a* was obtained by means of serially connected load resistor 8 and an ammeter 9, and a voltmeter 10 connected to the output side of the rectifier circuit 7. Curves *b* and *c* show voltage-current characteristic curves of the prior art circuits wherein piezoelectric transducers 1 and 2 are used independently. As can be seen from FIG. 3, with the prior art connection utilizing only one piezoelectric transformer the output voltage E*k* decreases rapidly as the load current increases whereas according to this invention decrease in the output voltage E*k* as the load current increases can be greatly alleviated. It is to be understood that the driving voltage is of course maintained at a constant level. It is believed that these phenomena are caused by the decrease in the internal resistance of the piezoelectric transformers because they use substrates of ceramic piezoelectric material. More particularly, when a plurality of piezoelectric transformers are connected in parallel according to the principle of this invention, the extent of the decrease in the internal resistance is decreased relatively whereby the drop in the output voltage can be precluded. Increase in the bandwidth of the output voltage is also believed to be one of the factors.

It should be understood that more than two piezoelectric transformers may be connected in parallel, if desired.

In a modified embodiment shown in FIG. 4 three piezoelectric transformers 101, 102 and 103 polarized in the same direction are connected in parallel. More particularly, the upper driving electrodes of these piezoelectric transformers are connected to a common terminal 110 while the lower driving electrodes to a common terminal 120. A capacitor 130 is connected across terminals 110 and 120. A coil 140 is connected to terminal 110 to form a series resonance circuit together with capacitor 130 having a resonance frequency equal to the natural frequency of the piezoelectric transformers 101, 102 and 103 or a higher harmonic of the natural frequency. A driving source 150 is connected between the other end of coil 140 and terminal 120. The frequency of driving source 150 is also equal to the natural frequency of the piezoelectric transformers or a higher harmonic of the natural frequency.

In operation, in response to the output from the driving source 150, the series resonance circuit resonates at the natural frequency (or a higher harmonic thereof) of the piezoelectric transformers 101, 102 and 103 to apply its output signal across driving electrodes of respective piezoelectric transformers. Thus, these piezoelectric transformers start to vibrate. Outputs of the piezoelectric transformers are supplied to load 170 via the voltage stepup rectifier circuit 160.

In this embodiment, too, the number of piezoelectric transformers is not limited to three but may be two or four.

It is to be understood that the invention is not limited to the illustrated embodiments and 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 high voltage generating apparatus comprising a plurality of piezoelectric transformers; each of said transformers including a substrate of piezoelectric material, a pair of driving electrodes applied on the opposite surfaces adjacent a first end of said substrate and an output electrode on the opposite end of said substrate; each of said piezoelectric substrates being residually polarized in a transverse direction extending between its associated pair of driving electrodes at its first end and in the same relative longituding direction extending from said first end to said opposite end; means for energizing in parallel said driving electrodes of respective piezoelectric transformers to polarize them in the same direction relative to their residual polarization; and means to connect in parallel the output electrodes of said plurality of piezoelectric transformers to a load to lessen decrease in the output voltage of said transformers as current through said load increases.

2. The high voltage generating apparatus according to claim 1 which further comprises a series resonance circuit comprised by a coil and the capacitance between said driving electrodes, said resonance circuit resonating to the natural frequency of said piezoelectric transformers.

3. The high voltage generating apparatus according to claim 2 including oscillator circuit means comprising said series resonance circuit, a transistor coupled to said coil, means biasing said transistor, a tank circuit tuned to said resonance frequency and connected to said transistor, said oscillator circuit means providing self-excited oscillations to drive said piezoelectric transformers.

4. The high voltage generating apparatus according to claim 1 wherein a series resonance circuit is connected between said energizing means and said driving electrodes.

* * * * *