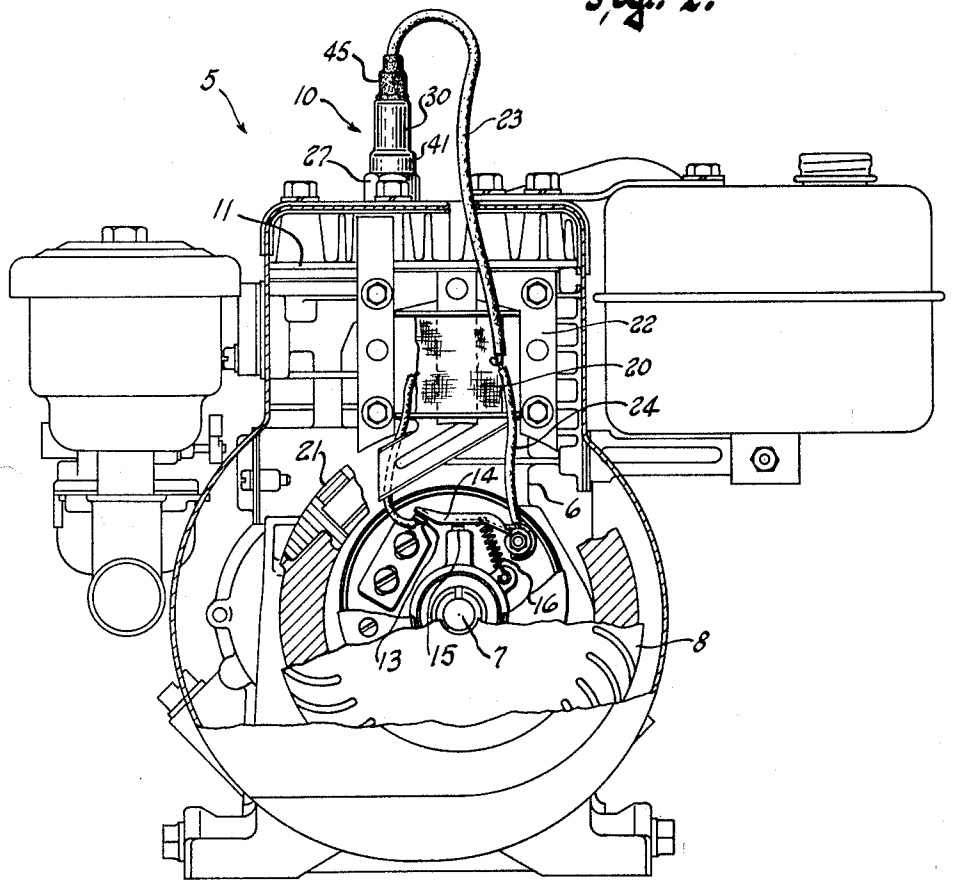
March 9, 1965 J. R. HARKNESS 3,173,055

RECIPROCATING ENGINE SPARK IGNITION APPARATUS

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Fig. 1.



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Fig. 2.

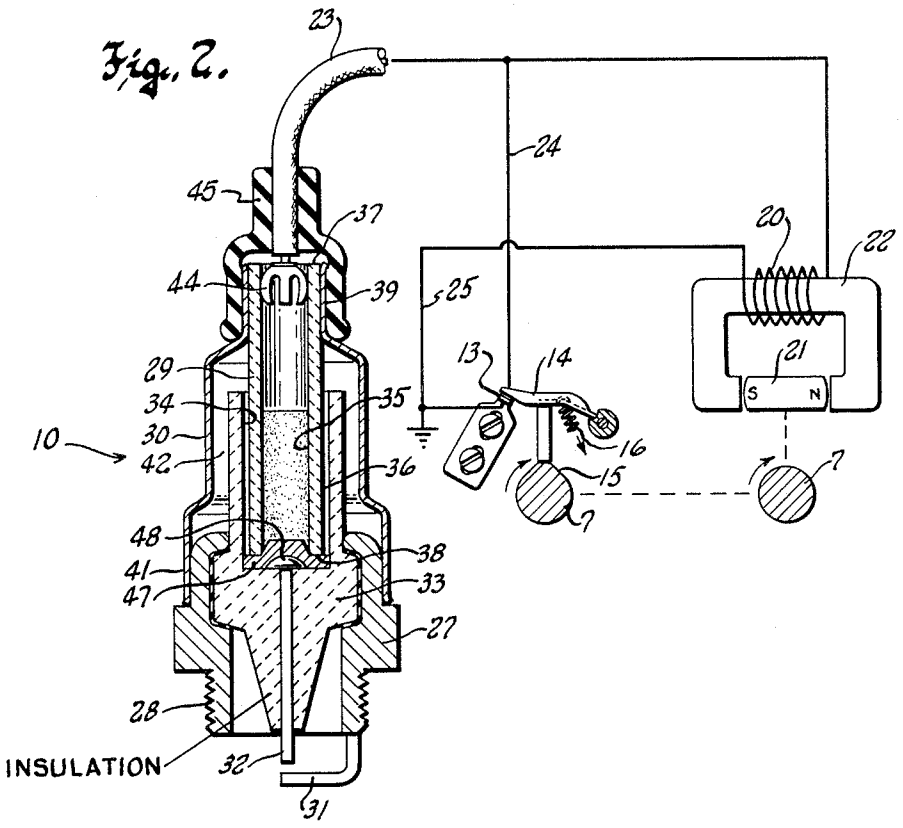
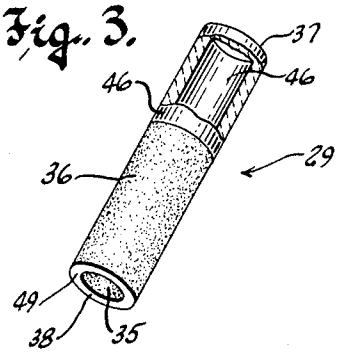


Fig. 3.



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RECIPROCATING ENGINE SPARK IGNITION APPARATUS

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This invention relates to spark ignition systems for reciprocating internal combustion engines and refers more particularly to such an ignition system wherein a piezoelectric element provides a novel means for stepping up low voltage currents to a voltage value high enough for sparking. The invention also relates to a novel spark plug for an ignition system of that type.

Recent developments in piezoelectric materials have produced a piezoelectric element which is capable of functioning as a transformer and by which an input current of one voltage value can be stepped up to a higher voltage output current without the necessity for windings such as are employed in conventional transformers. A piezoelectric element is one which is formed of a material that has the characteristic ability to effect a direct conversion of electrical energy to vibratory mechanical energy, and vice versa. Various piezoelectric materials evidence different supplemental characteristics to greater or lesser extents. Thus rochelle salt crystals, widely employed in radio applications, have been found particularly useful in maintaining a stable frequency of a high frequency alternating current, while polycrystalline piezoelectric elements of the class of materials that includes barium titanate can be subjected to high mechanical stresses without fracturing and are therefore useful for producing high voltage electrical outputs in response to mechanical stress. Recently it has been found that a class of materials that includes lead zirconate-titanate ceramics, when formed into elongated shapes, is capable of performing the function of an electrical transformer.

It is an object of the present invention to apply this recent discovery to the provision of a spark ignition system for reciprocating internal combustion engines, which system is inexpensive, very compact and light in weight, and very dependable.

More specifically, it is another object of this invention to provide a spark ignition system for reciprocating internal combustion engines which eliminates the secondary winding that has heretofore been present in conventional systems, either as the secondary of a magneto winding or as the secondary of a battery ignition coil, and whereby the cost, weight and bulk of such a secondary are eliminated along with the copper wire, insulation and potting required for the secondary.

It is another object of this invention to eliminate the condenser which has heretofore been conventional in both magneto and battery ignition systems.

In place of the secondary winding and condenser, the present invention contemplates the employment in a spark ignition system of a piezoelectric element which functions in the nature of a transformer and which can be incorporated in the spark plug. Thus an additional object of this invention is to provide a new and novel spark plug for internal combustion engines, which incorporates a piezoelectric element that performs the functions heretofore separately assigned to a secondary winding and a condenser.

Another and very important object of this invention is to provide an ignition system which eliminates the conventional high tension lead to the "hot" side of the spark plug, providing instead a low voltage lead that carries currents of no higher voltage value than those appearing

across the breaker points in heretofore conventional ignition systems.

Elimination of the high tension lead as such is of course a very desirable objective in an ignition system. In conventional ignition apparatus it has always been necessary to provide very sound insulation for the high tension lead, to prevent sparking from that lead to the engine body. When such sparking occurred, no spark could develop across the plug electrodes, and the engine therefore missed or failed to run at all. Since such sparking from the high tension lead could occur anywhere along its length, and it was necessarily in close proximity to the engine body (all parts of which were at ground potential) through a substantial portion of its length, shorting out of the spark plug was a common and very troublesome problem with prior ignition systems. Less well known is the fact that the high tension lead, because of its length, has a substantially high capacity, and therefore a large proportion of the energy output of the secondary of a conventional magneto or battery ignition system is devoted to merely charging the high tension lead capacitance.

With this in mind, it is still another object of this invention to provide spark ignition apparatus for a reciprocating internal combustion engine, featuring a novel spark plug that incorporates voltage step-up means, wherein the "hot" lead to the spark plug carries a very low voltage, no greater than that across the breaker points in a conventional ignition system, and which thus avoids the inefficiency and the possibility of troublesome shorting out of the plug that were inherent in prior ignition systems employing a high voltage spark plug lead.

With the above and other objects in view which will appear as the description proceeds, this invention resides in the novel construction, combination and arrangement of parts substantially as hereinafter described and more a particularly defined by the appended claims, it being understood that such changes in the precise embodiment of the hereindisclosed invention may be made as come within the scope of the claims.

The accompanying drawings illustrate one complete example of the physical embodiment of the invention constructed according to the best modes so far devised for the practical application of the principles thereof, and in which:

FIGURE 1 is an elevational view of a single cylinder gasoline engine incorporating an ignition system and spark plug embodying the principles of this invention, portions of the engine being broken away to show details of the ignition system;

FIGURE 2 is a vertical sectional view of the spark plug of this invention, shown connected to the ignition system of the invention which is represented more or less diagrammatically; and

FIGURE 3 is a perspective view of the piezoelectric element which is a component of the spark plug, with a portion of the element broken away.

Referring now to the accompanying drawings, the numeral 5 designates a portable single-cylinder gasoline engine which typifies one type of installation to which the ignition system of this invention is adaptable. The engine includes the usual cylinder 6 in which a piston (not shown) is reciprocable to rotatably drive a crankshaft 7, and the crankshaft carries a flywheel 8 that also serves as a blower by which cooling air is forced across the cylinder.

A spark plug 10 of this invention is mounted in the head 11 of the engine cylinder 6, being received in the threaded hole in the cylinder head in the same manner as a conventional spark plug. In fact, with suitable modification of other portions of the ignition system, the nature of which will become apparent as the description

proceeds, the spark plug of this invention can be used as a replacement for a conventional plug.

In addition to the novel spark plug 10, the ignition system of this invention comprises a pair of breaker points 13, one of which is fixed to the engine body and the other of which is mounted on an arm or carrier 14 that is actuated by cam mechanism 15, driven by the engine crankshaft, for swinging motion by which the movable breaker point is carried toward and from engagement with the fixed breaker point. A spring 16 biases the arm 14 in the direction to close the breaker points, and the points are maintained closed during the major portion of each crankshaft revolution. While herein referred to by the term "breaker points" it will become apparent that the points 13 are in the nature of ordinary switch contacts and do not function in the same manner as conventional breaker points.

In this case the ignition current source is a small generator comprising a winding 20, mounted on the engine body, and a permanent magnet 21 which is carried for orbital motion by the flywheel 8. The winding has a suitable magnetically permeable core 22 through which a flux circuit is established each time the flywheel carries the magnet to a position in its orbit at which the pole pieces of the magnet align with the pole pieces of the core. The buildup and collapse of the flux field thus linked with the winding as the magnet is swept through said position induces a voltage across the winding.

One end of the winding is directly connected with the "hot" side of the spark plug 10 by means of an insulated conductor 23, and with the movable breaker point arm 14 by means of a conductor 24 (see FIGURE 2). The other end of the winding is grounded to the engine body, as by means of a conductor 25. The fixed breaker point is also grounded, and therefore when the breakers are closed the winding is short circuited and no current can flow to the spark plug. Hence the cam mechanism 15 is so arranged that the breakers are open during that portion of each crankshaft revolution at which spark plug firing is to occur, and the winding 20 is so located with respect to the orbit of the permanent magnet 21 that the maximum voltage is developed across it at the time that the breaker points are open and such voltage is being applied to the spark plug 10.

The spark plug 10 comprises an annular metal base portion 27 which is threaded as at 28 for engagement in a conventional spark plug hole in a cylinder head, an elongated piezoelectric element 29, a metal shell 30 which is mechanically and electrically connected to the base portion 27 and to the piezoelectric element and which cooperates with the base portion to provide a housing for the piezoelectric element, and a pair of sparking electrodes 31 and 32, one of which, designated by 31, is secured to the base portion 27 and thus grounded to the engine body, and the other of which is coaxially mounted in an insulator 33. The insulator is coaxially supported by the base and has a downwardly opening coaxial bore in which the electrode 32 is snugly received and an upwardly opening counterbore in which the lower portion of the piezoelectric element 29 is received.

The piezoelectric element is preferably tubular, so as to have radially opposite inner and outer faces 35 and 36 and axially oppositely facing upper and lower end surfaces 37 and 38. It is made of a lead zirconate-titanate ceramic, and since such material is capable of satisfactory operation at temperatures as high as 500° F. a piezoelectric element of this type is well suited for incorporation in a spark plug.

The piezoelectric element 29 is coaxially held in the well defined by the counterbore 34 in the insulator 33 by means of the metal shell 30. To this end the upper end portion of the shell has a reduced diameter so as to be snugly engaged around the outer face of the piezoelectric element, as at 39, to thus provide a good electrical and mechanical connection between the shell and the piezoelectric element.

The lower portion of the shell, which is of relatively large diameter, is secured as at 41 to the base portion 27 of the plug and has a good electrical and mechanical connection therewith. The shell thus provides an electrode at its upper end which is in contact with the radially outer surface of the piezoelectric element near the upper end thereof and a conductor connecting said electrode with the grounded base portion 27 of the plug. Below its electrode portion the shell has an inside diameter which is substantially larger than the outside diameter of the piezoelectric element, so that all parts of the shell other than its electrode portion are well insulated from the piezoelectric element, both by an air space 42 and by the tubular wall of the upper portion of the insulator 33.

The other side of the input circuit to the piezoelectric element is provided by a spider-like electrode 44 having a plurality of diverging fingers that engage the radially inner face of the tubular element near its upper end which are biased radially outwardly to maintain a good mechanical and electrical connection with the piezoelectric element. The electrode 44 has the conductor 23 connected thereto and is thus connected with the ungrounded side of the winding 20. A boot 45 of rubber or the like fits snugly over the upper end of the shell and the adjacent end of the conductor 23 to keep moisture and the like out of the interior of the plug and provide additional support for the inner input electrode 44.

Preferably the radially inner and outer surfaces of the piezoelectric element near its upper end are coated with films 46 of silver or other highly conductive material (see FIGURE 3) to insure good electrical connections between the element and the electrodes 39 and 44.

The lower end surface 38 of the piezoelectric element is electrically connected with the ungrounded sparking electrode 32 by means of a suitably formed conductor disc 47 upon which the piezoelectric element rests, and which in turn rests upon the bottom of the well defined by the counterbore 34 in the insulator 33. To insure good contact between the piezoelectric element and the disc 47, the lower end surface of the element may be coated with a film 49 of silver or the like. Preferably the electrode 32 has an enlarged head 48 which engages the underside of the conductor disc 47 to make good contact therewith and which helps to fix said electrode in the insulator 33.

When the breaker points are open, to permit a momentary current flow from the generator to the input electrodes 39 and 44, the piezoelectric element is excited into a mechanical resonance along its length by the voltage applied across said electrodes, producing a strain along the length of the element which is transformed into a voltage appearing across the electrodes 38 and 39, the electrode 39 of course being grounded and common to both the input and output circuits.

For optimum results there must be a proper correlation between the rate of change of flux through the magnetic circuit due to orbital movement of the permanent magnet 21 relative to the winding core 22, the inductance of the winding 20, the capacity of the input circuit that includes the electrodes 39 and 44, and the natural resonant frequency of the piezoelectric element. Thus the inductance of the winding 20 and its magnetic circuit must have a natural frequency with the capacitance across the input electrodes 39 and 44 which is one of the natural modes of the mechanical vibration of the piezoelectric element.

It will be apparent that the ignition system of this invention requires no capacitor corresponding to the conventional ignition condenser because opening of the breaker points does not effect opening of the winding circuit but merely reconnects the winding with the piezoelectric element input circuit, which itself has capacitance across the input electrodes 39 and 44.

Obviously the generator comprising the magnet 21 and winding 20 can be replaced by a battery or similar

source of low voltage current, the breaker points being suitably reconnected to effect closure of the input circuit in timed relation to crankshaft rotation. Even with a battery current source, a winding in the input circuit may be found desirable to tune said circuit to a frequency which is one of the natural modes of mechanical vibration of the piezoelectric element.

From the foregoing description taken together with the accompanying drawings, it will be apparent that this invention provides a spark ignition system for reciprocating internal combustion engines wherein a piezoelectric element provides a novel means of stepping up low voltage currents to a voltage value high enough for sparking, and wherein such piezoelectric element is incorporated in a novel spark plug. It will be further apparent that the invention also does away with the conventional secondary windings of battery and magneto ignition coils, and the conventional ignition condenser, and has the further and very importat advantage that the "hot" lead to the spark plug carries only low voltage current.

What is claimed as my invention is:

1. A spark ignition system for a reciprocating internal combustion engine comprising: a low voltage generator comprising a magnet element and a coil element, one of said elements being driven by the engine crankshaft for movement relative to the other, for generation of a low voltage in the coil element; a pair of breaker points connected with the opposite ends of the coil element and engageable with one another to short-circuit the coil element; breaker point actuating means driven by the crankshaft for periodically engaging and disengaging the breaker points in timed relation to crankshaft rotation; an elongated piezoelectric element of lead zirconate-titanate ceramic having a pair of electrodes on opposite faces at one end thereof and one electrode at the opposite end thereof; conductor means electrically connecting the ends of the coil element with said pair of electrodes on the piezoelectric element; a pair of sparking electrodes mounted in spaced apart spark gap defining relationship; means electrically connecting one of said spark plug electrodes with one end of the coil element; and means electrically connecting the other of said spark plug electrodes with said one electrode on the piezoelectric element.

2. A spark plug for an internal combustion engine comprising: an elongated tubular piezoelectric element of lead zirconate-titanate ceramic; electrically conductive means providing a pair of low voltage input eletcrodes overlying inner and outer opposite faces of the piezoelectric element at one end thereof; a pair of sparking electrodes; insulating means mounting said piezoelectric element and the sparking electrodes in fixed relation to one another, with the sparking electrodes spaced from the other end of the piezoelectric element and substantially in line therewith; conductor means connected with said other end of the piezoelectric element and with one of said sparking electrodes; and other conductor means connected with one of said low voltage input electrodes and with the other sparking electrode.

3. The spark plug of claim 2, wherein said other conductor means comprises a metal shell and a metal plug body which cooperates with the shell to provide a housing for the piezoelectric element, said metal plug body having screw threads on a portion of the surface thereof by which the spark plug can be secured to an engine to provide a grounded connection, through the engine, with a current producing means.

4. A spark plug for an internal combustion engine comprising: an elongated tubular piezoelectric element of lead zirconate-titanate ceramic; a contactor having a plurality of fingers engaged under radially outward bias with the inner surface of the piezoelectric element, near one end thereof; a low voltage input terminal connected with said contactor; a conductive shell surrounding the piezoelectric element along the length thereof and having a portion engaged under radially inward bias with the radially outer surface of the piezoelectric element near said end thereof, all other portions of said shell being insulated from the piezoelectric element; a pair of sparking electrodes; conductive means cooperating with said shell and with one of said sparking electrodes to provide a connection between them and a means for securing the spark plug to an engine in electrically grounded relation thereto; and conductor means connecting the other sparking electrode with the other end of the piezoelectric element.

5. An ignition system for producing sparks in timed relation to rotation of the crankshaft of a reciprocating internal combustion engine, comprising: means including a crankshaft driven member for producing low voltage input current pulses in timed relation to crankshaft rotation; an elongated piezoelectric element of lead zirconate-titanate ceramic; a pair of input electrodes on opposite faces of one end portion of the piezoelectric element; means electrically connecting said input electrodes with said low voltage input current producing means; a pair of sparking electrodes mounted in spaced apart spark gap defining relationship; and means electrically connecting the sparking electrodes with the opposite end portions of the piezoelectric element.

6. An ignition system for producing sparks in timed relation to rotation of the crankshaft of an internal combustion engine, comprising: means for producing low voltage input current pulses in timed relation to crankshaft rotation, comprising a magnet element, a coil element, and means drivingly connecting one of said elements to the crankshaft for movement relative to the other, for generation of low voltage currents in the coil element; an elongated piezoelectric element of lead zirconate-titanate ceramic, having a pair of input electrodes on opposite faces at one end thereof; conductor means electrically connecting the opposite ends of the coil element with the input electrodes; crankshaft actuated switch means connected with the opposite ends of the coil element for short circuiting the same at times when sparking is not desired; a pair of sparking electrodes mounted in spaced apart spark gap defining relationship; and means electrically connecting the sparking electrodes with the opposite ends of the piezoelectric element.

7. The ignition system of claim 6, wherein the inductance of the coil element is such that when it is coupled with the capacitance provided by the input electrodes of the piezoelectric element the natural frequency of the circuit that includes said coil element and capacitance is equal to one of the natural mechanical vibration frequency modes of the piezoelectric element.

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