Jan. 11, 1966 J. W. CROWNOVER 3,229,154

PIEZOELECTRICAL IGNITION SYSTEMS

Filed June 4, 1962 3 Sheets-Sheet 1

Fig. 1.

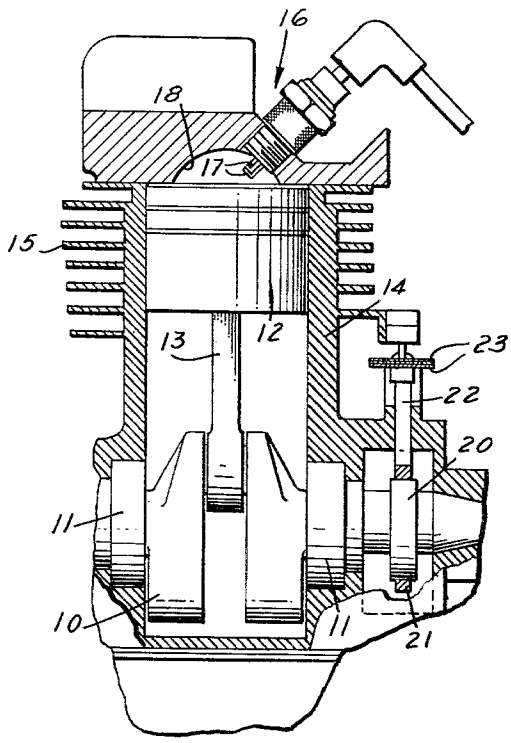
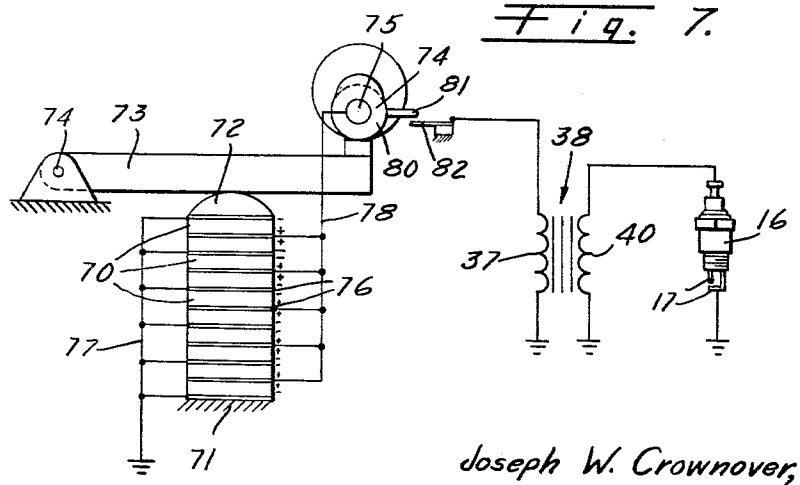


Fig. 7.



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PIEZOELECTRICAL IGNITION SYSTEMS

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Fig. 2.

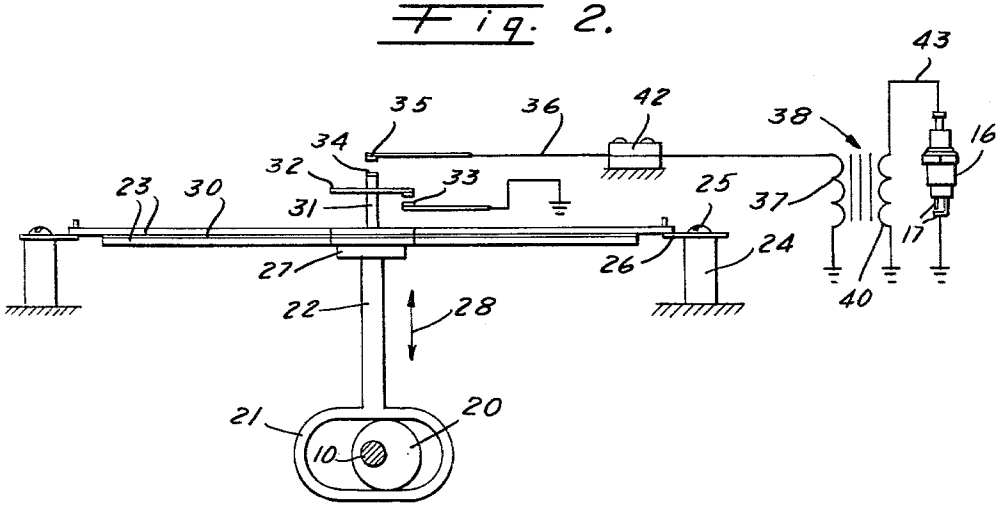
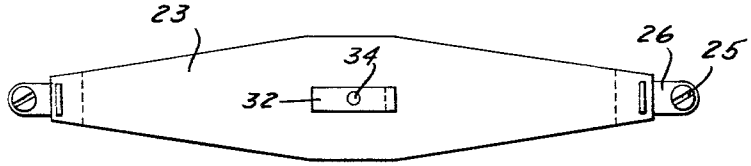


Fig. 3.



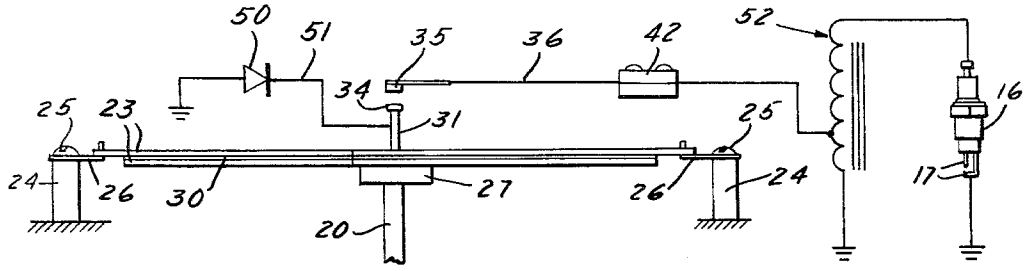


Fig. 4.

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Fig. 5.

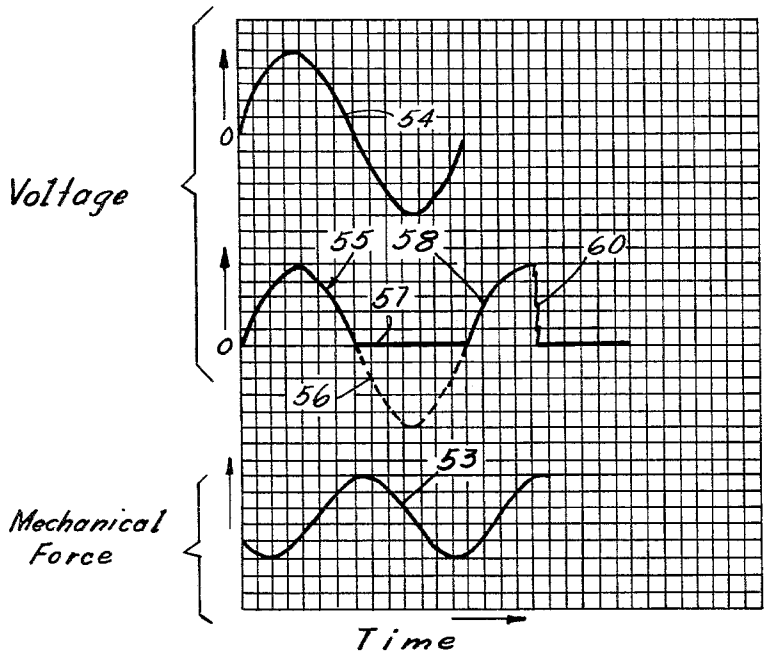
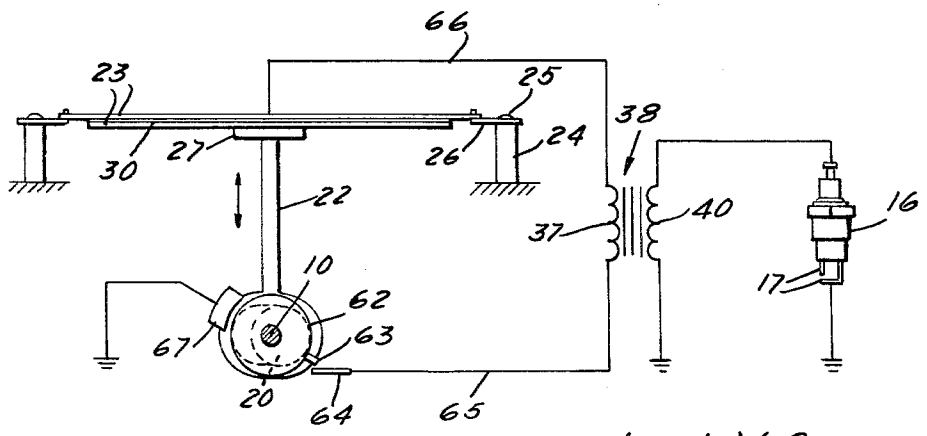


Fig. 6.



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3,229,154

PIEZOELECTRICAL IGNITION SYSTEMS

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Filed June 4, 1962, Ser. No. 199,949
11 Claims. (Cl. 315—55)

This invention relates generally to electrical ignition systems and particularly relates to an electrical system utilizing a piezoelectric element for providing the high voltage impulse required to operate the spark plug of an internal combustion engine.

Attempts have been made in the past to provide electrical ignition systems which make use of a piezoelectric crystal for generating the required voltage. A piezoelectric crystal will develop an electrical voltage when it is subjected to mechanical stress. The crystal, which may be polycrystalline, has an ordered lattice of ions of opposite charges. When such a crystal is subjected to mechanical stress the ions are displaced, and as a result an electrical voltage is developed across the crystal. Various polycrystalline ceramic materials have been developed, which have piezoelectric properties, of which the best known are barium titanate and lead zirconate-titanate.

In order to develop voltages of the order of 10,000 volts or more which are required to ignite the combustible mixture in the spark gap of an internal combustion engine, it has generally been the aim in the past to generate directly such high voltages. When the voltage obtained from the piezoelectric ceramic is of the order of 10,000 volts or more, a transformer or spark coil is not needed which is conventionally used in an ignition system operated from a battery. However, in order to obtain such high voltages from a piezoelectric crystal, it has been found necessary to stress the crystal suddenly by means of a mechanical impact. Since piezoelectric ceramics are relatively brittle, care has to be taken when applying the sudden mechanical impact so as not to shatter or break the crystal. Furthermore, many mechanical problems are created when such a sudden mechanical impact is to be provided.

A more important drawback of prior art ignition systems resides in the high voltage directly developed by the piezoelectric crystal. In order to obtain such a high voltage, even with a sudden impact, the crystal has to be designed in such a way that it has a relatively low capacitance. As a result the time constant associated with the crystal which depends upon its capacitance and its leakage resistance is relatively short. This in turn means that the high voltage peaks developed by the piezoelectric crystal will only exist for relatively short times, that is, times which are short compared to a cycle of the engine. Hence, a difficult timing problem arises because the high voltage must be applied to the spark plug with very precise timing or else the high voltage leaks off before it can be applied to the spark plug. Furthermore, due to the high voltage developed across the piezoelectric crystal, it will be obvious that a leakage problem exists. In other words, the high voltage developed across the crystal may easily leak off due to moisture or other electrical leakage before it can do its work.

It is accordingly an object of the present invention to provide an ignition system including a piezoelectric element which will provide a low output voltage which may then be transformed to a high voltage and which is substantially not subject to leakage currents.

Another object of the present invention is to provide an ignition system for internal combustion engines which includes a piezoelectric element having a relatively large capacitance and hence a long time constant so that the precise instant when the voltage pulse developed by the piezoelectric element is applied to the spark gap is not critical.

A further object of the present invention is to provide an electrical ignition system of the type referred to where stress does not have to be applied as a sudden impact to the piezoelectric element to develop the required output voltage.

Still another object of the invention is to provide an ignition system which includes a piezoelectric crystal utilized as a voltage generator where the peak voltage developed by the piezoelectric crystal is not subject to leakage.

In accordance with the present invention there is provided an ignition system of the type having a spark gap. The ignition system includes a piezoelectric element as well as means for mechanically and cyclically stressing the element to develop a comparatively low votage across the piezoelectric element. Further means are coupled to the piezoelectric element for deriving a peak voltage therefrom and transformer means are coupled in series with the last mentioned means and with the spark gap of the ignition system for delivering a transformed high-voltage pulse which is then applied to the spark plug of the system. Preferably, the piezoelectric element has the form of a cantilever beam to which mechanical bending stress is applied cyclically by means synchronized with the rotation of the engine shaft. The voltage of one polarity developed across the piezoelectric cantilever beam may either be grounded by means of a switch or may be grounded through a rectifier. The voltage of the opposite polarity is then applied to the transformer and the spark plug through a suitable switch. Alternatively, for a two-cylinder engine or an oppositely firing engine, both voltages of opposite polarity may be utilized.

Instead of utilizing a piezoelectric cantilever beam, it is also feasible to provide a stack of piezoelectric discs which are cyclically compressed to develop the voltage which is then transformed and thereafter applied to the spark plug.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both to its organization and method of operation, as well as additional objects and advantages thereof will be best understood from the following description, when read in connection with the accompanying drawings wherein like elements are designated by the same reference characters, and in which:

FIG. 1 is a side elevational view, partly in section, of a single cylinder internal combustion engine embodying the ignition system of the present invention;

FIG. 2 is a front elevational schematic view of the ignition system of the present invention utilizing a cantilever beam construction;

FIG. 3 is a top plan view of the system of FIG. 2;

FIG. 4 is a front elevational schematic view similar to that of FIG. 2 of an ignition system in accordance with the present invention and utilizing a rectifier;

FIG. 5 is a chart illustrating the voltages developed across the piezoelectric element of the system of FIG. 4 as a function of time as well as the mechanical force applied;

FIG. 6 is a schematic front elevational view and circuit diagram of a further modification of the invention utilizing a cantilever beam construction; and

FIG. 7 is a schematic elevational view of an ignition system in accordance with the present invention, utilizing a stack of piezoelectric discs.

Referring now to the drawings and particularly FIGS. 1 to 3, there is illustrated, by way of example, a single cylinder internal combustion engine embodying the ignition

system of the present invention. The engine illustrated in FIG. 1 includes a crankshaft **10** having bearings **11** and connected to a piston **12** through a piston rod **13**. The piston **12** reciprocates in the engine cylinder **14** which may have cooling fins **15**. A spark plug generally indicated at **16** has a pair of electrodes **17** and is disposed in a combustion chamber **18** of the engine cylinder **14**.

Mounted on the crankshaft **10** of the engine is a cam or eccentric **20** which rides within retainer **21** to push the lever **22** up and down in synchronism with the movement of the crankshaft **10**. As clearly shown in FIGS. 2 and 3, there are provided two cantilever beams **23** which preferably have a wide middle portion and tapered ends as illustrated in FIG. 3. The ends of the cantilever beams **23** are mounted on posts **24**, for example, by a screw **25** and a bent-over retainer **26**. The lever **22** is securely mounted to the cantilever beams as indicated at **27** so as to positively move the cantilever beams up and down as indicated by the arrows **28**.

Disposed between the cantilever beams **23** there is a piezoelectric element **30** which preferably is of the same shape as the cantilever beams **23**. The beams **23** may, for example, be made of steel or any other material which is yieldable or has mechanical compliance. Preferably, the piezoelectric beam **30** consists of a lead zirconate-lead titanate ceramic which has the general formula

$$PbZrO_3PbTiO_3$$

These piezoelectric ceramics are commonly referred to as lead zirconates. These ceramic materials exhibit an almost linear relationship between the electric charge and the mechanical stress up to their elastic limit.

Preferably, the ceramics are heat treated and polarized before use so as to orient the electric charges of the material which is generally polycrystalline. The electric dipoles formed by the ions of the piezoelectric material are oriented or poled by an applied electric potential and then the material is heat treated to obtain a domain orientation which will remain until the material is heated beyond the Curie point. The Curie temperature for lead zirconate is 300° C., and also its other mechanical and electrical properties are very favorable for purposes of the invention.

Mounted on the beams **23** is a rod **31** electrically connected to the piezoelectric beam **30** and which bears one arm **32** of a switch, the other arm **33** being fixed and grounded as shown. The upper end of the rod **31** may be formed to provide another switch contact **34** cooperating with a fixed contact **35**. Thus, it will be seen that as the lever **22** is moved up and down, the switch **32, 33** and thereafter the switch **34, 35** alternately open and close.

The switch contact **35** is connected through a lead **36** to the primary winding **37** of a transformer **38** having a secondary winding **40**. The lead or conductor **36** may be supported by a fixed and insulated clamp **42**. The lower terminals of the transformer windings **37** and **40** are grounded as shown. The transformer **38** may have an iron core as indicated, or an air core. The transformer **38** is designed to transform the output voltage derived from the piezoelectric cantilever beam **30** to a higher voltage which is then applied by a conductor **43** to one of the electrodes **17** of the spark plug **16**, the other electrode being grounded as shown.

The ignition system of FIGS. 1 to 3 operates as follows: When the engine is running the crankshaft **10** rotates and accordingly the cam **20** rotates with the crankshaft. As a result the cantilever beams **23** and the piezoelectric beam **30** are subjected to mechanical bending stress by being pushed up and down in synchronism with the rotation of the crankshaft. Consequently, an electrical voltage is developed across the piezoelectric beam **30** which varies approximately like a sine wave. During the downward movement of the beams the switch **32, 33** is closed thus grounding the negative voltage, for example, developed across the piezoelectric beam **30**. During the upward motion of the cantilever beams eventually the switch **34, 35** closes and as a result the peak of the positive voltage is then passed through conductor **36** and impressed on the primary winding **37**. A stepped-up voltage is developed across the transformer's secondary winding **40** which is then impressed across the spark gap **17**, one of the electrodes of which is grounded. This in turn will fire the spark plug and the combustible mixture in the engine cylinder.

Assuming that the force which acts through the lever **22** on the cantilever beams **23** is F_1 and that the stress generated in the piezoelectric material **30** is F_2, it can then be shown that the force or stress acting on the ceramic is given by the following formula:

$F_2=F_1\times 3l\div 16t$, where l is half the length of the piezoelectric beam **30** and t is the thickness of the beam. By way of example, let it be assumed that F_1 is 8 pounds, that the beam has a width of one inch, that is, l is 1.5 inches and the total thickness t is 0.025 inch. In that case:

$$F_2=8\times 3\times 1.5\div 16\times 0.025=90 \text{ pounds}$$

Under these conditions the potential generated by the piezoelectric material is 150 volts and the capacitance of the beam is 0.1 microfarad. Furthermore, under these conditions, the pressure per area amounts to 3,600 pounds per square inch. It can further be calculated that the resonant frequency of the cantilever beam supported at both ends corresponds to approximately 150 cycles per second. Thus, the beam could follow a revolutional speed of the motor up to about ten thousand r.p.m. The above calculations were made with the assumption that the cantilever beam is rectangular rather than tapered as shown in FIG. 3.

It may also be pointed out that with a capacitance of 0.1 microfarad and a leakage resistance of the order of 10 megohms, the time constant is approximately one second. This time constant is long compared to the mechanical cycle of a single piston combustion engine which may be of the order of 300 r.p.m. at the minimum or idle speed corresponding to five revolutions per second. The operating speed of the engine may be as high as 100 r.p.s.

Since the voltage generated by the piezoelectric cantilever beam is of the order of 150 volts, the transformer **38** preferably is designed to transform the voltage to approximately 12,000 to 18,000 volts as required by the spark plug..

Although a single piston engine has been illustrated in FIG. 1, it will be understood that the ignition system of the invention is also applicable to multi-cylinder engines. In that case, a conventional distributor and timer may be required to distribute the voltage generated by the piezoelectric element and applied to the various spark plugs in cyclic procession.

Referring now to FIG. 4, there is illustrated a modification of the invention. The ignition system of FIG. 4 utilizes the same cantilever beam construction as illustrated in FIGS. 1 through 3. However, instead of providing a switch **32, 33**, there is provided a diode or rectifier **50** connected by a lead **51** between the rod **31** and ground. Thus, the diode will act to effectively ground one polarity of the alternating voltage developed across the piezoelectric beam **30** when the beam is stressed.

Furthermore, instead of utilizing a transformer with a primary and a secondary winding, there is illustrated an autotransformer **52** having its lower terminal grounded. The lead **36** is connected to one of the lower windings of the autotransformer **52** so as to transform the voltage up. Hence, the peak voltage transferred when the switch **34, 35** closes is applied to the electrode **117** of the spark plug **16**.

The operation of the ignition system of FIG. 4 may best be explained by reference to FIG. 5. In FIG. 5, curve **53** illustrates the mechanical force which is applied as a function of time to the piezoelectric cantilever beam **30**. This force, as shown by curve **53**, varies essentially like a sine wave. In the absence of the rectifier **50** a voltage is developed across the piezoelectric beam **30**

which varies essentially like the curve 54 of FIG. 5. In other words, the voltage varies as a function of time in a sinusoidal manner.

Curve 55 of FIG. 5 illustrates the effect of the rectifier 50 on the voltage developed across the piezoelectric beam 30. The voltage initially builds up to a mixmum value and then begins to fall. As shown by the curve portion 57, when the voltage becomes approximately zero, the rectifier 50 begins to conduct. Thus, instead of the voltage becoming negative as shown by the dotted curve portion 56, the voltage remains at approximately zero volts until the voltage begins to rise again. The voltage now rises, as shown by curve portion 58 during the positive half cycle. When the peak voltage has been reached, the switch 34, 35 closes transferring the voltage to the autotransformer 52.

The curve portion 60 illustrates the effect of the discharge across the electrode 17 of the spark gap. It will be noticed that there is a high frequency oscillation which occurs due to the relatively large capacitance of the system and the low inductance of the auto transformer 52. This high frequency oscillation promotes a cleaner discharge through the spark gap and a better ignition of the combustible mixture in the engine cylinder.

As pointed out out before, the time constant of the ignition system of the invention is relatively large, and hence, the precise instant the voltage is applied to the spark plug is in no way critical with respect to the piezoelectric element because the voltage does not rapidly leak off before it can be applied.

Another modification of the present invention is illustated in FIG. 6 to which reference is now made. Here again there are provided two cantilever beams 23 and a piezoelectric beam 20, which is again operated through the cam 20 and lever 22. However, in FIG. 6, a disc 62 is secured to the crankshaft 10 and bears a switch arm 63 which cooperates with the fixed switch arm 64. The switch arm 64 is connected through a conductor 65 to the primary winding 37 of the transformer 38. The other terminal of the primary winding 37 is connected through conductor 66 to the piezoelectric element 30, thus forming an electric circuit which is closed through the switch arm 63, 64.

It will thus be seen that every time the crankshaft 10 makes one revolution, the switch 63, 64 closes to apply a voltage pulse to the transformer primary winding 37. A stepped-up voltage is obtained from the transformer secondary winding 40 which is then applied to one of the electrodes 17 of the spark plug.

Another switch arm 67 is mounted in a fixed position approximately opposite the switch arm 64 and is grounded as shown. This will serve to ground the opposite voltage peak developed when the piezoelectric beam 30 is flexed in the opposite direction. Thus, the arrangement of FIG. 6 is the equivalent of that shown in FIGS. 1 through 3.

In accordance with the present invention, it is not necessary that the piezoelectric element be flexed or stressed as explained in connection with FIGS. 1 through 6. It is also feasible to compress a pile of piezoelectric discs or elements and this has been illustrated in FIG. 7. As shown in FIG. 7, there is provided a plurality of piezoelectric discs 70 which may, for example, be of a circular form and pressed against the fixed support 71 and an end piece 72 of hemispherical shape may be utilized to apply force through a lever 73 pivoted at 74. The lever 73 preferably consists of a yieldable material having mechanical compliance such as steel. The free end of the lever 73 is in contact with an eccentric or cam 74 which is rotated by a shaft 75 which may, for example, be the crankshaft of an engine. Between each pair of piezoelectric discs 70 there is provided a conductive layer 76 which may, for example, be a suitable metallic foil or conductive coating which may consist of silver, copper or brass. As indicated in the drawings the discs 70 have opposite polarization and are connected electrically in parallel. Thus, the conductor 77 is grounded and may be connected to the negative terminals of the discs 70. The conductor 78 connects all the positive terminals of the discs in parallel. The conductor 78 may be connected to a rotating disc 80 having a switch arm 81 cooperating with a fixed switch arm 82 which in turn is connected to one terminal of the primary winding 37 of the transformer 38.

As a result, when the shaft 75 rotates, the discs 70 are cyclically compressed to develop during one portion of their cycle, a positive voltage which is then impressed through the switch 81, 82 upon the transformer 38 and then to one of the electrodes 17 of the spark plug.

Preferably, an even number of discs is used so that both ends of the stack of discs 70 may be maintained at ground potential.

The capacitance of the discs 70 is approximately the same as that of the beam previously described. On the other hand, it is possible to obtain an output voltage of 650 volts from the pile of piezoelectric discs of FIG. 7. This voltage can be obtained with an applied force of the order of 1600 pounds and with a stack of 26 discs having a diameter of ¾ inch and a thickness of 0.040 inch. The total capacitance of the discs is approximately 0.1 microfarad.

There has thus been disclosed an ignition system for internal combustion engines which will develop a voltage suitable for firing the spark plug of the engine. The ignition system includes a piezoelectric element which preferably consists of a lead zirconate ceramic. The piezoelectric element may either be in the form of a cantilever beam in which case it is cyclically stressed or it may consist of a pile of piezoelectric discs which are cyclically compressed. As a result, a relatively low alternating voltage is developed across the element which may then be transformed to the high voltage required for the spark plug. The piezoelectric element has a relatively high capacitance and consequently, a long time constant which may be of the order of the revolution of the combustion engine or substantially greater. Accordingly, the problem of precisely timing the transfer of the voltage to the spark plug is greatly minimized. Furthermore, leakage of the voltage is reduced to a minimum. Since the stress applied to the piezoelectric element can be applied cyclically, there is no need to produce a sudden impact on the element which may shatter or crack the ceramic.

I claim:

1. In an ignition system having a spark gap:

(A) a piezoelectric element having a time constant determined by its capacitance and its leakage resistance of the order of one second;

(B) means for mechanically and cyclically gradually stressing said element to develop a reltaively low varying voltage across said element;

(C) means coupled to said piezoelectric element for deriving a peak voltage from said piezoelectric element; and

(D) transformer means coupled in series with said means for deriving and the spark gap for delivering a transformed high voltage pulse.

2. In an ignition system for an internal combustion engine having a spark gap:

(A) an elongated piezoelectric element having a time constant determined by its capacitance and its leakage resistance which is long compared to the reciprocal of the mechanical cycle at the idle speed of the internal combustion engine;

(B) means for mechanically and cyclically bending said element in opposite directions to develop a relatively low alternating voltage across said element;

(C) means coupled to said piezoelectric element for effectively grounding one polarity of said alternating voltage and for deriving a peak voltage of opposite polarity from said piezoelectric element; and

(D) transformer means coupled in series with said means for grounding and the spark gap for delivering to the spark gap a transformed high voltage pulse.

3. In an ignition system having a spark gap:
(A) an elongated piezoelectric element having a capacitance of the order of 0.1 microfarad and a resulting time constant of the order of one second;
(B) means for mechanically and cyclically bending said element to develop a relatively low alternating voltage across said element;
(C) switch means coupled to said piezoelectric element for effectively grounding one polarity of said alternating voltage and for delivering a peak voltage of opposite polarity from said piezoelectric element; and
(D) transformer means coupled in series with said switch means and the spark gap for delivering to the spark gap a transformed high voltage pulse.

4. In an ignition system having a spark gap:
(A) an elongated piezoelectric element;
(B) means for mechanically and cyclically bending said element in opposite directions to develop a relatively low alternating voltage across said element;
(C) a rectifier connected to said piezoelectric element for grounding one polarity of said alternating voltage developed by said piezoelectric element;
(D) a switch electrically and mechanically connected to said piezoelectric element for delivering a peak voltage of opposite polarity; and
(E) transformer means coupled in series with said switch and the spark gap for delivering to the spark gap a transformed high voltage pulse.

5. In an ignition system having a spark gap:
(A) a piezoelectric element having a time constant of the order of one second determined by its capacitance of the order of 0.1 microfarad and its leakage resistance;
(B) means for mechanically and cyclically gradually compressing and decompressing said element to develop a relatively low varying voltage across said element;
(C) means coupled to said piezoelectric element for deriving a unidirectional peak voltage from said piezoelectric element;
(D) and transformer means coupled in series with said means for deriving and the spark gap for delivering to the spark gap a transformed high voltage pulse.

6. In an ignition system for an internal combustion engine having a shaft and a spark gap:
(A) a piezoelectric cantilever beam;
(B) means operating in synchronism with the rotation of the engine shaft for mechanically and cyclically applying bending stress to said piezoelectric cantilever beam to develop a relatively low cyclically varying voltage thereacross;
(C) a rectifier electrically connected to said piezoelectric beam for effectively grounding one polarity of said varying voltage;
(D) a transformer for delivering an increased output voltage;
(E) and a switch between said piezoelectric beam and said transformer, said switch being arranged to be closed in timed relation with the rotation of the engine shaft to deliver a voltage peak to said transformer, and said transformer being coupled across said spark gap.

7. In an ignition system for an internal combustion engine having a shaft and a spark gap:
(A) a pair of cantilever beams mounted back to back;
(B) a piezoelectric element disposed between said cantilever beams;
(C) means operating in synchronism with the rotation of the engine shaft for mechanically and cyclically

applying bending stress to said cantilever beams and piezoelectric element to develop a relatively-low cyclically-varying voltage across said element;
(D) a rectifier electrically connected to said piezoelectric element for effectively grounding one polarity of said varying voltage;
(E) a transformer for delivering an increased output voltage;
(F) and a switch having a terminal connected to said piezoelectric element and having its other terminal connected to said transformer, said switch being arranged to be closed in timed relation with the rotation of the engine shaft to deliver a voltage peak to said transformer, and said transformer being coupled across said spark gap, whereby high frequency oscillations are developed across the spark gap upon ignition thereof.

8. In an ignition system for an internal combustion engine having a shaft and a spark gap:
(A) a pair of cantilever beams mounted back to back;
(B) an elongated piezoelectric element disposed between said cantilever beams;
(C) means operating in synchronism with the rotation of the engine shaft for mechanically and cyclically applying stress to said cantilever beams and piezoelectric element to develop a relatively-low alternating voltage;
(D) rectifier means electrically connected between said piezoelectric element and one electrode of the spark gap;
(E) a transformer having a primary and a secondary winding for delivering an increased output voltage;
(F) and a switch having one terminal connected to said piezoelectric element and having its other terminal connected to said transformer, said switch being arranged to be closed in timed relation with the rotation of the engine shaft to deliver a voltage peak to the primary winding of said transformer, the secondary winding of said transformer being connected across said spark gap, whereby high-frequency oscillations are developed across the spark gap upon ignition thereof.

9. In an ignition system for an internal combustion engine having a shaft and a spark gap:
(A) a piezoelectric cantilever beam;
(B) means operating in synchronism with the rotation of the engine shaft for mechanically and cyclically applying bending stress to said piezoelectric cantilever beam to develop a relatively-low cyclically varying voltage thereacross;
(C) a transformer for delivering an increased output voltage;
(D) and a double-pole, double-throw switch having a first pair of contacts electrically connected between said piezoelectric beam and said transformer, said switch having a second pair of contacts electrically connected between said piezoelectric beam and ground, said switch being arranged to be closed in timed relation with the rotation of the engine shaft to ground a voltage of one polarity to deliver a voltage peak of the opposite polarity to said transformer, and said transformer being coupled across said spark gap.

10. In an ignition system for an internal combustion engine having a shaft and a spark gap:
(A) a pair of cantilever beams mounted back to back and having tapered ends and a relatively wide central portion;
(B) an elongated piezoelectric element disposed between said cantilever beams and having a time constant determined by its capacitance and leakage resistance which is long compared to the reciprocal of a mechanical cycle at idle speed of the internal combustion engine;

(C) means operating in synchronism with the rotation of the engine shaft for mechanically and cyclically applying bending stress to the central portion of said cantilever beams and piezoelectric element to develop a relatively-low alternating voltage across said element;

(D) a transformer for delivering an increased output voltage;

(E) and means including a switch coupled between said piezoelectric element and transformer and arranged to be closed in timed relation with the rotation of the engine shaft to deliver a voltage peak to said transformer, said transformer being coupled across said spark gap.

11. In an ignition system having a spark gap:

(A) a plurality of piezoelectric elements stacked upon each other with opposite polarity, said elements having a time constant of the order of one second determined by a capacitance of the order of 0.1 microfarad and the leakage resistance;

(B) means for mechanically and cyclically gradually compressing and decompressing said elements to develop a relatively-low alternating voltage across said elements;

(C) conductor means connected to one end of each of said piezoelectric elements for grounding them and connected to the other end of each of said elements for deriving a peak voltage from said piezoelectric elements;

(D) and transformer means coupled in series with said conductor means and the spark gap for delivering to the spark gap a transformed high voltage pulse.

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