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CYCLICLY OPERATING PIEZOELECTRIC VOLTAGE SOURCE

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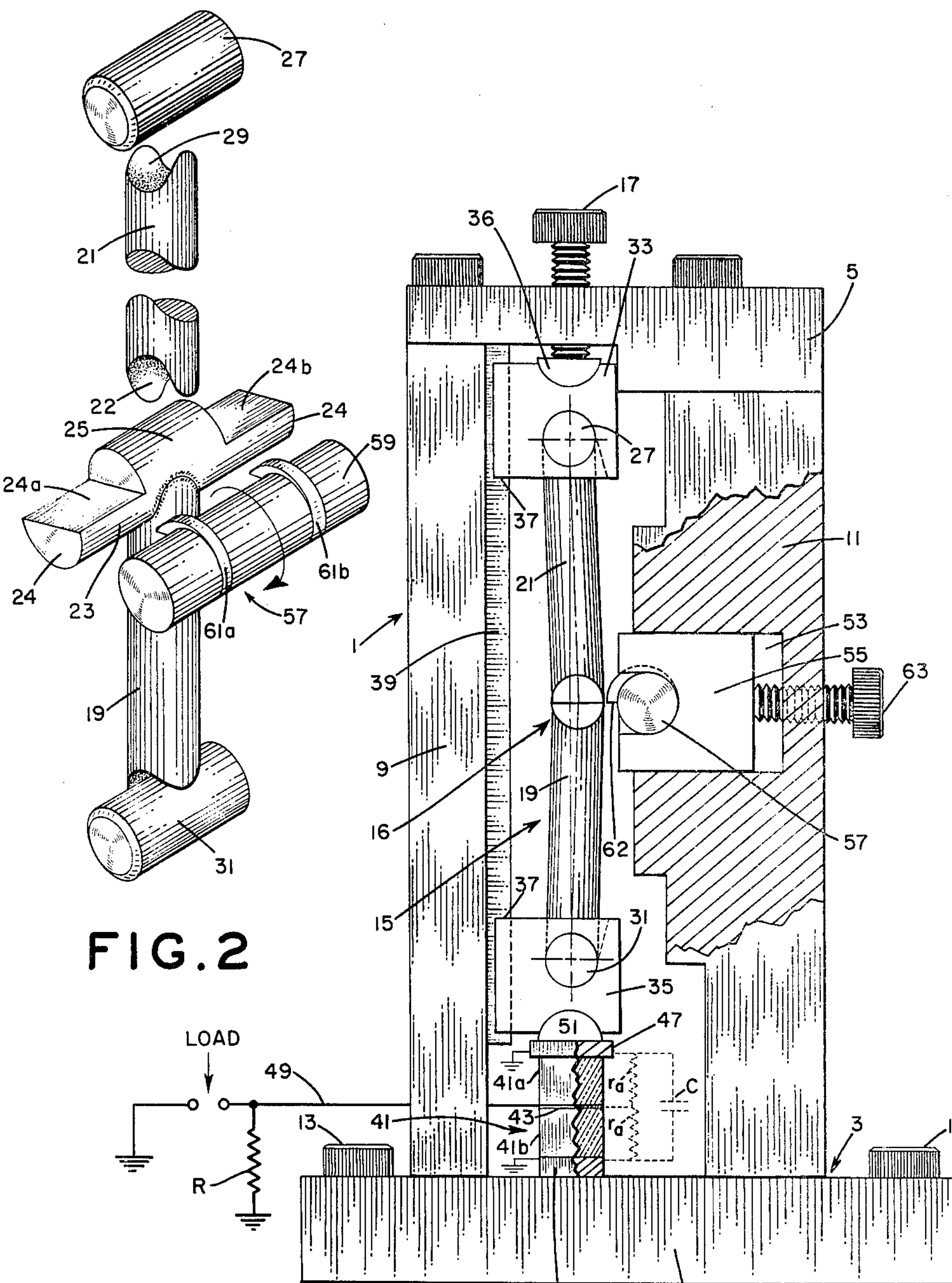

FIG. 2

FIG. 1

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CYCLICLY OPERATING PIEZOELECTRIC VOLTAGE SOURCE

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This invention relates to piezoelectric devices and, more particularly, concerns a piezoelectric voltage source in which a piezoelectrically responsive element is slowly compressed and the compressive stress is suddenly released to generate an electric potential.

The term time constant as used herein denotes the time required to charge a capacitor to 63 percent of maximum voltage or to discharge it to 37 percent of its final voltage. In other words, a time constant in a circuit consisting of a capacitor and a resistor connected in series equals the capacitance of the capacitor multiplied by the series resistance, $T=RC$.

The prior art comprises, basically, two categories of piezoelectric voltage generators. In piezoelectric voltage generators of the first category an electric potential is generated by hammering a piezoelectrically responsive element. The impact on the element occurs during a period of time which is shorter than the time constant of the circuit. Hammering, also referred to as impact loading, produces, simultaneously, two separate vibrations in the piezoelectric element: one is a compressive sound wave which travels back and forth between the ends of the piezoelectric element and which does not deposit a charge on the electrodes; the second is a lengthwise vibration which causes the piezoelectric element to alternately shorten and lengthen very rapidly, each change in lengths representing a change in stress and producing a charge on the electrodes, the charge being of opposite polarity from the one immediately preceding. When the piezoelectric generator is part of a circuit that includes a spark gap, each spark of sufficient voltage sparks the gap producing a series of sparks of alternating polarity which appear in rapid sequence giving the appearance of a single spark to the unassisted eye. The sparking across the gap continues until sufficient energy has been dissipated so that not enough voltage is generated to spark the gap. A device of this type is shown and described in J. R. Harkness' U.S. Patent Nos. 2,649,488, 2,717,589, and 2,717,916; also British Patent No. 712,803, issued to McCullough Motors Corporation.

The disadvantages of hammering or impact loading are of a mechanical as well as an electrical nature. More particularly, impact loading of the piezoelectric element causes a noise to be generated which is highly objectionable and which just about destroys any usefulness of the device. Since the piezoelectric voltage source is desirable for use in an internal combustion engine ignition system, numerous attempts have been made in the past to overcome this noise problem by introducing various shock absorbing components, for instance see J. R. Harkness' U.S. Patent No. 2,871,280. However, no generally acceptable solution has been found to this date.

Another feature which limits the applicability of the devices of the first category is the chemical composition of the piezoelectric elements commonly in use today; an example is barium titanate. Such material does not provide a high tensile strength body; the ceramic element may be considered as being quite similar to glass in that it is highly fragile except in compression. Hence, the utility of an impact actuated piezoelectric ceramic element is not conducive to long life.

Hammering or impact has another very distinct disadvantage. The voltage generated by impacting the piezoelectrically responsive element is much lower than the voltage that can be generated by actuating the device in accordance with this invention under like conditions.

Above, it has been noted that impact loading causes a propagation of a pressure wave in the piezoelectric element. The element is, therefore, not instantaneously uniformly stressed and, accordingly, the voltage and/or current generated is less than the maximum voltage and/or current of which the element is capable. This is partly due to the fact that the voltage generated by a hammer blow upon the piezoelectric element results purely from the piezoelectric phenomenon; this type of impact precludes an action of reversible ferroelectric domain switching nature which otherwise might add greatly to the voltage and/or curent that can be generated by the element.

The second category of piezoelectric voltage source devices may be classed as those in which the piezoelectrically responsive element is statically loaded, i.e., the element is gradually squeezed and then the stress is gradually released, see Hufferd et al. U.S. Patent No. 3,009,975 assigned to the same assignee as the instant invention. The load which is applied to the piezoelectric element produces a single contraction and a single expansion of the element; the load is applied slow enough and is controlled at all times so that no vibration occurs in the piezoelectric element.

In devices of the latter category the objective is to build up a charge slowly and to hold the charge for a certain period of time and then release the same suddenly through a switch, usually at the time of maximum voltage. The circuit must be well insulated to prevent leakage during the charging period. The time during which the compressive stress is applied must be shorter than the period of time of the time constant for the circuit, otherwise the charge will bleed off before ever reaching the maximum voltage capability of the device. This also applies to the release of the compressive stress, the stress must be relieved during a period of time which is shorter than the time constant. This system generates an electric potential of one polarity during squeezing and another electric potential of opposite polarity when the compression is relieved.

Again, the interposition of a switch to hold the voltage is required to electrically disconnect the piezoelectric element from the spark gap (e.g., spark plug) while a compressive stress is applied to the element and then to connect the spark gap to the piezoelectric element at the time of maximum voltage. Without the switch the voltage is dissipated across the spark gap during the relatively long period of time when the piezoelectric element is compressed.

The principle of the present invention is to load the piezoelectric element relatively slowly and take advantage of the time constant of the circuit to bleed off the compression charge during a period of time which is longer than the time constant of the circuit and then suddenly release the load during a period of time which is substantially below the period of time of the time constant, and depend on the charge being built up quickly enough to obtain accurate timing. This enables a direct electric connection between the piezoelectric element and a spark gap (e.g., spark plug) without any intervening switching mechanism for holding the voltage. The gradual squeeze causes a single contraction of the piezoelectric element and the sudden release causes a single expansion of the piezoelectric element which is, however, not accompanied by vibration to any objectionable degree, and moreover includes a cumulative effect of the reversible ferroelectric domain switching action.

The marked advantages of this invention over the prior art as discussed above are manifested as follows:

(1) The stress on the piezoelectric element produced by gradual squeezing and sudden drop off is about one-half of the stress produced by hammering under similar conditions. Piezoelectric ceramics commonly used for devices of this type are inherently fragile and are not able to withstand high impact load.

(2) No objectionable noise is generated.

(3) Obviates the need for a switch to hold the voltage, i.e., to connect and disconnect the piezoelectric element generator and the "load" at point of maximum voltage (over gradual squeeze and gradual release).

(4) Greater voltage is generated by:

(a) Utilization of reversible ferroelectric domain switching action (over hammering).
(b) Generating the voltage over a period of time which reduces or prevents voltage dissipationi.
(c) Increased efficiency of the system: compactness of device, reduction of energy losses, etc.

(5) No vibration occurs in the piezoelectric element during application and release of load (over hammering).

The present invention is based on and derived from the recognition that the piezoelectric element must be loaded during a period of time which is long enough to permit the charge to be dissipated through an external resistor, or an internal resistor normal to a piezoelectric ceramic, the period of time during which the ceramic is compressed must substantially equal or preferably be greater than the time constant of the circuit. The release of the compressive stress on the piezoelectric element must occur during a comparatively shorter period; this period may not exceed the time constant of the circuit, and preferably be considerably less than the time constant.

These conditions must occur so that the charge produced by the application of the compressive stress is discharged to a very substantial degree; any residual charge cancels out with the charge generated by the sudden drop off which is of opposite polarity. Thus, if the time during which the piezoelectric element is compressed equals the time constant, 63 percent of the voltage is dissipated and 37 percent will cancel out with the potential of opposite polarity. Conversely, the release of the compressive stress must occur at a rapid rate, during a period of time less than the time constant to prevent dissipation of a significant portion of the charge.

It is therefore the primary object of this invention to provide an improved piezoelectric voltage generator which avoids the shortcomings of the devices of prior art as pointed out in the preceding paragraphs.

It is a further object of this invention to provide a device for slowly squeezing a piezoelectrically responsive element and for suddenly releasing the squeeze on the element.

It is a further object of this invention to provide a piezoelectric voltage source which is adapted to be employed in an internal combustion engine ignition system, and which vitiates the need for the interposition of a switching device to hold the voltage in a circuit between the voltage source and a spark gap, such as an engine spark plug.

It is a further object of this invention to provide a piezoelectric voltage source which is constructed to facilitate control and variability of the voltage output.

A further object of this invention is to provide a voltage source having attributes of extreme operating flexibility and in which a controllable force is employed to generate a voltage.

A further object of this invention resides in the provision of a piezoelectric voltage source including a toggle action mechanism to actuate a crystal or ceramic element for piezoelectric response and to enable variation in the voltage output of the device.

An aspect of the present invention resides in the provision of a cyclicly operating piezoelectric voltage generator comprising a piezoelectric element means, means for mounting the piezoelectric element means, and means for cyclicly stressing the piezoelectric element over a relatively long period of time and then to relieve the stress over a comparatively short period of time to generate an electric potential.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings:

FIGURE 1 is a view of the device in elevation, partly fragmentary, and with a front plate removed; and

FIGURE 2 is a perspective view, partly exploded, of components shown in FIGURE 1.

Referring now to the drawing, the invention is embodied in a piezoelectric voltage source **1** which comprises a housing **3**, constructed in multiple sections and including a top plate **5**, a bottom plate **7** and vertical plates **9** and **11**. The bottom plate **7** is provided with bolts **13** extending therethrough to mount the device **1** to a support not shown.

Compressed between the top plate **5** and the bottom plate **7** of the housing **3** is an assembly **15** comprised of, generally, longitudinally extending bodies the aggregate longitudinal length of which is greater than the distance between the top plate **5** and bottom plate **7**. The top and bottom plates constitute an abutment, or support for an abutment, and moreover the plates serve to restrain the assembly **15** against translational displacement.

The assembly **15** comprises a toggle action mechanism **16** which includes a first and a second compression rod **19**, **21**, formed of noncompressible material. The rods are substantially elongated and are disposed in the housing **3** in an end-to-end relationship in such a manner that their respective longitudinal axes define an obtuse angle with respect to each other. Interposed between compression rods **19** and **21** is a cam follower **23** formed of an elongated cylinder and welded to compression rod **19**. The cam follower **23** has outer ends **24** which are semi-cylindrically shaped. An intermediate portion **25** of the cam follower **23** provides a circular bearing surface which is in sliding engagement with one end of rod **21**. The rod **21** has a curvature at its outer end **22** suitably formed, see FIGURE 2, to bear against surface **25**.

A cylindrical pivot pin **27** provides bearing support for the slidable end portion **29** of rod **21**. Another pin **31** constructed in the same manner as pin **27**, is in sliding engagement with rod **19**. The pins **27** and **31** are securely mounted in identical pivot pin blocks **33** respectively **35**. The block **33** is a partly hollow body adapted to receive rod **21**, the block **35** is similarly provided with a bore to suitably receive the rod **19**. A longitudinally extending U shaped groove **37** is provided in both pin blocks **33**, **35**; the grooves fit into a longitudinally extending guide tongue **39**, which is integral with the plate **9** of housing **3**. The guide tongue and groove arrangements prevent lateral or side movement of blocks **33**, **35**.

The pin block **33** has a semispherical aperture which receives therein a semispherical adjustment member **36**. An adjustment screw **17** extends through plate **5** and engages the semispherical member **36** to prevent longitudinal or upward movement of block **33**. The screw **17** permits pre-loading of the assembly, wear adjustment and symmetrical alignment of the assembly **15** as will hereafter become apparent.

Referring now to the opposite end of the assembly **15**, there is disposed between the block **35** and bottom plate **7** a piezoelectrically responsive element **41** comprised of two separate cylindrical elements, **41*a*** and **41*b***, mounted in end-to-end relationship. The piezoelectric elements are composed either of crystal elements or piezoelectrically responsive ceramics. Preferably, the elements are comprised of poly-crystalline ceramic material such as barium titanate, lead titanate, zirconate or the like.

The elements **41***a* and **41***b* are suitably polarized, to be piezoelectrically responsive in compression, electroded and electrically grounded. The two elements **41***a* and **41***b* are shown mechanically in series and electrically parallel. An electric circuit adjacent to the element is shown in the drawing to indicate that the elements have a certain internal resistance r_a+r_b and capacitance *c*. The total resistivity and capacitance of the complete circuit determines the time constant of the circuit which must be of a predetermined period. Preferably, the ceramic element has a chemical composition suitable to provide low internal resistivity; alternatively, an external resistor may be utilized within the circuit where the resistivity of the ceramic element is too high. For instance see R. In the latter case the elements **41***a* and **41***b* may be heavily insulated.

The disc **45** is interposed between element **41***b* and bottom plate **7**, while disc **47** is disposed between element **41***a* and a semispherical disc **51** secured in block **35** and serving for the identical purpose as member **36**. A terminal **49** is shown connected to the disc **43** to transmit an electric potential to a "load" shown in the form of a suitably grounded spark gap.

The vertical plate **11** has an opening **53** to slidably support a movable support structure **55**. The structure **55** is apertured to rotatably carry and support an actuator cam **57** which is operatively associated with the toggle action mechanism **16** of assembly **15**. The actuator cam **57** is comprised of, see FIGURE 2, an elongated cylinder **59** upon which are superimposed two cam surfaces **61***a*, **61***b*. The distance between the cam surfaces **61***a* and **61***b* is slightly greater than the length of the circular surface **25** of cam follower **23**.

An adjusting screw **63** protrudes through side plate **11**; the adjusting screw is in engagement with the movable support member **55** and serves to adjust the position of the movable support member in the opening **53** of the vertical plate **11**. The screw **63** can be used to change the force that can be applied against elements **41***a* and **41***b* by enabling an increase or decrease in the obtuse angle between rods **19** and **21** to suit operating conditions.

The actuator cam **57** is connected to a manually or mechanically operated drive (not shown) for rotating the actuator cam in clockwise direction.

To operate the device **1**, the actuator cam **57** and more particularly the cylindrical portion thereof is placed against the cam follower **23** after the proper angular relationship between rods **19** and **21** has been determined.

The actuator cam is rotated in accordance with a predetermined cycle. The cam surfaces **61***a* and **61***b* move the cam follower **23** laterally which is effective to widen the obtuse angle between rods **19** and **21** and to straighten the substantially longitudinally extending assembly **15**. At the same time the resistance of the angularly disposed rods to such straightening introduces a force at the cam follower resisting this movement.

The actuator cam **57** and more particularly the rise of the cam surfaces **61***a* and **61***b* are suitably constructed to move the cam follower to a predetermined position when the resisting force at the cam follower is of a predetermined value; the increase in the distance between the axial center of cam follower **23** and the axial center of actuator cam **57** is equivalent to the rise of the cam surfaces.

The displacement of the cam follower **23** over a predetermined period of time causes the rods to straighten relative to one another, as described in the preceding paragraphs, and to compress the piezoelectric elements **41***a*, **41***b* generating a charge or electric potential of one polarity. This period of time (which is relatively long) during which the piezoelectric elements are compressed must be greater than the time constant for the electric circuit so that a sufficient quantity of electrical energy that is generated by the compression of the piezoelectric elements is dissipated through the resistor of the circuit. It is also possible and in some instances advantageous to bleed the potential generated by the application of compressive stress on the element slowly across a suitable gap, e.g., a spark plug, in the circuit. However, for applications where combustible gases are in close proximity with the spark gap dissipating the charge across the gap has obvious drawbacks.

Upon juxtaposition of drop off portion **62** of cam surface **61***a* and **61***b* with flat surface **24***a* and **24***b* of outer ends **24** on the cam follower **23**, the force acting against the cam follower suddenly ceases to support the follower **23** and the cam follower returns immediately to its relaxed position where again the cam begins to operate to move the follower in the predetermined travel. FIGURE 1 shows the position of the cam drop off portion **62** just at the point of release. The sudden release of the compressive stress on the piezoelectric elements causes a potential of opposite polarity to be generated which is transmitted through terminal **49** to be used at the point of "load" as required. In order to obtain an accurate and repeatedly uniform potential it is necessary that the drop off, or release of the compressive stress occurs during a period of time which is less than the time constant of the circuit. Where the "load" is constituted by a spark gap the charge generated by the release of the stress must be of a sufficient energy level to ionize the gap and spark across it.

In summary then, the arrangement is effective for cyclicly stressing the piezoelectric elements **41***a* and **41***b* over a period of time and then to relieve the stress over a comparatively short period of time to generate a voltage.

Furthermore, the ratio of the force available for compression on the piezoelectric elements to the force applied on the cam follower **23** depends largely on the relative position of the compression rods **19** and **21**. The ratio becomes greater as the obtuse angle between the compression rods increases, with a theoretical limit of infinity being available when the compression rods **19** and **21** are completely coaxially aligned. Thus, by suitably varying the obtuse angle, any desired force ratio may be obtained; the actual force on the piezoelectric element being fixed by the applied force at the cam follower.

While there have been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. A cyclicly operating piezoelectric generator comprising, in combination: piezoelectric element means; means for mounting said piezoelectric element means; means for cyclicly stressing said piezoelectric element means over a relatively long period of time and then to relieve the stress over a comparatively short period of time to generate an electric potential.

2. A device according to claim **1**, wherein said means for cyclicly stressing said piezoelectric element means and to relieve the stress is constituted by a toggle action actuating means.

3. A cyclicly operating piezoelectric generator unit comprising, in combination: piezoelectric element means; means for mounting said piezoelectric means; means for cyclicly stressing said piezoelectric element means over a relatively long period of time to dissipate a substantial part of the piezoelectric charge generated by said stressing, then to relieve the stress over a period of time which is short compared to the aforesaid period of time and adapted to generate an electric potential; and means to effect said dissipation.

4. A device according to claim 3, wherein the means to effect dissipation of said charge is constituted by the internal resistivity of said piezoelectric element means.

5. A cyclicly operating piezoelectric generator unit interposed in an electric circuit having a time constant, comprising, in combination: piezoelectric element means constituting a capacitor in said electric circuit; means for mounting said piezoelectric means; means for cyclicly stressing said piezoelectric element means over a period of time at least equal to the time of said time constant to dissipate a substantial portion of the electric charge produced by said stress, and then to suddenly relieve said stress over a period of time less than said time constant; and means within said circuit to effect said dissipation.

6. A device according to claim 5, and a load gap connected in series with said circuit constituting said last named means effective to dissipate at least part of the charge when the said element means is stressed; and the charge generated by the release of said stress being sufficient to ionize the gap and spark across it.

7. A device according to claim 5, wherein the resistance of the time constant is constituted by a separate external resistor within the circuit.

8. A device according to claim 5, wherein the resistance of the time constant is constituted at least partly by the internal resistivity of said piezoelectric element means.

9. A device according to claim 5, wherein the means for cyclicly stressing said piezoelectric element means and then to suddenly relieve said stress is constituted by a toggle action actuating means.

10. A device according to claim 7, and a load gap connected in series with said circuit, and the charge being generated by the release of said stress being sufficient to ionize the gap and spark across it.

11. A device according to claim 9, wherein said toggle action actuating means includes a drop off cam.

12. A toggle action piezoelectric voltage source comprising, in combination: an assembly comprising a plurality of longitudinally extending bodies at least one of which is piezoelectrically responsive in compression, at least two of said bodies having respective longitudinal axes defining an obtuse angle with respect to each other; first and second fixed abutment means spaced at a given distance less than the aggregate longitudinal length of said bodies; said assembly of bodies being disposed between said abutment means substantially in end-to-end relationship, each of the outer ends of said assembly being secured to one of said abutment means against translational displacement; and means for applying a lateral force to said assembly to increase said obtuse angle whereby said piezoelectrically responsive body is compressed to generate a voltage.

13. A toggle action piezoelectric voltage source comprising, in combination: an assembly comprising a plurality of longitudinally extending bodies, including a first body piezoelectrically responsive in compression, a second and a third body formed of non-compressible material and having respective longitudinal axes defining an obtuse angle with respect to each other, all of said bodies being disposed in operative substantially end-to-end relationship; housing means having first and second abutment means spaced at a given distance less than the aggregate longitudinal length of said bodies; said bodies being disposed between said first and second abutment means substantially in end-to-end relationship and against translational displacement; and means for applying a lateral force to said assembly to increase the obtuse angle between said second and third body whereby said first body is compressed to generate a voltage.

14. A toggle action piezoelectric voltage source according to claim 13, and radial bearing means between said second and third body.

15. A toggle action piezoelectric voltage source according to claim 13, and pivot means between said second body and said first abutment means, and another pivot means between said third body and said second abutment means.

16. A toggle action piezoelectric voltage source comprising, in combination: an assembly comprising longitudinally extending first body means piezoelectrically responsive in compression, and second body means formed of non-compressible material, said body means being disposed in end-to-end relationship; housing means, including first and second abutment means spaced at a given distance less than the aggregate longitudinal length of said first and second body, the bodies being disposed between said first and second abutment means and one of said body means being pivotably mounted between the other body means and the abutment means adjacent to the said other body means; and actuating means in said housing operatively associated with said first and second body means for applying a lateral force to said assembly to increase the longitudinal length of said bodies whereby said first body means is compressed to generate a voltage.

17. A toggle action piezoelectric voltage source according to claim 16, wherein said actuating means comprises rotatably disposed cam means operably engaging at least one of said bodies.

18. A piezoelectric voltage generator constituting part of an electric circuit having a time constant comprising, in combination: housing means including an abutment rigid against displacement; piezoelectric element means within said housing means piezoelectrically responsive in compression, one end of said element means being disposed in fixed relation to said abutment; force applying and releasing means operably arranged in bearing relation to said element means and effective to apply force to the other end of said element means to compress said element and store therein a predetermined amount of potential energy; means for bleeding off the piezoelectric charge generated by the compressive force; and means operatively associated with said force applying and releasing means for releasing the mechanical potential energy from zero velocity and at a rate determined solely by the inertia of the force applying and releasing means, the total time of release being less than the time constant of the circuit in which the piezoelectric element is placed, to generate an electric potential in said element means.

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