March 19, 1963

G. H. HUFFERD ET AL

3,082,333

VOLTAGE OR SPARK SOURCE

Filed May 29, 1961

4 Sheets-Sheet 1

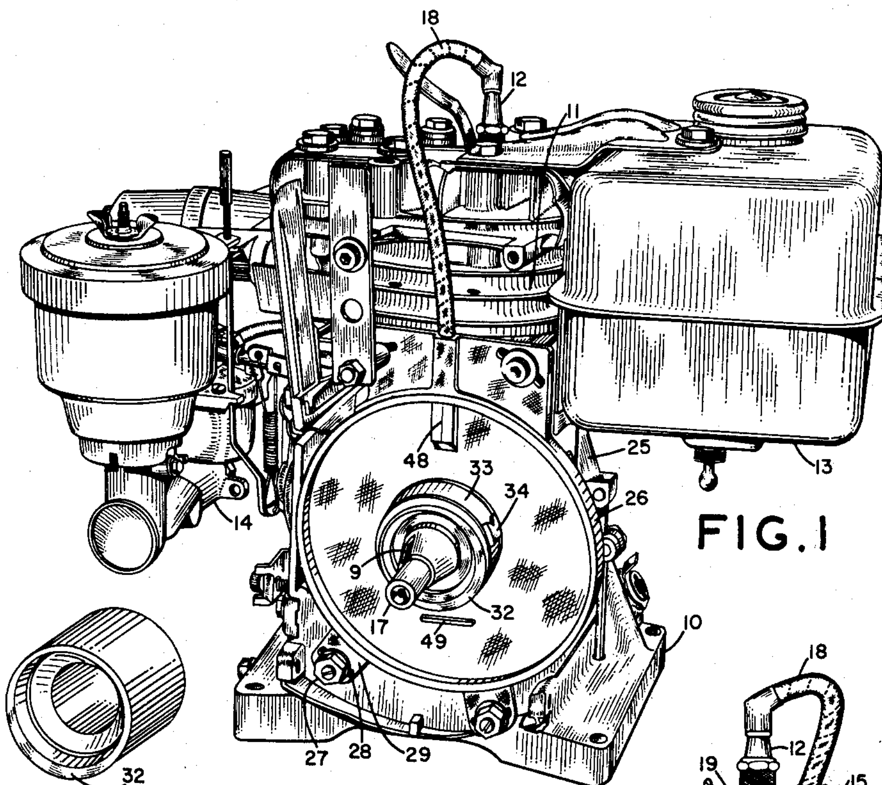

FIG. 1

FIG. 5

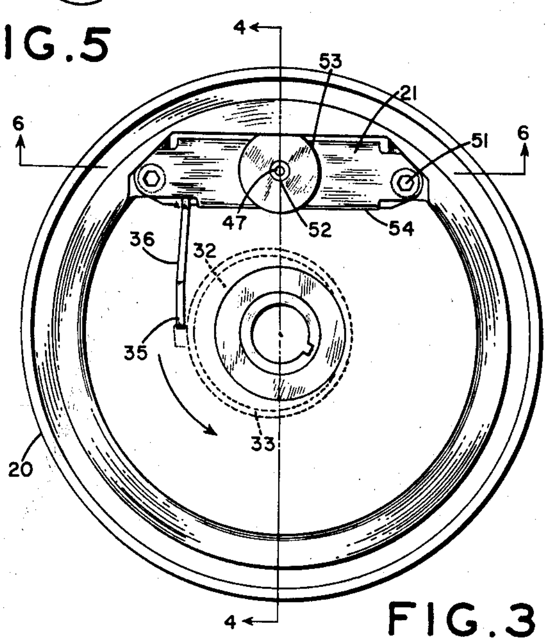

FIG. 3

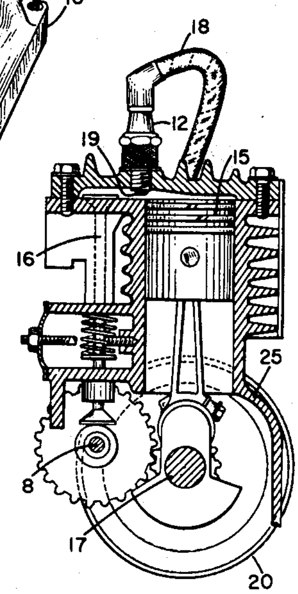

FIG. 2

INVENTORS
GEORGE H. HUFFERD
HERMAN LANSING VAIL JR.
BY ROBERT H. JOSEPHSON

Eber J. Hyde
ATTORNEY

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4 Sheets-Sheet 2

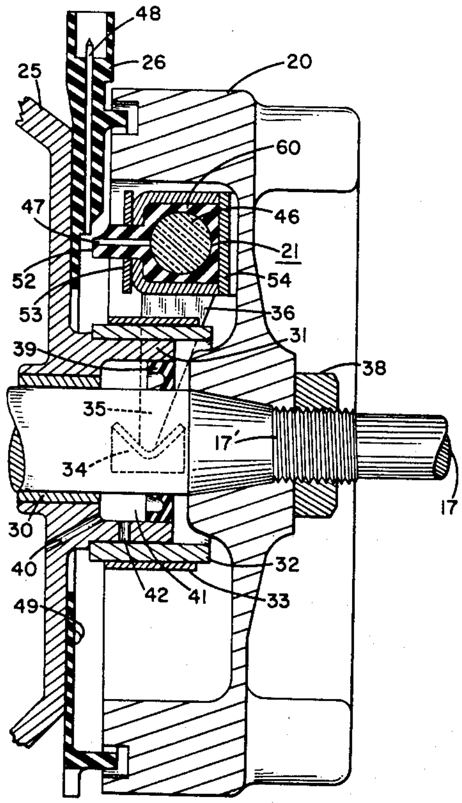

FIG. 4

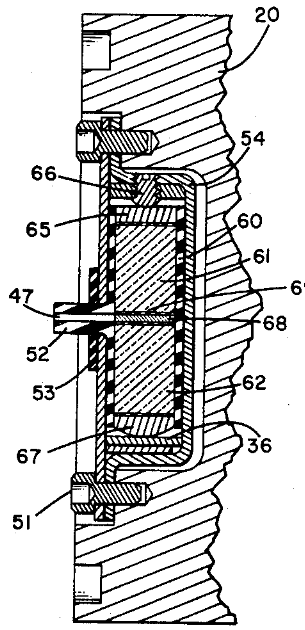

FIG. 6

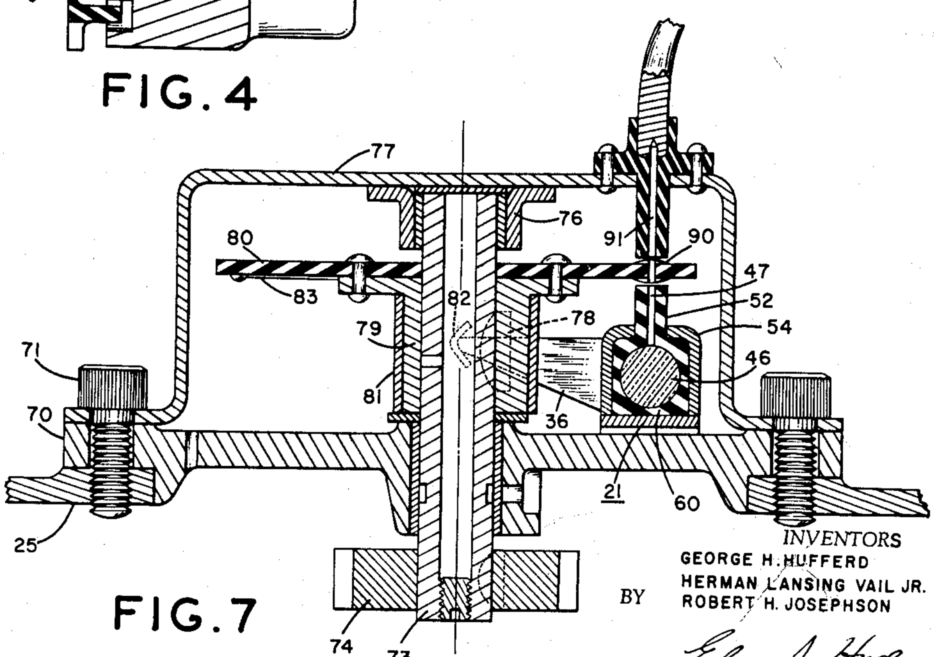

FIG. 7

INVENTORS
GEORGE H. HUFFERD
HERMAN LANSING VAIL JR.
ROBERT H. JOSEPHSON

BY Eber J. Hyde
ATTORNEY

March 19, 1963 G. H. HUFFERD ET AL 3,082,333

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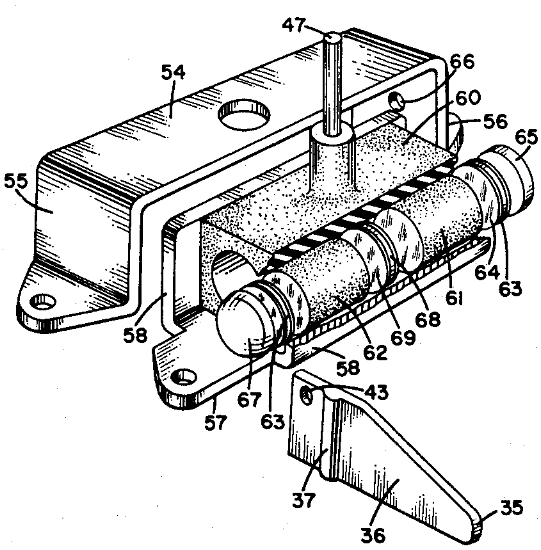

FIG. 8

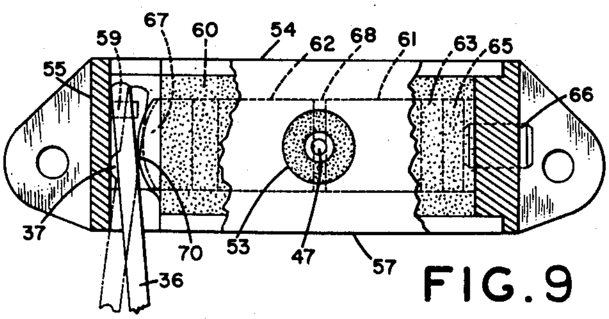

FIG. 9

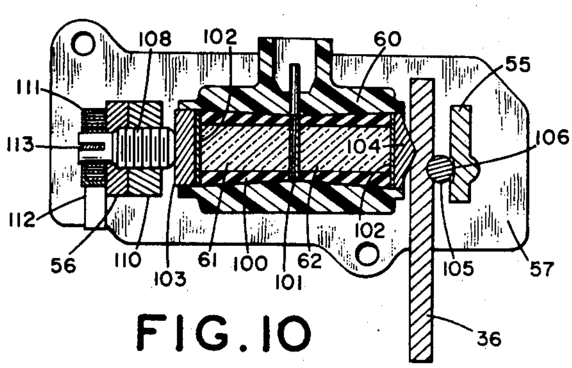

FIG. 10

INVENTORS
GEORGE H. HUFFERD
HERMAN LANSING VAIL JR.
BY ROBERT H. JOSEPHSON

Eber J. Hyde
ATTORNEY

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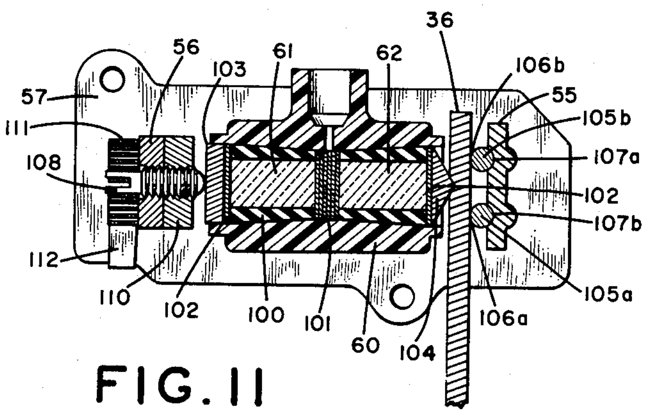

FIG. 11

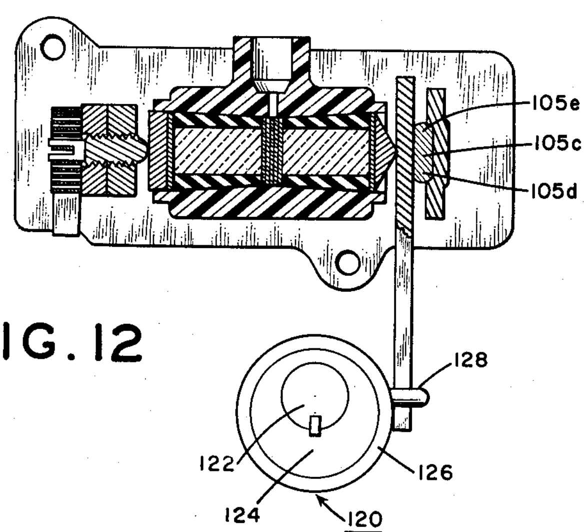

FIG. 12

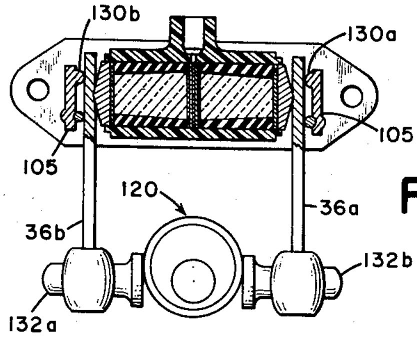

FIG. 13

INVENTORS
GEORGE H. HUFFERD
HERMAN LANSING VAIL JR
ROBERT H. JOSEPHSON

BY Eber J. Hyde

ATTORNEY

United States Patent Office

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VOLTAGE OR SPARK SOURCE

George H. Hufferd, Lyndhurst, Herman Lansing Vail, Jr., Shaker Heights, and Robert H. Josephson, Cleveland Heights, Ohio, assignors to Clevite Corporation, a corporation of Ohio

Filed May 29, 1961, Ser. No. 113,155
13 Claims. (Cl. 310—8.3)

This invention pertains to a source of an electric spark, which spark may be applied to an internal combustion engine, or may be used to ignite an oil or gas furnace, or may be used to ignite a gas clothes dryer. Further, the device may be used to establish an A.C. potential without sparking, or through rectifiers may be used to establish and maintain a D.C. potential.

This is a continuation-in-part of our application Serial No. 776,793, filed November 28, 1958, for a Spark Source for an Internal Combustion Engine, wherein there was shown, described and claimed an ignition device for igniting an ignition means in timed relation to a predetermined point in a cyclic period of time, such for example as igniting the spark plugs of an internal combustion engine; and our application Serial No. 85,358, filed January 27, 1961, which is directed to the sparking device per se which may be actuated in a cyclic manner to establish a spark in timed relation to another event, or which may be continuously actuated to establish repeated sparks, or which may be actuated only once in a while to establish a single spark.

The present application includes specific refinements of the lever system which is used in the sparking device to facilitate squeezing of the ceramic element.

In the past it has been known to impact, squeeze, twist and bend piezoelectric elements to produce voltages. Impacting has advantages such as its tendency to fracture the element, and in many applications such as for igniting furnaces, clothes dryers, in ignition systems etc., repeated impaction is too noisy. Also, where exact timing of the spark is required impacting is at a severe disadvantage compared to a system wherein a squeezing action is used to generate a voltage and a timer device is used subsequently to discharge the voltage in the form of a timed spark.

When a piezoelectric element is hammered or impacted in order to produce a voltage which is substantially instantaneously used in the form of a spark, leakage of the voltage through the element, or across the surface of the element, or across other circuit components is of substantially no importance. However, in the device of the present invention wherein the element is squeezed over a period of time in order to generate a high voltage, and wherein the voltage is held until the proper time to discharge it in the form of a spark, electrical leakage is very important since it greatly reduces the energy in the spark.

It was for the above reasons that the inventors of the devices shown in British Patent 712,803 issued July 28, 1954, to McCulloch Motors and United States Patents 2,649,488, 2,717,589 and 2,717,916, issued to Harkness, were not greatly concerned with the insulation of the piezoelectric element. All of those systems involved impacting the piezoelectric element so that it would vibrate at its natural longitudinal frequency, and the voltage generated thereby was substantially instantly used.

Another outstanding advantage obtained by squeezing the piezoelectric element rather than hammering it is that it produces a much higher voltage. When a piezoelectric element is hammered, the stress in the element is produced by the propagation of a pressure wave. Hence, the element is not instantaneously uniformly stressed, and accordingly, the voltage generated is less than the maximum of which the element is capable. Also, the voltage

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generated by a hammer blow upon a piezoelectric element results from purely the piezoelectric phenomenon, whereas squeezing the element produces, in addition to the piezoelectric action, a reversible ferroelectric domain-switching process which adds greatly to the voltage built up in the element. Tests have shown that by the squeezing action a 50 to 100% increase in voltage generated is to be expected over that obtainable by applying a hammer blow to the piezoelectric element, and since the ferroelectric domain-switching process is reversible, the same energy increase is obtained when the squeezing force is released, it being understood that the change in the stress upon the element during release of the squeezing pressure generates a voltage in the element in the same way that the squeezing action does if the squeeze potential has previously been discharged.

This dual voltage generation obtained from the periodic application and release of squeezing pressure upon the element gives the present invention another important advantage over the prior Harkness piezoelectric ignition system. Thus, where with the prior system it was possible to produce but one spark with each hammer blow, the successive squeezing and releasing of the element in accordance with this invention makes possible two separate sparks, well separated from one another timewise.

From the foregoing discussion it will be clear that the objects of this invention are:

To provide a piezoelectric device which is actuated by a squeezing and/or releasing action, to establish a voltage which can thereafter be utilized, either instantly or after a time delay, the voltage being used in the form of a spark discharge or as a relatively slow reduction from the maximum voltage, or being used to maintain continuously a high voltage as in dust precipitators or the like.

It is an object of the present invention to provide a piezoelectric voltage or spark source wherein a unitary device may be actuated by a mechanical advantage system, such as a lever system, acting to apply force to the piezoelectric element, the unitary device being so constructed that the piezoelectric element is electrically insulated and the lever movements are applied to the insulated element.

Another object of the invention is to provide a piezoelectric voltage or spark source which is capable of establishing voltages on the order of 15–20,000 volts, and is capable of holding high voltage over a period of time with only relatively small voltage drop.

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.

With reference to the drawings:

FIGURE 1 shows a typical internal combustion engine equipped with the ignition system of this invention, the fly-wheel being removed and the drive shaft being modified in accordance with the present invention;

FIGURE 2 is a cross sectional view through the engine showing the internal mechanism of a portion of the engine;

FIGURE 3 is a plan view of the inside face of the fly-wheel illustrating the location of the piezoelectric unit;

FIGURE 4 is a longitudinal sectional view through the flywheel taken along line 4—4 of FIGURE 3, showing the piezoelectric unit and its relation to a spark distributor at the instant of firing;

FIGURE 5 is an isometric view of an eccentric bushing which mounts on a stationary portion of the engine;

FIGURE 6 is a detail sectional view through FIGURE 3 on the plane of the line 6—6, showing details of the piezoelectric unit;

FIGURE 7 is a detail sectional view showing a modified type of distributor unit;

FIGURE 8 is an isometric exploded view of the piezoelectric unit for generating a high voltage;

FIGURE 9 is a sectional view, partially broken away, showing the assembled piezoelectric unit; and

FIGURES 10 to 13 are views shown in section of a modified piezoelectric device.

An aspect of the invention lies in the provision of a piezoelectric unit which is lever operated for establishing high voltages, wherein one or more piezoelectric elements are mounted in a housing and are electrically insulated therefrom. One end of the element is restrained by one end of the housing, and at the other end of the housing a lever is mounted between the element and the housing in such a manner that actuation of the lever causes high compressional forces to be exerted against the element, the reaction forces thereto being taken on the housing whereby a completely self-contained, insulated, unit is provided.

The invention hereafter is described in conjunction with an internal combustion engine, it being understood however that the voltage or spark source per se comprises the present invention, and that the voltage source may be hand operated to establish a spark or voltage, and that the voltage source may be continuously or intermittently operated as by a motor driven cam to continuously or intermittently establish high voltage or sparks.

With reference to the drawings, FIGURE 1 shows an internal combustion engine of the general type used for lawn mowers and snow plows, but it is to be understood that the engine illustrated is merely an example since the invention herein disclosed is applicable to all types of internal combustion engines, including multi-cylinder engines for automotive use.

As is well known in the art, internal combustion engines generally have a base **10** including an integral cylinder block **11** into which a spark plug **12** extends. A gasoline tank **13** is mounted on the engine, and through suitable carburetor means **14** (not described in detail) fuel is supplied to the cylinder or cylinders in timed relation to motion of the piston **15**, the valves **16**, the crankshaft **17**, the camshaft **8**, etc. (shown in FIGURE 2).

An ignition system, which is the subject of the present invention, periodically supplies a high voltage electrical spark to each of the one or more cylinders by means of one or more lead wires **18**. The spark is produced by an electrical potential being quickly discharged to ground across the spaced electrodes **19** of the spark plug **12**, as is well known in the art.

A flywheel **20** is mounted on the end of the crankshaft **17**, or on the end of a shaft driven by the crankshaft, so that it rotates with the shaft.

In accordance with one phase of the present invention shown in FIGURE 3, a piezoelectric unit **21** is the source of the spark potential and is mounted on the inside face of the flywheel **20** and rotates with it. The details of the piezoelectric unit will later be described in detail in connection with FIGURES 6 and 8. The piezoelectric unit **21** contains one or more piezoelectric crystal elements **46** which are squeezed to cause them to generate and hold a high voltage electrical potential until the potential is discharged, and thereafter, upon the squeezing action being released, the piezoelectric crystal elements **46** generate another spark potential of the opposite polarity.

In the device shown in FIGURES 1 to 6 the crystal element **46** of the piezoelectric unit **21** is squeezed once and is released once during each revolution of the flywheel. The details of the squeezing and releasing mechanism are described in detail in connection with FIGURES 8 and 9, and comprise the subject matter of the present invention.

The crankcase housing wall **25** has an insulating plate **26** made of "Bakelite" or the like connected to it for limited rotary adjustment about the crankshaft axis by means of bolts **27** which extend through arcuate slots **28** in ears **29** which are integral with plate **26**. Thus the insulating plate **26** may be rotated slightly in a forward or reverse direction to alter the timing of the motor, as will later become apparent. This timing adjustment may be manual or automatic, as is known to the art. A bushing **30** mounted in the crankcase wall **25** has the crankshaft **17** journaled therein, and an outwardly projecting annular boss **31** encircling the shaft **17** in radially spaced relation thereto, has an eccentric collar or bushing **32** press-fitted thereon. The collar or bushing is made of bearing material and rotatably mounts a sleeve **33** for rotation with the flywheel **20**.

Sleeve **33** has welded to its outside face a V-shaped lever retainer **34** in which one end **35** of a lever arm **36** rests. The other end of the lever **36** extends into and forms a part of the piezoelectric unit **21** to alternately squeeze and release its element **46**, in a manner to be explained, as the sub-assembly comprising the flywheel **20**, the piezoelectric unit **21**, the lever arm **36** and the sleeve **33**, rotates around the stationary eccentric bushing **32**. The rotating flywheel **20**, through the piezoelectric unit **21** and the lever arm **36**, drives the sleeve **33** around the stationary eccentric collar **32**, in the direction shown by the arrow in FIGURE 3. To impart such rotation to this sub-assembly the flywheel **20** is secured to the crankshaft **17** by means of a key **9** and a nut **38** threaded onto the outer end portion **17** of the shaft. The flywheel **20** with its piezoelectric unit must have a fixed positional relationship to the position of the shaft **17**, key **9** being provided to maintain that relationship.

Within the annular projecting portion **31** of the crankcase wall **25** is an oil seal **39**, and an oil return hole **40** extends from the sealed space **41** into the crankcase. The eccentric bushing **32** preferably is slightly porous and receives its lubrication through bushing **30**, through the oil hole **40** and through an oil hole **42** which extends from the sealed space **41** to the internal surface of the bushing **32**. There can be no pressure build-up within space **41** due to oil hole **40**.

As the flywheel **20** and the piezoelectric unit **21** mounted thereon rotate, the stationary eccentric bushing **32** actuates the lever arm **36** causing, by compression of the crystal element **46** therein, a high voltage spark potential to be generated. FIGURE 9 which is later described shows how actuation of the lever **36** causes compression of the crystal element **46**. This potential is held across the piezoelectric crystal element, which serves as a capacitor, until the proper time for firing the spark plug. This instant is determined by the juxtapositioning of the hot lead **47** of the crystal element and a stationary conductive pin **48** which is mounted in the "Bakelite" plate **26**, as is shown in FIGURE 4. Prior to this juxtapositioning there is no conductive path adjacent the hot lead **47** and consequently the charge is held across the crystal element **46** so long as the crystal element is maintained in a compressed state, but when the hot lead **47**, due to the rotation of the flywheel **20**, comes close to the conductive pin **48** a high voltage spark jumps from the lead **47** to the pin **48**, and as shown in FIGURE 1, pin **48** is directly connected to the spark plug **12**. Thus plug **12** is fired by having the entire charge from the crystal element **46** substantially instantly applied across its electrodes.

Timing of the engine is effected by slightly rotating the insulating plate **26** thereby altering the position of the conductive pin **48** with respect to the position of the other moving parts of the engine such as the piston, valves, crankshaft, camshaft, etc. An arm (not shown) may be connected to the plate **26** and extend outwardly to a position readily accessible to the operator. Bolts **27** are sufficiently tight to maintain the plate **26** in a selected position, yet permitting movement to adjust the timing.

Upon the flywheel **20** rotating another 180° around the eccentric bushing 32 the pressure exerted on the crystal element by lever 36 is relieved, but this is after the high voltage potential has been discharged through the spark plug. Relieving the pressure on the crystal element after the squeeze potential has been discharged generates another high voltage electrical potential of a polarity opposite the polarity of the squeeze potential. For certain engines, such as a two-stroke cycle engine, which fire only once during each revolution of the flywheel, it is essential to bleed this second potential to ground without going through the spark plug, or it can be discharged through the spark plug at a time when no ignitable gases are present in the cylinder. Preferably this spark is grounded about 180 degrees from the conductive pin 48 by means of the electrically grounded contact 49. When the crystal element lead 47 approaches the grounded contact 49 the second or undesired spark jumps to it thereby discharging the crystal element and rendering it operative to establish another spark potential during the next 180 degrees of rotation. If the squeeze potential is utilized the release potential is grounded; however, it is also feasible to use the release potential and to ground the squeeze potential.

The piezoelectric unit 21, as shown in FIGURE 3, is bolted to the inside surface of the flywheel 20 by means of bolts 51, and it is obvious that the flywheel should be balanced. The hot lead 47 from the crystal element 46 within the unit 21 extends through a rubber insulator 52, and an enlarged insulator disc 53 may be provided at the base of the insulator 52 to prevent the hot spark from prematurely flashing to ground through the metal case 54 which is around the crystal element 46. The crystal element 46 may generate around 20,000 volts upon being severely squeezed. It is a great advantage to have this high voltage and to apply it almost instantaneously to the plug at the proper time. However, 20,000 volts is not easy to contain over a period of time. Consequently the position of the rise portion of the eccentric sleeve 32 should be so related with respect to the position of the discharge wire 48 that the potential is not held across the crystal unit 46 any longer than is necessary. In determining the proper relationship the timing adjustment should be taken into consideration. Timewise, the maximum squeeze of the crystal element 46 should be immediately ahead of the earliest instant at which the plug is to be fired. The location of the bleed-off contact 49 is not critical, however the release spark should be discharged sufficiently early in the cycle of revolution that the crystal element can thereafter be squeezed over a short period of time to produce its desired spark potential.

Because of the high potential involved, and because many of the applications of the electric potential producing device require that the potential be held over a period of time, it is essential that electrical leakage and undesired shunt circuits be reduced to a minimum. This is not easy since the piezoelectric element must be squeezed and released, and the forces required to produce 15,000 to 20,000 volts from a ceramic piezoelectric element are very high and the motion in the element is very slight. Ordinarily if an engineer wanted to completely moisture-proof an element he would think of potting the element in rubber-like or hardenable plastic material. In the device of this invention presence of a small amount of rubber or plastic material between the lever 36 and the piezoelectric element 46 "absorbs" most of the small amount of motion which is available, thereby reducing to a very low degree the force available to compress the crystal element, with consequent severe reduction in the voltage output.

The device of the present invention utilizes two ceramic piezoelectric elements each ¾ inch long, with a cross-sectional area of .11 square inch. The lever 36 is about 1.500 inches long from the point where it engages the cam 32 to its fulcrum 37, and it is about .100 inch long from fulcrum 37 to the point where it engages the rounded

metal plate 67. Motion of the rounded metal plate 67 is approximately .002 inch. The force on the crystal element is calculated to be about 8000 lbs. per sq. in., and the crystal element contracts only about .00075 inch each under maximum compressive force. A further complicating factor lies in the requirement that the forces on the crystal must be reasonably well distributed over its cross-sectional area or the crystal element will fracture due to high shear stresses. Thus to adequately moisture-proof the unit and to distribute the stresses without introducing soft elements which "absorb" the small motions involved is quite a problem.

Between the metal housing 54 and the crystal element 46 is a thick layer of rubber or other insulating material 60 which insulates the element 46 and which mounts it within the metal housing 54. The insulator 60 must have good insulating qualities, its inside surface adjacent the crystal element 46 must be clean and free of any conductive materials, and the outside surface of the crystal element 46 must also be clean and free of conductive material. Otherwise the high electrical potential generated in the unit will discharge internally either by a spark or by gradually bleeding off.

As best shown by FIGURES 6 and 8, the crystal element 46 preferably is comprised of two separate cylindrical elements 61, 62, electroded in their end faces, and mounted end-to-end within the rubber insulator 60. At the other end of crystal element 61 there is a thin metal plate 63 whose major faces are covered with a very thin layer of electrically conductive rubber 64, and adjacent the rubber covered metal plate 63 there is a heavy metal end plate 65. The conductive rubber 64, the metal plate 63 and the end plate 65 establish the electrical ground connection for the crystal element 61, and in addition distribute the compressional forces at the end of the crystal element. A set screw 66 extends through the housing 54 into engagement with the metal end plate 65 completing the ground connection. At the outer end of the crystal element 62 there is a rounded metal plate 67 adjacent to which is the end of the force transmitting lever 36. Between the outer end of the crystal element 62 and the rounded metal plate 67 there is another thin metal plate 63 covered with conductive ruber 64; also between the two crystal elements there is a third thin, rubber covered metal plate 68 which equally distributes the pressure on the abutting end surfaces of the elements 61, 62. The metal plate 68 is covered on both faces with a thin layer of electrically conductive elastomer 69 to help distribute pressures and to serve as the hot connector to the crystal elements 61, 62. The inner end of the hot lead 47 is positioned close to the metal plate 68, and from the metal plate 68 the hot lead 47 extends to a point outside the housing 54. Lead 47 need not be soldered to plate 68 since the electric potential is sufficiently high to cause a spark to jump from plate 68 to the lead 47. The set screw 66 is turned to pre-load the crystal elements with, for example, about 200 pounds per square inch. Thus wear of parts over a period of time does not materially reduce the voltage output from the crystal elements. The elastomer which covers the three pressure distributing plates 63, 63, 68 should be thick enough to provide good alignability and conformability of parts, but thin enongh to prevent extrusion under the forces involved. It has been found that conductive rubber on the order of .002" to .005" thick is suitable.

Preferably the crystal elements 61, 62 are cylindrical pieces of polycrystalline ceramic material such as barium titanate, lead titanate zirconate or the like, suitably polarized and electroded so that upon squeezing, the ends of the two elements adjacent the hot lead 47 are at a high potential while their opposite ends are grounded to the case 54. Thus the high potential portion is in the center of the housing 54 where the rubber enclosing member 60 adequately protects it from moisture and humidity.

The two piezoelectric elements are shown, 61, 62 are mechanically in series and electrically in parallel, and the elements used successfully have been in the size range of 1/4 inch to 1/2 inch in diameter and about 3/4 to 1 inch long. Such elements, when squeezed, generate a high voltage and have sufficient storage capacity to hold the charge for the required short instant of time prior to discharge.

While two piezoelectric elements are shown in the preferred embodiment, it is understood that one element can be made to work, and that more than two elements may be used.

FIGURE 3 clearly illustrates how the rotation of the piezoelectric unit **21** around the eccentric collar **32** causes motion of the end **35** of the lever arm **36**.

FIGURE 9 illustrates how the motion of the lever arm **36** causes a compressional force to be applied to the crystals **62**, **61**. The strong metal housing **54** includes two ends **55**, **56**. The set screw **66** extends through end **56** into engagement with the metal plate **65**. A base member **57** having two upstanding side walls **58** is secured to the housing **54** by rivets, bolts or by welding, with the rubber insulator **60** and the piezoelectric elements positioned between the base and the sidewalls. The front wall **55** of the housing carries a positioning pin **59** extending inwardly toward the piezoelectric crystal **62**. The upper end of the lever arm **36** has an integral ridge **37**, and it has a hole **43** through it. The positioning pin **37** extends through hole **43** in order to accurately locate the position of the lever **36** between the end wall **55** and the rounded metal end plate **67**. The ridge **37** is against the inner face of the wall **55** and the other face of the lever **36** is held tightly at point **70** against the rounded end of the metal end plate **67**. The lever **36** moves about 3° due to the eccentric bushing **32** and as it moves it rocks about the ridge **37**.

Thus the ridge **37** is the fulcrum for the lever **36**. The fulcrum **37** is below the contact point **70** and the fulcrum ratio is such that about a 15 or 20 to one force ratio is obtained.

In the device shown in FIGURE 7 the piezoelectric unit **21** is independent of the flywheel, being mounted on stationary plate **70** which is connected to the crankcase **25**. A rotatable shaft **73** is driven by gear **74** in timed relation to the crankshaft, and the end of the shaft is journaled at **76** in the housing **77** which is connected to the mounting plate **70** by the bolts **71**. Housing **77** may be sealed to the mounting plate **70** to protect the entire electrical system from dirt and moisture. Around the rotatable shaft **73** and keyed to it by key **78** is an eccentric bushing **79** which has an insulating plate **80** connected to it by means of rivets. Around the rotatable eccentric bushing **79** is a stationary metal sleeve **81** having secured to it a V-shaped retainer **82** for the end of the lever **36** which stresses the piezoelectric element. The piezoelectric unit and the lever arm **36** are stationary and by means of the retainer **82** keep the metal sleeve **81** from rotating with the eccentric bushing **79**. The internal construction of the piezoelectric unit **21** is similar to that shown in FIGURES 1–6. Thus, as the eccentric bushing **79** rotates relative to the stationary lever arm **36**, the arm is actuated thereby stressing the crystal element and generating two spark potentials during each revolution, as has previously been described. Simultaneously with the rotation of the eccentric bushing **79** the insulating plate **80** rotates carrying with it a conductive rivet **90** which extends through the plate **80**. When the rivet **90** is positioned between the hot lead **47** and the wire **91** which extends to the spark plug, a spark will jump, thereby substantially instantaneously discharging the potential through the spark plug. The timing of the engine may be varied by making the position of the piezoelectric unit variable with respect to the bushing **79**. Thus, while the engine is operating, the housing **77** with its piezoelectric unit may be turned to advance or retard the instant of the spark discharge. For timing adjust-

ment it may be advisable to have the conductor **90** extend a few degrees around the disc **80**. The release potential is grounded by wire **83** mounted on the disc **80** about 180 degrees around from the conductive rivet **90**, the wire **83** being connected directly to the metal bushing **79** for grounding the release charge when the wire obtains a position adjacent the hot lead wire **47**.

FIGURE 10 shows a somewhat modified voltage producing unit wherein there is a base plate **57** on which is mounted a heavy metal U-shaped frame having ends **55**, **56** similar to the structure shown in FIGURE 8. Between the ends **55**, **56** is a piezoelectric unit formed of two elements **61**, **62** mounted in a thick plastic housing **60**. Two rubber insulating sleeves **100** are positioned between the housing **60** and the piezoelectric elements **61**, **62**. The sleeves are tapered so that their wall is thinner at the central area of the housing **60**. This greatly facilitates inserting the crystal elements into the insulating housing so that the elements are tightly held and no moisture can penetrate between the rubber sleeves and the crystal elements. This is important to prevent leakage of the high voltage across the surface of the crystal elements. The internal diameter of the rubber sleeves **100** is somewhat smaller than the diameter of the elements **61**, **62** so that when the elements are inserted into the rubber sleeves the sleeves are stretched and the rubber is in tight engagement with the elements. Then as the rubber encased elements are forcefully pushed into the open ends of the plastic housing the taper permits ready insertion and further squeezes the rubber against the elements. There are a plurality of thin soft aluminum discs **101** between the two crystal elements **61**, **62**, making electrical contact with them and making electrical contact with the hot lead **47**. It has been found that a plurality of thin soft aluminum discs is better than one thick member, and is better than conductive rubber in equalizing the pressures from one element to the other. It is virtually impossible to have the end faces of the two elements absolutely parallel, and consequently due to the high pressures on the element breakage occurs at the junction of the two faces if the aluminum discs, or their equivalent, are not present.

A thin, aluminum end plate **102** is inserted into each end of the housing, and then heavy metal end plates **103** and **104** are inserted into the plastic housing **60** into contact with the aluminum discs **102**. Metal end plate **104** has a raised peak which is aligned with the central axis of the ceramic crystal elements **61**, **62** forming a fulcrum for the lever **36**. Instead of the integral fulcrum **37** (shown in FIGURE 9) a separate fulcrum pin **105** is positioned between the lever **36** and the housing end leg **55**. An arcuate section **106** is cut out from the lever **36** so that the lever **36** can roll slightly on the pin **105**. At the opposite end of the unit a screw **108** extends through the leg **56** and through a threaded locking nut **110** into tight engagement with the plate **103**. A spring **111** is tightly wound about the screw **108**, and has one of its ends **112** mounted against the base plate **57** and its other end **113** engaged in the slot in the screw **108** to continuously bias and maintain the screw tightly against the plate **103**. This spring is shown, described and claimed in U.S. patent application Serial No. 26,560, filed in the name of Robert H. Josephson and Charles B. Small, and assigned to the same assignee as the present application.

FIGURE 11 illustrates a modification of the voltage source disclosed in FIGURE 10. In the instant device the lever system includes a lever **36** and a double fulcrum point means such as fulcrum pins **105*a*** and **105*b***. The fulcrum pins **105*a***, **105*b*** are located on opposite sides of a plane through the longitudinal axis of the element substantially perpendicular to the lever **36**. The fulcrum pins **105*a*** and **105*b*** are positioned between the lever **36** and the housing end **55**. Arcuate sections **106*a*** and **106*b*** are cut out from the lever **36** so that the lever

36 can roll slightly on the pins. The end leg **55** is similarly provided with arcuate sections **107***a*, **107***b* which are formed by a depression in the end leg **55** to rollably support each pin.

The lever **36** is in neutral position when the ceramic elements **61**, **62** are relaxed and the lever rests on both fulcrum pins. To actuate the voltage source the lever **36** is shifted or driven off this neutral position into a pressure exerting position with respect to the element, which with respect to FIGURE 11 may be said to be a lever movement to the right and left of the illustrated neutral position. Each drive to the left of the neutral position produces a squeeze potential and, after releasing the squeeze potential, the return movement of the lever to the neutral position produces a release potential in the piezoelectric element which may be used or grounded. Similarly, each movement to the right of the neutral position produces a squeeze potential which may be used or grounded, and thereafter return of the lever to its neutral position produces a release potential which may be grounded or used. It will thus be appreciated that a single complete cycle of movement of the lever can produce four electric potentials, of which two are release and the other two are squeeze potentials. The relationship of the lever to the pins during this cycle constitutes in effect an arrangement in which the lever in the movement to the right acts as a first class lever and in the movement to the left constitutes a second class lever.

FIGURE 12 illustrates a modification of the voltage source shown in FIGURE 11. Herein the double fulcrum means, or pins **105***a* and **105***b*, is a single pivot member **105***c* and the fulcrum points at **105***d* and **105***e* are near the ends of the pin or pivot member **105***c*.

In FIGURE 12 there is also shown an actuating means **120** for effecting such alternate squeezing and release of the piezoelectric element as described in connection with FIGURE 11. The actuating means **120** comprises a bushing **124** eccentrically mounted about and keyed to an actuating shaft **122** and a motion transmitting connection consisting of a sleeve **126** surrounding the bushing and in which the bushing is journaled, and a U-channel **128** connected at one end to the sleeve and at opposite end enclosing the lever bar. The eccentricity of the bushing and the rigid connection of the stationary bearing **126** to the lever, causes the lever to be moved off neutral position when the shaft is rotated. The extreme position to the left is reached when the center of the minor axis is perpendicular to the lever and the extreme position to the right is reached when the center of the major axis is perpendicular to the lever and the U-channel. The actuating means may of course by suitably changed to increase the number of displacements per shaft revolution.

FIGURE 13 illustrates still another modification of the voltage source which is particularly suitable for an application requiring eight sparks per revolution of a shaft or the like. In this arrangement the mechanism for stressing the crystal elements is in principle the same as aforestated, but instead of a single lever **36** there are provided two levers **36***a* and **36***b*, one at each end of the housing **54**. To accommodate the two lever arrangement two rounded metal end plates **104***a* and **104***b* are suitably disposed at each end of the unit.

Each end plate has a limit stop **130***a*, **130***b* in the form of a small protuberance integral with each plate. Each lever has a cross arm **132***a*, **132***b* which abuts against the eccentric actuating means **120**. The lever system may be constructed and arranged so as to act solely as a first class lever, substantially as disclosed and described with respect to FIGURE 10, or each lever **36***a*, **36***b* may be adapted to act as a first and second class lever by utilizing a double fulcrum arrangement as shown and described with respect to FIGURES 11 and 12.

The function of the rigid end plate **103**, as previously described, is herein taken up alternately by each lever.

When the actuating means shifts one lever from neutral to pressure exerting position with respect to the element, the other lever provides an abutment rigid against longitudinal expansion of the piezoelectric element. While the lever is in neutral position the respective limit stop **130***a*, **130***b* serves to engage the lever against the plate **105** until the eccentric re-engages the lever to carry the lever action through the next cycle.

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.

We claim:

1. A piezoelectric voltage source comprising: a housing rigid against longitudinal expansion and having a first and a second end portion; elongated piezoelectric element means mounted in said housing between said end portions with one of its ends restrained by the first of the said housing end portions and with its opposite end spaced from the second housing end portion; an end cap on the said opposite end of said piezoelectric element means; lever means including a fulcrum positioned between said piezoelectric element and said second end portion with the fulcrum located between one side of the lever and the second end portion, the other side of said lever being against said end cap, the location of said fulcrum being offset from the longitudinal axis of said elongated piezoelectric element means; and electrical insulating means around the piezoelectric element means.

2. A piezoelectric voltage source as set forth in claim 1, further characterized by there being two piezoelectric elements located between said first and said second end portions of said housing and positioned end to end; electrically conductive separator means positioned between said two piezoelectric elements and having an electrical lead extending through said insulation around said piezoelectric elements; and electrically conductive end plates positioned against each end of said piezoelectric element means and in electrical contact therewith, said housing means being in electrical contact with said two electrically conductive end plates.

3. A piezoelectric voltage source as set forth in claim 1, further characterized by adjustment means mounted on said first end portion of said housing for biasing said piezoelectric element means away from said first end portion toward and against said lever means.

4. A piezoelectric voltage source as set forth in claim 1, further characterized by said fulcrum being integral with said lever means and comprising a ridge which bears against the second end portion of said housing.

5. A piezoelectric voltage source as set forth in claim 1, further characterized by said fulcrum being a separate member and comprising a roller which bears against the lever and against the second end portion of said housing.

6. A piezoelectric voltage source comprising: an electrically conductive housing rigid against longitudinal expansion and having a first and a second end portion; elongated piezoelectric element means comprising two elements mounted in end-to-end relation in said housing between said housing end portions; tubular electrical insulating means surrounding the piezoelectric element means and extending beyond the ends of the elongated piezoelectric element means; first end plate means located within said tubular electrical insulating means and having an electrically conductive face in engagement with one end of said piezoelectric element means and having its opposite end restrained by the first end portion of said housing and electrically grounding the one end of the piezoelectric element means to said housing; second end plate means located within said tubular electrical insulating means and having an electrically conductive face in

engagement with the other end of said piezoelectric element means and having its opposite end rounded, said second end plate electrically grounding the said other end of said piezoelectric element means; an electrically conductive plate mounted within said tubular electrical insulating means and in engagement with both of said piezoelectric elements forming the high potential end of the electrical circuit through the piezoelectric element means; an electrical lead from said conductive plate through said tubular insulating means; and lever means mounted and held between said second end plate means and the second end of said housing for squeezing and releasing said piezoelectric element means to generate high electrical potentials between said housing and said electrical lead.

7. A piezoelectric voltage source comprising: a housing rigid against longitudinal expansion and having a first and a second end portion; elongated piezoelectric element means mounted in said housing between said end portions with one of its ends restrained by the first of the housing end portions and with its opposite end spaced from the second housing end portion; electrical insulating means surrounding the piezoelectric element means; an end cap on said opposite end of said piezoelectric element means; a lever system, including a lever means and a double fulcrum means, positioned between said piezoelectric element and said second end portion, said double fulcrum means having fulcrum points located on opposite sides of a plane through the longitudinal axis of said element perpendicular to said lever.

8. A piezoelectric voltage source as set forth in claim 7, wherein said double fulcrum means is comprised of a single pivot member.

9. A piezoelectric voltage source as set forth in claim 7, wherein each individual fulcrum point comprises a single pivot member.

10. A piezoelectric voltage source comprising: a housing rigid against longitudinal expansion and having a first and a second end portion; elongated piezoelectric element means mounted in said housing between said end portions with one of its ends restrained by the first of the housing end portions and with its opposite end spaced from the second housing end portion; an end cap on said opposite end of said piezoelectric element means, electrical insulating means surrounding the piezoelectric element means; a lever system constructed and arranged to be normally in a neutral position, said lever system including

a lever means and a double fulcrum means positioned between said piezoelectric element and said second end portion, said double fulcrum means having fulcrum points located on opposite sides of a plane through the longitudinal axis of said element perpendicular to said lever, said lever being in a neutral position when said lever engages both of said fulcrum points; and means for moving said lever off neutral position to cause said lever to act alternately as a first class lever and as a second class lever.

11. A piezoelectric voltage source comprising: a housing rigid against longitudinal expansion and having a first and second end portion; elongated piezoelectric element means mounted in said housing spacedly between said end portions; electrical insulating means surrounding the piezoelectric element means; an end cap secured on opposite ends of said piezoelectric element means; a lever system, including first and second lever means and fulcrum means, said first lever means including fulcrum means operatively positioned between said element and said first end portion and said second lever means including fulcrum means operatively positioned between said element and said second end portion.

12. A piezoelectric voltage source as set forth in claim 11, wherein said fulcrum means is comprised of double fulcrum points located on opposite sides of a plane through the longitudinal axis of said element perpendicular to either of said levers.

13. A piezoelectric voltage source comprising: a housing rigid against longitudinal expansion and having a first and second end portion; elongated piezoelectric element means mounted in said housing spacedly between said end portions; electric insulating means surrounding the piezoelectric element means; an end cap secured on opposite ends of said piezoelectric element means; a lever system including a first and second lever means and a plurality of fulcrum means, said first and second lever means being each operatively associated with a fulcrum means and each lever and fulcrum means being positioned between said element and one of said end portions; and actuating means operatively associated with said lever system for alternately shifting the levers into neutral and pressure exerting position against said element; and lever abutment means causing one lever to constitute an abutment rigid against longitudinal expansion of said element while said other lever is in pressure exerting position against said element.

No references cited.