Jan. 16, 1968 L. R. GIATTINO ETAL 3,363,566

PIEZOELECTRIC POWER SUPPLY

Filed April 5, 1966

2 Sheets-Sheet 1

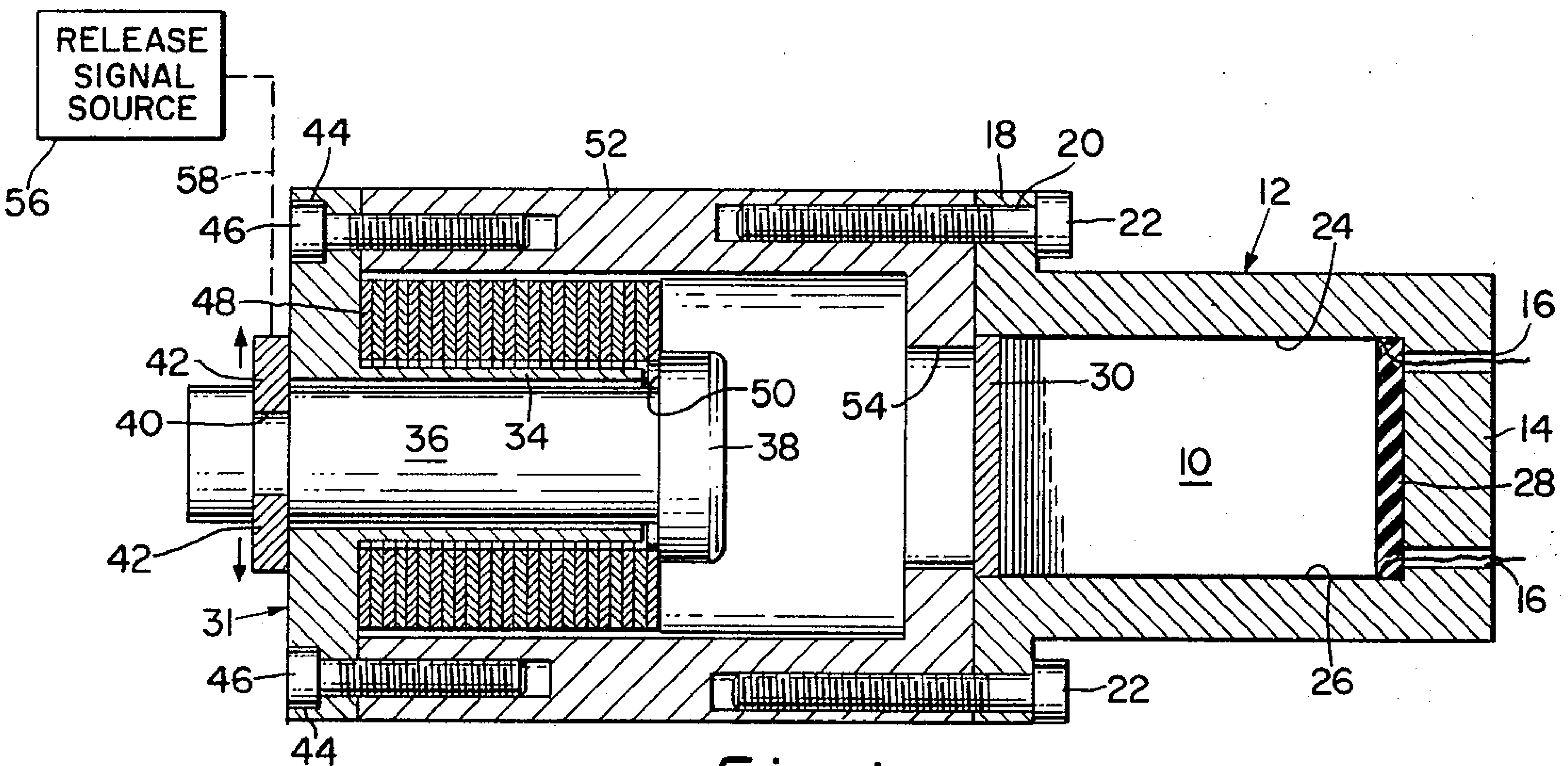

Fig. 1

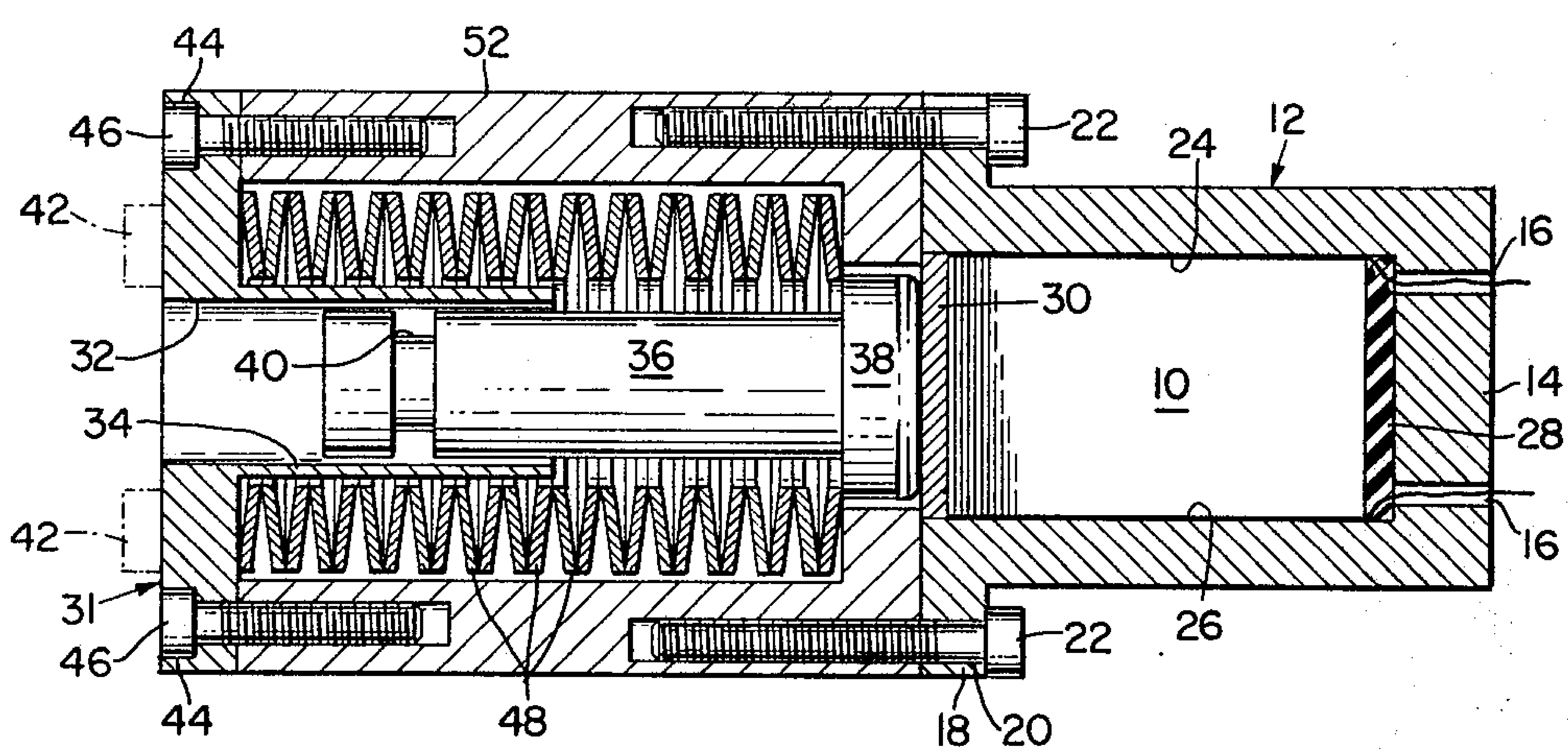

Fig. 3

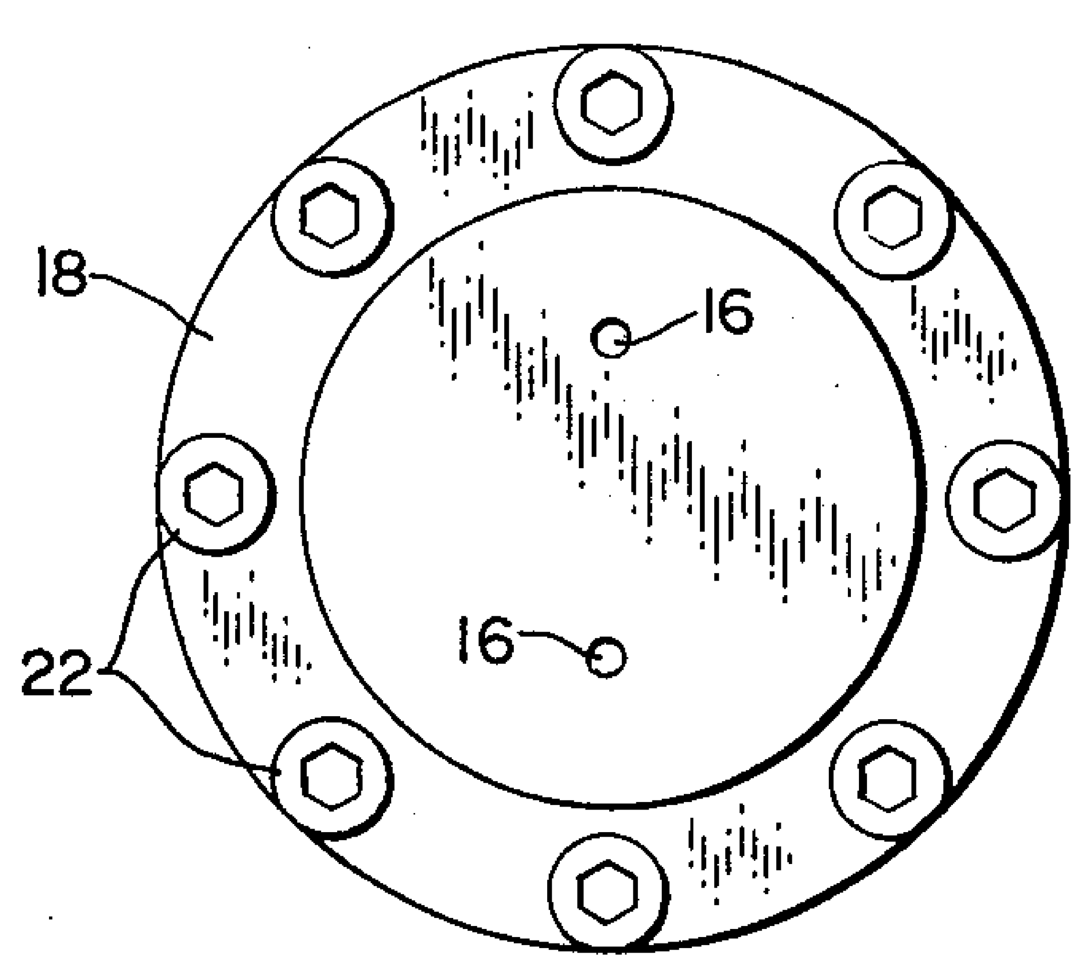

Fig. 2

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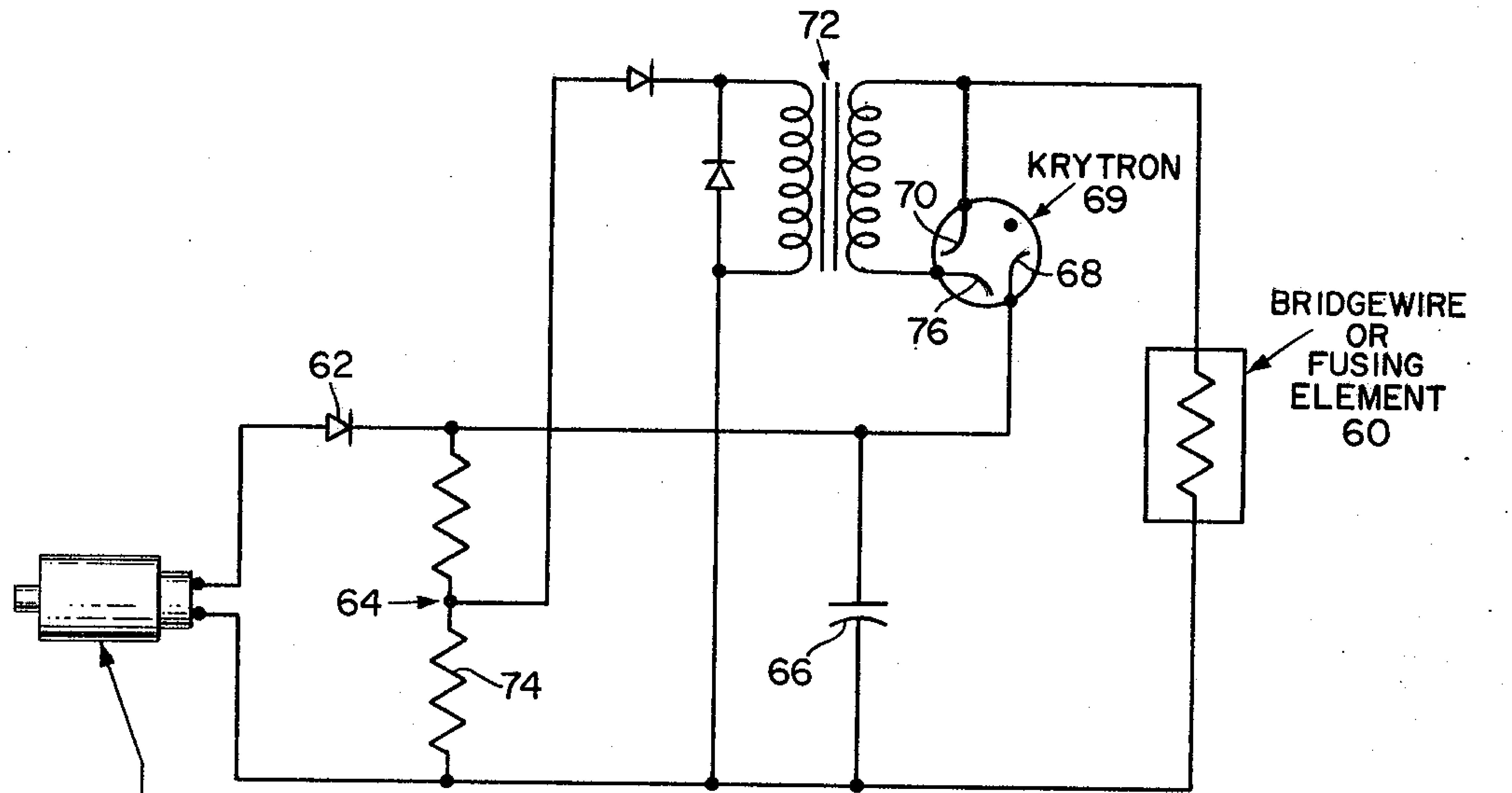
72
KRYTRON
69
70
68
76
BRIDGEWIRE OR FUSING ELEMENT 60
62
64
74
66

Fig. 4

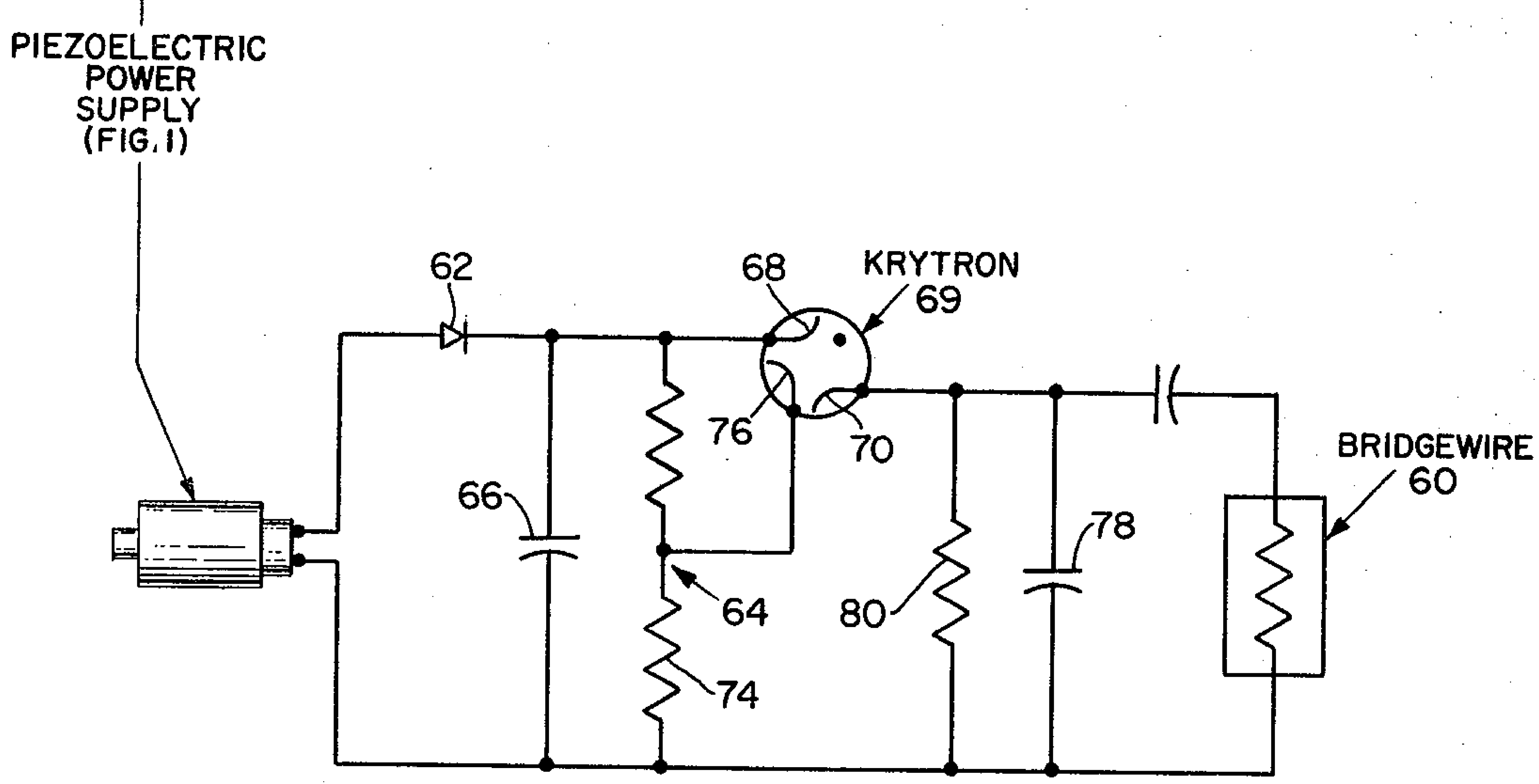
PIEZOELECTRIC POWER SUPPLY (FIG. 1)
62
68
KRYTRON
69
76
70
66
64
74
80
78
BRIDGEWIRE
60

Fig. 5

United States Patent Office

3,363,566

Patented Jan. 16, 1968

3,363,566

PIEZOELECTRIC POWER SUPPLY

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Filed Apr. 5, 1966, Ser. No. 540,415
8 Claims. (Cl. 102—70.2)

ABSTRACT OF THE DISCLOSURE

A mechanically-energized piezoelectric power supply particularly suitable for use with missiles and incorporating a spring-driven plunger or bolt adapted to impact a stack of piezoelectric crystals to thereby develop a surge of output current of an amplitude sufficient to disintegrate a bridgewire and hence detonate an explosive carried by the missile. A feature of the concept lies in the design of the spring so that a uniform pressure is developed on the crystal stack when the latter is impacted by the bolt or plunger.

The present invention relates to a mechanically-energized piezoelectric power supply particularly adapted for incorporation into a detonator circuit of the type employed on missiles or other projectiles having an explosive charge contained therewithin.

A majority of missiles designed for use under combat conditions incorporate therewithin an explosive charge which is intended to be detonated upon impact with a target or when the missile reaches a point of closed proximity thereto. It is customary to ignite this explosive charge by means of a detonator circuit which conventionally makes use of a bridgewire or another fusing element embedded in or otherwise intimately associated with the explosive charge per se. Upon the passage of an electrical current through the bridgewire, the charge is ignited in practically instantaneous fashion.

An exploding bridgewire initiator of the above type requires a considerable amount of input energy in order to insure reliable operation, even though this energy is applied for a time period as short as 10^{-5} seconds. One arrangement which is now being employed in practice makes use of a source of electrical power carried by the missile as a separate and independent component. However, with the severe demands now being placed upon the range and maneuverability of practically all projectiles, the addition weight of such a separate power supply is frequently unacceptable, apart from the fact that the space requirements of such a unit often cause an appreciable enlargement of the missile's instrumentation package.

It is therefore highly desirable that some means be available which is capable of providing electrical power for an exploding bridgewire device without requiring a separate electrical source. Under such circumstances, the elimination of this separate source would prolong the so-called "shelf life" of the missile, as the risk of launching the latter with a power unit which has gradually deteriorated over a period of time would no longer be present. In addition, the size and weight of the missile could be reduced, or, an an alternative, additional instrumentation could be added.

It is known that certain piezoelectric materials exhibit exceptional dielectric properties, examples of such materials being barium titanate, lead titanate, etc. Such substances have frequently been made use of in devices which convert mechanical energy into electrical energy. As an example, a tablet of sintered barium titanate, which has been polarized by application of a D-C voltage, may have a normal dielectric constant of between 1500 and 1800. Upon sudden application of a pressure pulse, the tablet produces a charge across its terminals rising to a maximum of several kilovolts in proportion to the increase in applied pressure. If the terminals of the tablet consist of metallic layers applied to the opposite surfaces thereof, these terminals may be connected in parallel with an electro-responsive detonator, and the latter will be ignited when the derived energy reaches a predetermined level.

Inasmuch as bridgewire detonators of the type discussed above require a high-energy pulse of short duration in order to be effective, it has been found that, for optimum operation, the output of the piezoelectric assembly should be applied to an energy-storage device which retains such energy therein until the latter has reached a predetermined value. At this point, the energy is applied directly to the bridgewire through a spark gap (or other breakdown device) which yields a very-high-amplitude, short-time-duration surge of current ideally adapted to operate the detonating mechanism.

Although several proposals have been made for the utilization of a piezoelectric crystal assembly to develop a short-time-duration output pulse, nevertheless these expedients have in general been relatively ineffective due to the particular requirements inherent in a transducing device of this nature. For example, one of the most important considerations involved in converting mechanical energy into electrical energy through the use of piezoelectric means is that the applied pressure be evenly distributed across the entire face of the crystal, or, in cases where a plurality of crystals are stacked together, evenly across the entire stacked assembly. Failure to so distribute the pressure results in a marked decrease in voltage output, possibly to a point below that at which operation of the utilization device occurs. Many attempts have been made to design a transducer unit meeting this particular requirement, none of which have heretofore proven completely satisfactory in practice. It is an objective of the present invention to provide such a transducer.

One object of the present invention, therefore, is to provide an electro-mechanical transducer especially useful for incorporation into missiles or other projectiles to replace a battery or other conventional source of electrical power employed to control the detonation of the missile's explosive charge.

A further object of the invention is to provide an electromechanical transducer capable of developing an essentially uniform pressure over the entire surface area of either a single piezoelectric crystal or a plurality of such crystals stacked together as a unit.

An additional object of the invention is to provide an electrical network designed for incorporation into a missile or other projectile and serving to develop a high-intensity, low-time-duration surge of current particularly useful in controlling the detonation of the explosive charge carried by such missile or projectile.

Other objects, advantages, and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a sectional view of a piezoelectric transducer designed in accordance with a preferred embodiment of the present invention, showing the various components in the relative positions they assume prior to the development of an electrical output therefrom;

FIG. 2 is an end view of the transducer assembly of FIG. 1;

FIG. 3 is a view similar to that of FIG. 1 but showing the various components of the transducer in the relative positions which they assume after their displacement to generate an electrical output;

FIG. 4 is a schematic diagram of an electrical circuit into which the transducer unit of FIGS. 1 thru 3 may be advantageously incorporated; and

FIG. 5 is a modification of the circuit of FIG. 4.

Referring first to the transducer unit illustrated in FIGS. 1 thru 3 of the drawings, there is shown a piezoelectric crystal array generally designated by the reference numeral **10**. This crystal array **10** may be of conventional design, and is made up of a plurality of crystal wafers of disc-like configuration stacked together in face-to-face relationship within an enclosure or housing **12** of generally tubular form. One end of the tubular housing **12** is open to permit insertion of the crystal array **10**, while the opposite end of the housing **12** is closed by an integrally-formed wall portion **14** through which extend a pair of diametrically-opposed apertures **16** the purpose of which will be subsequently set forth. The open end of the housing **12** has a radially-extending flanged portion **18** formed with a plurality of circumferentially-spaced openings **20** designed to respectively receive therewithin a plurality of bolts **22**. In a manner which will subsequently become apparent, the tubular housing **12** and the crystal array **10** contained therewithin form a sub-assembly the various parts of which may be interrelated with one another prior to their association with the other components of the transducer.

Before proceeding with a description of the remaining sub-assemblies shown in FIGS. 1 thru 3 of the drawings, it might be mentioned that the piezoelectric crystal array **10**, while entirely conventional in design, is so made up that the individual crystals are electrically connected in parallel but are physically disposed in series with one another with respect to pressure exerted upon one end of the crystal array in a direction parallel to the axis of the tubular enclosure **10**. It is only believed necessary in the present application to mention that each individual crystal of the array **10** has both of its faces coated with an electrically-conductive film, and that one set of corresponding faces of the stacked crystals are electrically connected to a common conductor **24** which passes to an output circuit through one of the openings **16** formed in the end wall **14** of the housing **12**. In similar fashion, the remaining set of faces of the crystal array are electrically connected to a common conductor **26** which passes through the other end wall opening **16**, as best shown in FIG. 1 of the drawings. An integral disc **28** of insulating material is provided between the crystal array **10** and the end wall **14** of the housing **12**, while a separate metallic disc or plug **30** covers the exposed end of the crystal array **10** and lies in face-to-face relationship with the outer surface of such array. The disc or plug **30** is not secured to any portion of the housing **12**, but is free to move axially thereof when a force is received thereupon in a manner now to be described.

A second sub-assembly of the transducer unit shown in FIGS. 1 thru 3 of the drawings includes a face plate **31** of annular configuration and having an axial opening **32** formed therein (see FIG. 3). A tubular extension **34** of this free plate **31** extends inwardly in the manner illustrated, this tubular extension **34** (together with the opening **32** in the face plate **31**) being designed to receive therewithin a cylindrical bolt or plunger **36** which, when in the position shown in FIGS. 1 and 3 of the drawings, lies essentially coaxial with the remainder of the transducer assembly. The bolt **36** is formed with an enlarged head portion **38** adapted to impact the metallic disc or washer **30** when impelled into such position by the action of a spring assembly the design and operation of which will be hereinafter described. It should be noted, however, that the outer end of the bolt or plunger **36** is formed with an annular groove **40** within which a retaining member **42** is selectively receivable. The plate **31** is formed with a plurality of circumferentially-spaced openings **44** within which a plurality of bolts **46** are respectively receivable. Encircling the tubular extension

34 of the plate **31** is a bank of Belleville springs **48** lying between the inner surface of the plate and the shoulder **50** formed on the bolt or plunger **36** by its enlarged head portion **38**.

When the spring assembly is in its compressed condition prior to operation of the transducer, the various components have an interrelationship as set forth in FIG. 1—that is, the bolt or plunger **36** lies largely within the tubular extension **34** of the plate **31**, with its head **38** in close proximity to the edge of such tubular extension. In such a position, the annular recess **40** in the bolt **36** lies outside the plate **31**, and the retaining member **42** is positioned within such recess. As best shown in FIG. 1 of the drawings, the presence of this retaining member **42** within the groove **40** precludes any inward movement of the bolt **36** and maintains the spring assembly **48** in a compressed condition. In this condition, the individual washer-like spring elements of the assembly are aligned so that they lie essentially parallel to one another and in surface-to-surface relationship. An essentially equal force is consequently developed around the entire periphery of the head portion **38** of the bolt **36** due to equal pressures being applied at all points lying on the shoulder **50**. Expressed differently, the tension under which the bolt **36** is placed when the components have the relationship shown in FIG. 1 of the drawings is such as to impart a solely axial motion to the bolt **36** when the latter is free to move upon removal of the retaining element **42** in a manner which will subsequently be brought out.

The third sub-assembly of the transducer shown in FIGS. 1 thru 3 of the drawings consists essentially of an open-ended tubular housing portion **52** designed to have an outer diameter equal to that of the annular plate **31** and also equal to that of the flanged extension **18** of the housing member **12**. Each end of the housing portion **52** is provided with a plurality of threaded openings circumferentially spaced and aligned to respectively receive the bolts **46**, on one hand, and the bolts **22**, on the other. That portion of the housing **52** which is associated with the housing portion **12** has a flange extending radially inwardly to form an opening **54** of such dimensions as to receive therewithin the head **38** of the bolt **36**, as best shown in FIG. 3 of the drawings. This opening **54** is also slightly smaller than the diameter of the metallic disc **30**, so that when the various sub-assemblies are as shown in FIG. 1, the crystal array **10** is precluded by the presence of the disc **30** from any axial movement prior to the time that the transducer assembly becomes operative.

In assembling the various portions of the transducer for operation, the spring unit **48** is first compressed by pressure applied to the bolt head **38** and the retaining member **42** placed in position within the groove **40**. This sub-assembly is then placed within the tubular housing portion **52** and the bolts **46** inserted and tightened. The crystal array **10** is inserted into the housing portion **12** so that the electrical leads **24** and **26** extend through the openings **16**, the metallic disc **30** is positioned to overlie the exposed end of the crystal array, and then this sub-assembly placed in position adjacent the flanged end **54** of the housing member **52** so that the bolts **22** can be inserted in the openings **20**. When this has been accomplished, the transducer assembly components have relative positions as shown in FIG. 1 of the drawings, and the unit is ready for operation.

It is contemplated that the retaining member **42** be released from its position within the groove **40** in response to an environmental or control signal. Such a signal may, for example, be generated in a source **56**, and applied by any suitable means **58** to cause the retaining member **42** to move out of the groove **40** in a direction shown in FIG. 1 of the drawings by the arrows. However, such releasing signals and the means responsive thereto are well known in the art, and since they form no part of the present invention no detailed description thereof will be given in the present specification. It is only necessary to recognize that the retaining member 42 is caused to leave the groove 40 at a given instant of time.

With the retaining member 42 no longer present, the bolt or plunger 36 is now free to move. Release of the spring assembly 48 from the tension under which it has been placed results in such a movement of the bolt 36 in an axial direction until the bolt head 38 impacts the surface of the steel disc 30. In other words, the components of FIG. 1 of the drawings now assume a position such as shown in FIG. 3. The sharp impact of the head 38 of bolt 36 upon the disc 30 produces an electrical output in a manner known in the art from the crystal stack 10 which appears across the conductors 24 and 26. This electrical output may be utilized in the detonator circuit of a missile or other projectile, as will be described in connection with FIGS. 4 and 5 of the drawings.

Inasmuch as it may be desirable under certain circumstances to bring the spring assembly 48 back to a compressed condition as shown in FIG. 1 from a released condition as shown in FIG. 3 without removing the bolts 46, a blocking pin (not shown) may be radially inserted through an opening in the housing portion 52 so as to lie between the bolt head 38 and the metallic disc 30 during the time that the spring assembly 48 is being compressed. This would preclude an accidental release of the bolt 36 when only partial compression on the springs has been achieved. As soon as the retaining member 42 is inserted into the annular recess 40, then such blocking pin may be removed and the device is ready for subsequent operation.

Referring now to FIG. 4 of the drawings, there is illustrated one preferred circuit arrangement in which the piezoelectric power supply of FIGS. 1 thru 3 may be advantageously employed. Purely as an example, the arrangement of FIG. 4 may be incorporated into a missile or other projectile having an explosive charge (not shown) which is to be ignited by energization of a bridgewire or other fusing element 60. The element 60 is of a type which requires a high-amplitude, short-time-duration surge of energy, which, when received, results in a rapid disintegration of the bridgewire and consequent detonation of the explosive charge associated therewith. However, such fusing elements are well known in the art, and the details thereof form no part of the present invention.

To develop the short-time-duration pulse of energy required for operation of the circuit of FIG. 4, the output of the piezoelectric power supply of FIGS. 1 thru 3 is applied through a diode or other uni-directional circuit component 62 to the opposite terminals of a resistive voltage divider 64 and a capacitor 66 connected in parallel relationship therewith. Consequently, following operation of the piezoelectric power supply in the manner above described, a charge is rapidly built up on the capacitor 66. This charge appears on one electrode 68 of a three-terminal discharge device 69 such as a Krytron. However, other spark-gap devices may obviously be substituted for this component. A further electrode 70 of the discharge device 69 is connected through the bridgewire 60 to that plate of capacitor 66 opposite to the one which is electrically joined to the electrode 68. In other words, bridgewire 60, capacitor 66, and the discharge device electrodes 68 and 70 are all electrically connected in series. As a result, when the Krytron 69 is non-conductive, no current passes through the bridgewire 60.

It is desired to trigger the Krytron 69 into conduction as soon as a sufficient charge has built up on capacitor 66 to cause an instant disintegration of the bridgewire 60. This triggering action is brought about by means of a transformer 72 the primary winding of which is connected in parallel with the lower portion 74 of the voltage divider 64. As shown in the drawing, the secondary winding of transformer 72 has one of its extremities connected to the electrode 70 of the Krytron 69 and the other of its extremities to a third electrode 76. The design of the transformer 72 and the resistance values assigned to the respective portions of the voltage divider 64 are such that the magnitude of the rising voltage flowing through the primary winding of transformer 72 will induce a voltage in the secondary winding thereof which is applied to the "trigger" electrode 76 of the Krytron 69, and, when this voltage has reached a predetermined threshold, the Krytron 69 "breaks down" and forms a conductive path between the electrodes 68 and 70 thereof. This permits a high-amplitude, short-time-duration surge of current to flow from the capacitor 66 through the bridgewire 60 to result in instant disintegration of the latter and detonation of the explosive charge associated therewith.

Other circuit arrangements may be substituted for that shown in FIG. 4, one alternative combination being set forth in FIG. 5. In this latter figure, an additional capacitor 78 and a resistor 80 are connected in parallel relationship both with one another and with the bridgewire 60. Depending upon the values assigned to these components 78 and 80, the waveform of the voltage surge developed when the Krytron 69 becomes conductive may be modified in accordance with the particular design of the bridgewire 60 in order to achieve optimum operation of the circuit.

Other arrangements may be substituted for those of FIGS. 4 and 5 depending upon the specific requirements of the missile or other projectile in which the apparatus is incorporated, as well as upon the design of the piezoelectric power supply of FIGS. 1 thru 3. For example, certain piezoelectric crystal arrays, such as the one identified by the reference numeral 10 in FIGS. 1 and 3 possess sufficient capacitance per se so that the storage capacitor 66 of FIG. 4 (for example) may be entirely omitted, and the output of the piezoelectric power supply applied directly through the Krytron 69 or other spark gap to the bridgewire 60. However, this depends on the characteristics of the crystal array itself, as well as upon the current necessary to result in disintegration of the fusing element 60.

Although many types of piezoelectric crystal arrays may be incorporated into the device of FIGS. 1 thru 3 of the drawings, it has been found in practice that a "stack" of crystal wafers 2" long by 1½" in diameter provides an output of energy sufficient to disintegrate a bridge wire of conventional design. Although under certain circumstances it may be possible to substitute for this crystal "stack" a solid ceramic slug, nevertheless the output energy derived from a single impulse on such a slug may be insufficient for the purposes of the present concept.

Although the apparatus herein disclosed is intended to serve as a primary unit for detonating a missile or other projectile, it can obviously be utilized as a "stand-by" or "back-up" arrangement which only operates upon a malfunction of the basic system power. In many missile designs, the disclosed arrangement can serve to replace a safety-arming package, an inverter, and a standard electrical firing unit.

It will now be recognized that the transducer assembly herein disclosed possesses a number of advantages over other electro-mechanical piezoelectric devices now known in the art. For example, the Belleville spring unit is capable of exerting a strong pressure immediately upon expansion from a compressed state, this pressure being developed during a relatively limited movement of the bolt 36. In other words, this particular spring design results in a short-stroke mode of operation as compared to helical springs, thus conserving space as well as requiring less material during manufacture. Furthermore, as a corollary to the above, the time delay, or lag, following development of a control signal from source **56** may be reduced to a minimum before the bolt **36** strikes the disc **30**, since the bolt travels for only a short distance before maximum striking pressure is generated by the spring assembly.

Each portion or sub-assembly of the transducer is readily separated for replacement or repair, as the case may be, or merely for inspection at periodic intervals. Since the piezoelectric crystal array is most likely to require such periodic inspection and/or testing, it may be readily separated from the remainder of the unit by removal of the bolts **22**. This can be done by an unskilled technician. Simiarly, removal of the bolts **46** allows the spring assembly to be detached from the housing portion **52**, so that the former may be compressed and returned to its original position following a decompression thereof such as might occur during a testing of the unit prior to installation in a missile or other projectile.

The blocking pin (not shown) insertable between the bolt head **38** and the disc **30** may act as an "arming" element in the sense that it remains in position during storage or inactivation of the missile on which the system is installed. Removal of such blocking pin consequently has the effect of "arming" the projectile and making it ready for use in combat situations.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

We claim:

1. Apparatus for igniting a detonator, said apparatus including:

- a detonator ignitable by the reception thereby of a predetermined amount of electrical energy;
- an electromechanical transducer incorporating means responsive to the impact of a moving mass thereupon to generate a progressively increasing amount of electrical energy;
- a circuit for applying the electrical energy generated by said transducer to said detonator at an instant of time when such energy has increased to said predetermined amount;
- a movable mass;
- means for producing a movement of said mass to impact said electrical generating means; and
- means for controlling the operation of said movement-producing means.

2. Apparatus according to claim **1**, in which said means responsive to the impact of a moving mass thereupon to generate a progressively increasing amount of electrical energy comprises a stack of piezoelectric crystals of disc-like configuration arranged physically in series and electrically in parallel.

3. Apparatus according to claim **2**, in which said transducer includes a housing of generally tubular form, with

said stack of disc-shaped piezoelectric crystals being contained within said housing and oriented so that the longitudinal axis of such stack coincides with the axis of said tubular housing, and in which said mass comprises a piston-like member also contained in said housing and movable axially thereof from a position remote from said stack of crystals into a position of direct contact therewith.

4. The combination of claim **3**, in which said piston-like member comprises a cylindrical bolt having an outer diameter less than the inner diameter of the tubular housing portion within which it is contained, and in which said means for producing a movement of said mass comprises means within said housing for moving said bolt axially from a position remote from said stack of crystals into a position of direct contact therewith.

5. The combination of claim **4**, in which said means for moving said bolt axially from a position remote from said stack of crystals into a position of direct contact therewith includes compressible means lying between the outer surface of said bolt and the inner surface of said housing, and in which said means for controlling the operation of said movement-producing means includes means for maintaining said compressible means in a compressed condition while said bolt is in a stationary position remote from said stack of crystals.

6. The combination of claim **5** in which said compressible means is a stack of Belleville springs of annular configuration.

7. The combination of claim **6** in which said bolt extends through one wall of said housing and has a recessed surface portion, and in which said means for maintaining said compressible means in a compressed condition includes a retaining member located exterior of said housing and receivable in the recessed surface portion of said bolt.

8. The combination of claim **7**, in which said means for controlling the operation of said movement-producing means includes means for controlling the removal of said retaining member from the recessed surface portion of said bolt and thereby permit said stack of Belleville springs to expand from a compressed condition and cause said bolt to move axially into a position of direct contact with said stack of piezoelectric crystals to produce an electrical energy output from said transducer.

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