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HYDRAULICALLY ACTUATED PIEZOELECTRIC VOLTAGE GENERATOR

Filed April 1, 1964

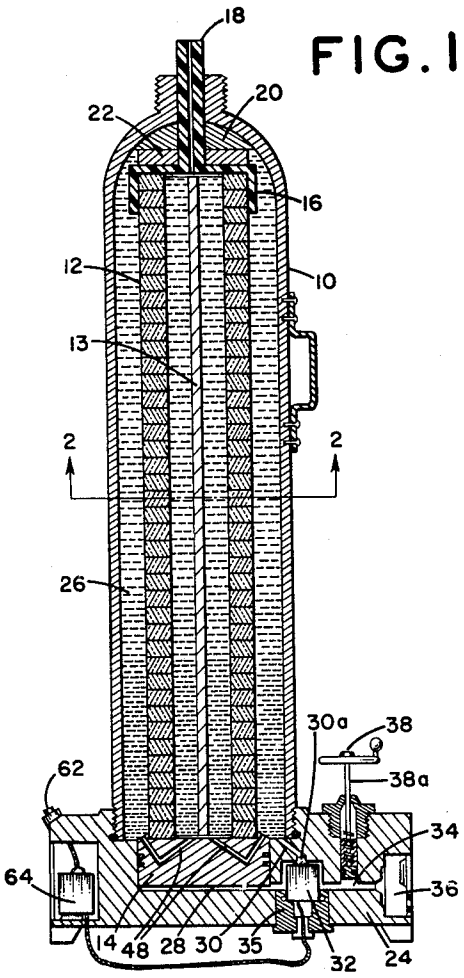


FIG. 1

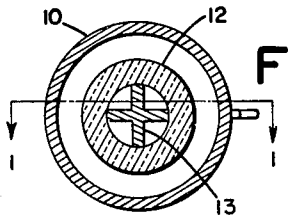


FIG. 2

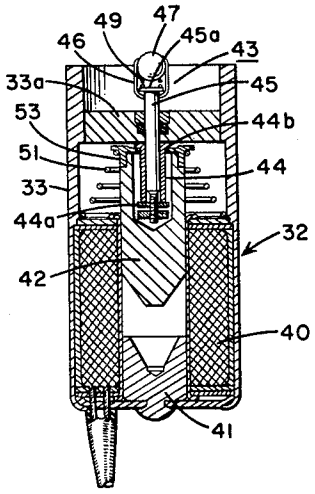


FIG. 3

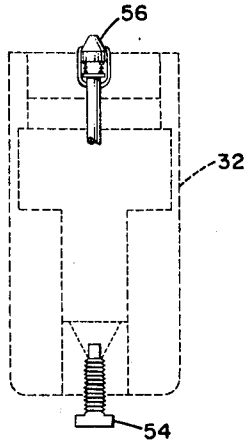


FIG. 4

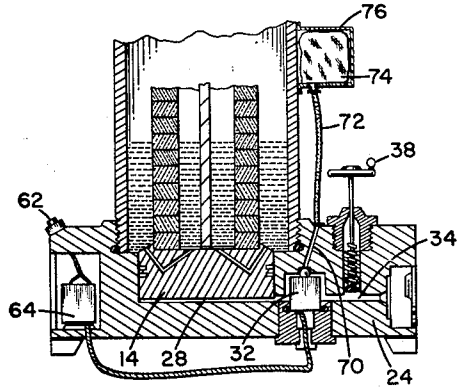


FIG. 5

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HYDRAULICALLY ACTUATED PIEZOELECTRIC VOLTAGE GENERATOR

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15 Claims. (Cl. 310—8.7)

This invention relates generally to a voltage generator and, more particularly, to a hydraulicallly actuated piezoelectric voltage source. This application is a continuation-in-part of co-pending application Serial No. 207,298, filed July 3, 1962, and assigned to the same assignee as the instant application.

The invention is concerned with a piezoelectric voltage generator adapted to be employed to generate relatively high voltages, the term "high" denoting a range of 80,000 to several million volts. However, while the unique structure illustrated is particularly useful to generate high voltages, the invention may, nevertheless, be utilized to generate voltages very substantially below the magnitude indicated above.

The invention is established by a unique hydraulically actuated piezoelectric system by means of which such high voltages are obtained. The invention also enables the construction of a device exhibiting a great degree of flexibility with respect to the voltage output wave form. It is now recognized that the wave form produced by mechanical actuation of the piezoelectric element will vary with the rate of stress application. Thus, if a piezoelectric element is gradually stressed, and this stress is released over a period of time substantially equal to the period of time of stress application, a sinusoidal wave form will be established. On the other hand, when the stress is gradually applied and, thereafter, suddenly released, the characteristics of the wave form will differ materially. This invention permits a very substantial variation in the wave form.

This flexibility to vary the high voltage wave form is of considerable import in a number of fields of technology. For example, in the X-ray field it is desirable to be able to vary the voltage wave form so as to obtain certain qualities that are essential for producing X-ray penetration or contrast. For a further discussion of this subject see our co-pending application Serial No. 191,054, disclosing in part similar subject matter, filed April 30, 1962, and assigned to the same assignee as the instant invention.

Another example of the applicability of this invention is in the internal combustion engine field. When a piezoelectric element is squeezed periodically at a constant rate, it is known that, due to the time factor involved, the output is not always quite uniform. This has led to the use of a switching device between the piezoelectric generator and the spark plug. To obviate the need for a switch and to establish greater accuracy in timing, it has been proposed to gradually squeeze the piezoelectric element and then to suddenly release the stress application at a rate which is less than the time constant for the particular circuit. For a further discussion see co-pending applications Serial No. 150,808, filed November 7, 1961, and Serial No. 231,891, filed October 22, 1962, and assigned to the same assignee as the instant invention. The instant invention is also capable of performing this function.

It is the primary object of this invention to provide a piezoelectric device adapted to be employed to generate a voltage output ranging from at least eighty to several thousand kilovolts.

It is another object of this invention to provide a device having a great degree of flexibility to vary the voltage output wave form.

It is still another object of this invention to provide a device utilizing a hydraulic circuit to accomplish the foregoing.

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 drawing, and its scope will be pointed out in the appended claims.

In the drawing:

FIGURE 1 is a longitudinal cross sectional view of this invention taken along line **1—1** of FIGURE 2;

FIGURE 2 is a sectional view through FIGURE 1 taken along the plane of line **2—2**;

FIGURE 3 is a longitudinal sectional view of the solenoid valve;

FIGURE 4 illustrates a slight modification of FIGURE 3; and

FIGURE 5 is a fragmentary view of the invention as shown in FIGURE 1, and includes some modifications thereof.

An aspect of the present invention resides in the provision of a hydraulically actuated piezoelectric voltage source which includes a housing arrangement providing an abutment rigid against longitudinal expansion, the housing including a high pressure and a low pressure fluid chamber or reservoir and a fluid passageway therebetween. There is also provided a stack of piezoelectric elements piezoelectrically responsive in compression and arranged within the housing, one end of the stack being disposed in fixed relation to the abutment. A piston means is operably disposed in relation to the high pressure reservoir and to the other end of the stack to compress the stack against the abutment. A pressure producing arrangement is operably disposed in relation to the high pressure reservoir to increase the pressure in the reservoir in response to actuation of the pressure producing arrangement. The invention also includes a valve means within the fluid passageway for controlling the pressure differential between the reservoirs, and a hydraulic fluid is provided within both of these reservoirs.

Turning now to the drawing there is shown a hollow housing **10** constructed of a conventional heavy duty steel cylinder with one end open and the other end being formed substantially semispherically. The housing is generally rigid and, particularly the spherical end, is constructed to prevent longitudinal displacement thereof.

Disposed within the housing **10** is a plurality of annular, piezoelectrically responsive, elements **12**, coaxially mounted forming a longitudinally extending stack. The elements are individually polarized in a direction parallel to the axis center of the housing and are electroded face to face and at opposite ends to establish electrical connection in series. The piezoelectric elements are composed of crystal elements or piezoelectrically responsive ceramics. Preferably, the elements are made of polycrys-

talline ceramic materials such as barium titanate, lead titanate-zirconate or the like.

For structural support of the stack of annular piezoelectrically responsive elements **12**, a support member **13**, in cruciform, is suitably disposed in the tubular stack. The longitudinal length of the support **13** is slightly less than the equivalent length of the stack **12**. Care must be taken that the support member consists only of insulating material or, alternatively, is heavily insulated to avoid jumping of the electric charge.

The stack of piezoelectric elements **12** is suitably grounded by means of a grounding member **14** contacting an electrode (not visible as such) on the lower end of the stack **12**. The grounding member **14** is hereafter also referred to as a piston member. The opposite end of the piezoelectrically responsive stack of elements **12** constitutes the "hot side" which is partly encircled by a ceramic insulating member **16**. A centrally located conduit in member **16** carries a hot lead cable **18** which is electrically connected to the outermost electrode at the upper end (also not visible). To avoid elasticity in the semispherical portion of the housing **10** there is cast, or melted, into this housing portion a low melting point metal, for instance a bizmuth alloy. The same constitutes a support and an abutment **20** against which the stack of piezoelectric elements can be compressed. Interposed between the support and abutment **20** there is shown a spacer member **22** made of a metallic material, the function of this spacer being primarily to prevent, or to compensate for, slack in the aforedescribed construction.

A partly hollow base **24**, constituting part of the main housing **10**, is threadedly connected with the main housing. The base establishes a means for precompressing, or pressure adjustment of, the stack of piezoelectric elements **12**.

The base **24** of the housing **10** contains the various components necessary to apply mechanical pressure to the piezoelectric elements **12**. The pressure is applied by means of a hydraulic circuit which includes a high and a low pressure chamber or reservoir for hydraulic fluid. The low pressure reservoir **26** comprises, basically, all the space within the main housing **10** not occupied by the stack of piezoelectric elements **12**, the support **13**, etc., and the high pressure reservoir **28** is located between piston **14** and the base **24**. A U channel within the bottom of the piston will also work satisfactorily. The low pressure and the high pressure reservoirs **26**, **28** are in fluid communication with each other by means of a passageway **30**. A solenoid valve **32** is effectively interposed therebetween to control the flow of fluid between the two reservoirs as hereafter further described, and a retainer member **35** secures the valve **32** to the base **24**. What may also be considered part of the high pressure reservoir **28** is a fluid channel **34** operably exposed to a pressure gauge **36** mounted to the base **24** and to a manual pressure producing member **38** of conventional construction. The member **38** is effective to control the fluid pressure in the high pressure reservoir, and the member **38** includes a movable stem **38***a* extending into the channel **34**. It should be noted that there always exists fluid flow communication between reservoir **28** and channel **34** although components of the solenoid valve **32** are physically interposed.

More specifically, referring now to FIGURE 3, the solenoid valve **32** includes a housing **33** containing a solenoid winding **40**, a plunger **42** coaxially disposed and movable within the central opening of the winding **40**, and an abutment member **41** within the opening of winding **40** for engaging the plunger **42**.

The plunger **42** has an axial bore to receive a longitudinally extending valve closure member **43** which includes a tubular sleeve **44** coaxially surrounding a rod **45** in fixed relation thereto and having at each end a radial flange **44***a*, **44***b* respectively. The rod **45** extends out of the axial bore through an intermediate housing member

33*a* and is adapted to retain a container member **46** telescoped around the flanged end **45***a* of the rod **45**. A ball **47** is movably disposed within container **46**, and a spring **49** is interposed between the ball **47** and the flanged end **45***a*. The plunger **42** and the closure member **43** are normally held in the position illustrated in FIGURE 3 by means of a spring **51** acting against the solenoid and oppositely engaging a flanged retainer member **53** secured to plunger **42**. In the normal position the retainer member **53** abuts flange **44***b*. The ball **47** is suitably sized to fit sealingly into the opening of passageway **30** to prevent any fluid intercourse between the high and the low pressure reservoirs.

Preferably, transformer oil is used as hydraulic fluid to simultaneously serve to insulate the piezoelectric elements **12** from the housing **10**. Fluid communication between the inner cylinder formed by the piezoelectric elements and the outside thereof is established by means of a plurality of fluid channels **48** contained in the piston member **14**.

The sequence of operation is as follows. The pressure producing member **38** is turned in a counterclockwise direction raising stem **38***a* whereby a partial vacuum is created within the hydraulic circuit causing the hydraulic fluid from the low pressure area to force the spring biased plunger member **42** and, more particularly, the ball **47** free of the opening of the passageway **30** so that the area constituting the high pressure reservoir is completely filled with fluid. It will be appreciated that a motorized pump can be readily substituted for manual member **38**. Upon reaching a predetermined pressure, the pressure producing member **38** is turned in a clockwise direction whereupon, immediately thereafter, the spring biased plunger **42** moves back to the "normal" position by virtue of a slight increase in pressure, and the ball **47** is again suitably positioned to block fluid flow between the two reservoirs. The pressure member **38** is then further actuated until a predetermined pressure has been reached.

In response to the gradual increase of pressure in the high pressure reservoir **28** and channel **34**, the piston member **14** is lifted and acting as a pressure applying means is forced against the stack of piezoelectric elements **12** whereby these piezoelectric elements are compressed. The compression of the piezoelectric elements causes the elements to generate an electric charge of a given polarity which can be applied to any suitable device. Adjustment of the rate of stress application and the time constant of the electric circuit will allow a variation in the voltage output wave form. In some applications it will not be desirable to utilize this charge because of dissipation factors. Therefore, it may be desirable to eliminate this charge altogether by applying the pressure over a period of time which equals or is greater than the time constant of the electric circuit, so that the charge is dissipated through the internal resistivity of the ceramic elements **12**.

The stack of piezoelectric elements **12** is now in a state of maximum mechanical compression, and the release of such compression causes an electric potential of opposite polarity to be generated. This condition may be likened to a condenser which is charged and can instantaneously, or almost instantaneously, be discharged. The stress release, whether it be gradual, sudden or therebetween, is initiated by energizing the solenoid winding **40** by means of push button **62** operated by a battery **64** to draw the plunger **42** toward the axial center of the solenoid core.

More particularly, when the plunger **42** is drawn electromagnetically to the center of the magnetic field, the retainer member **53** glides along the sleeve **44** of the valve closure member **43** gradually increasing its speed until the retainer **53** hits the lower flange **44***a* with considerable impact. This causes the ball **47** to be suddenly separated from valve seat **30***a* in passageway **30** and establishes again fluid flow between the two reservoirs, and the pressure in the high pressure reservoir **28** is

relieved into the larger low pressure reservoir **26**. This permits the contracted elements **12** to expand and return to their original longitudinal length whereby, as above noted, a potential of opposite polarity is generated.

In order to gain a greater degree of control over the rate of stress application or release thereof, the electric input may be suitably modulated to vary the intensity of the magnetic field. A modification by mechanical means is shown in FIGURE 4. A set screw **54** protrudes through the abutment **41** effective to engage the plunger **42**. The set screw **54** serves to restrict the movement of the plunger **42** and to reduce the space of separation between the valve seat **30***a* and the ball **47**, shown in FIGURE 3. This serves to control the rate of fluid flow between the two reservoirs.

The same result can be accomplished by substituting for ball **47** a truncated cone **56**, see FIGURE 4. The cone **56** normally closes valve seat **30***a*, but once the cone is withdrawn, the fluid flow opening in the passageway widens more gradually than is the case with ball **47**.

Referring now to FIGURE 5, there is shown the bottom part of the high voltage generator to illustrate a modification of the above described preferred embodiment.

Herein at least portions of the hydraulic system are located remote to either the housing **10** or base **24**. It will be appreciated by those skilled in the art that the low pressure reservoir for supplying fluid can be located anywhere within reasonable proximity to the housing or base. When the low pressure reservoir is located outside the housing, the transformer fluid within the housing and surrounding the piezoelectric elements acts merely as an insulating material and is not connected to the hydraulic circuit. More specifically, as shown in FIGURE 5, the low pressure reservoir in this alternative construction consists of a passageway **70** located in base **24** and a conduit **72** connecting the passageway to a rubber-like bladder **74** for holding fluid which is supported by a steel frame or housing **76** and attached to the main housing **10**. The passageway **70** functions in the same manner as passageway **30** shown in FIGURE 1. That is to say, it establishes fluid intercourse between the fluid supply such as the fluid contained in bladder **74** and the high pressure chamber or reservoir **28** as aforedescribed. While portions of the high pressure system may be contained in a conduit, chamber, or the like remote from the main housing **10** or base **24**, it will be appreciated that the high pressure chamber must terminate proximate to the piston **14** in order to move the piston for squeezing the stack of piezoelectric ceramics **12**.

While there have been described what are at present considered to be the preferred embodiments 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.

What is claimed is:

1. A hydraulically actuated piezoelectric voltage source comprising, in combination: housing means providing an abutment and being rigid against longitudinal expansion; a high pressure and a low pressure fluid reservoir operatively associated with said housing; fluid passageway means between said reservoirs; piezoelectric element means disposed within said housing means and piezoelectrically responsive in compression, one end of said piezoelectric element means being disposed in fixed relation to said abutment; pressure applying means operably disposed in relation to said high pressure reservoir and to the other end of said element means for compressing the latter against said abutment; pressure producing means operably disposed in relation to said high pressure reservoir to increase the pressure in said reservoir in response to actuation of said pressure producing means; and valve means within said fluid passageway for controlling the pressure differential between the fluids in said reservoirs.

2. A device according to claim 1, wherein said high pressure reservoir is located within said housing and at least portions of said low pressure reservoir are located outside said housing.

3. A hydraulically actuated piezoelectric voltage source comprising, in combination: housing means providing an abutment rigid against longitudinal expansion, said housing including a high pressure and a low pressure fluid reservoir and a fluid passageway between said reservoirs; piezoelectric element means disposed within said housing and piezoelectrically responsive in compression, one end of said piezoelectric element means being disposed in fixed relation to said abutment; pressure applying means operably disposed in relation to said high pressure reservoir and to the other end of said element means to compress the latter against said abutment; pressure producing means operably disposed in relation to said high pressure reservoir to increase the pressure in said reservoir in response to actuation of said pressure producing means; valve means within said fluid passageway for controlling the pressure differential between said reservoirs; and hydraulic fluid within both of said reservoirs.

4. A device according to claim 3, wherein said piezoelectric element means comprises a plurality of annular piezoelectric elements coaxially mounted and secured together to provide a stack of piezoelectrically responsive elements; and said hydraulic fluid substantially encircles said stack to provide electrical insulation between said stack and said housing.

5. A device according to claim 4, wherein said elements are polarized parallel to the axial center of said housing and electroded face to face to establish electrical connection in series.

6. A device according to claim 4, wherein said stack is tubular and substantially filled with hydraulic fluid; and means for equalizing the pressure between the inner and the outer area of said tubular stack.

7. A device according to claim 5, wherein said pressure applying means is adapted to electrically ground one end of said stack; and a conducting member engaging the opposite end of said stack.

8. A device according to claim 5, wherein said stack is tubular in shape; and a longitudinally extending support member secured within the central bore of said tubular stack, said support member being constructed substantially of non-conductive material, the longitudinal length of said support member being less than the corresponding length of said tubular stack.

9. A device according to claim 7, and an insulating cap encircling an end of said stack proximate to said conducting member.

10. A device according to claim 3, wherein said pressure producing means is adapted to gradually increase the pressure in said reservoir over a relatively long period of time, and said valve means within said passageway is adapted upon actuation to release the pressure of said high pressure reservoir into said low pressure reservoir during a period of time which is short compared to the aforesaid period of time.

11. A device according to claim 10, wherein said valve means includes a valve seat, a valve closure member cooperating with said valve seat for closing said fluid passageway, and a plunger member operatively associated with said closure member to impact the latter member for suddenly separating the closure member from said valve seat, and means for actuating said plunger.

12. A device according to claim 11, wherein said plunger is a solenoid type plunger, and a solenoid coil constructed and arranged for moving said plunger.

13. A device according to claim 3, wherein said pressure producing means is adapted to gradually increase the

pressure in said reservoir over a relatively long period of time, and said valve means within said passageway is adapted upon actuation to release the pressure of said high pressure reservoir into said low pressure reservoir during a period of time which is substantially the same as aforesaid period of time.

14. A device according to claim 3, wherein said pressure producing means is adapted to increase the pressure in said reservoir over a predetermined period of time and said valve means within said passageway is adapted upon actuation thereof to release the pressure of said high pressure reservoir into said low pressure reservoir also over a predetermined period of time; and means for varying said predetermined periods of time.

15. A device according to claim 3, wherein said pressure producing means is adapted to increase the pressure in said reservoir over a predetermined period of time and said valve means within said passageway is adapted upon actuation thereof to release the pressure of said high pressure reservoir into said low pressure reservoir also over a predetermined period of time.

No references cited.