

Feb. 4, 1964

R. J. McCRORY ET AL
GENERATOR

3,120,220

Original Filed May 16, 1958

2 Sheets-Sheet 1

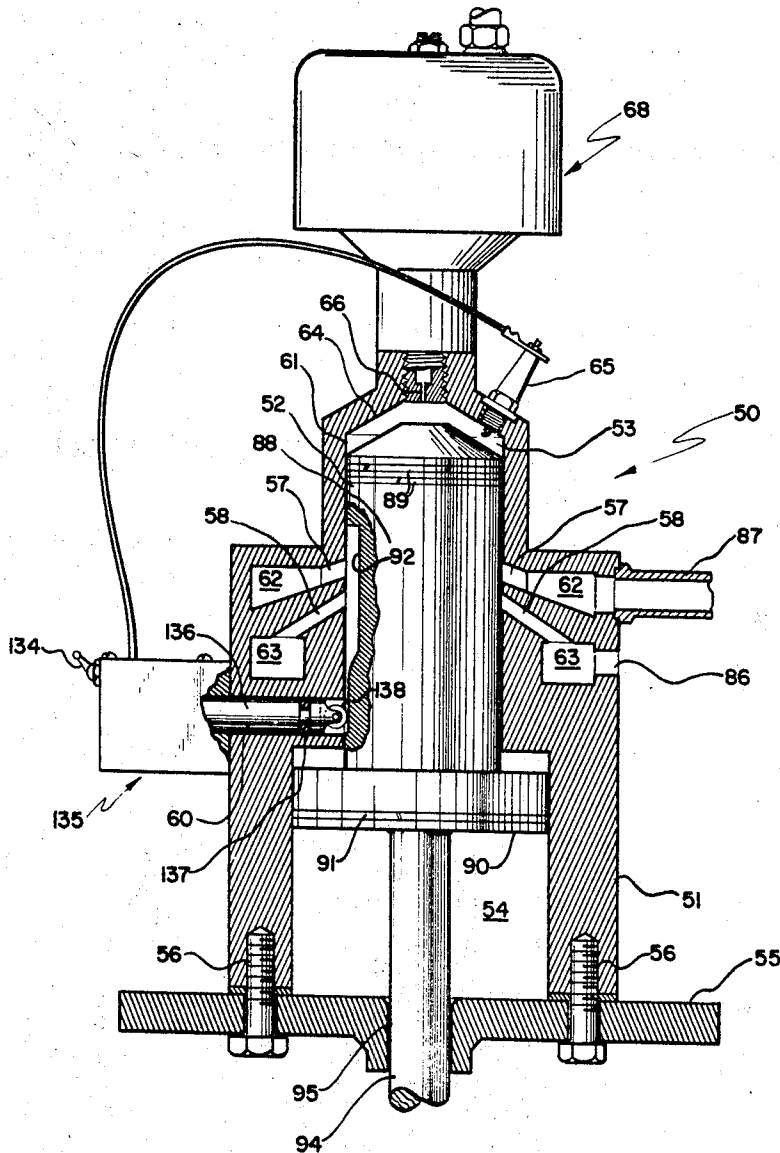


Fig. 1

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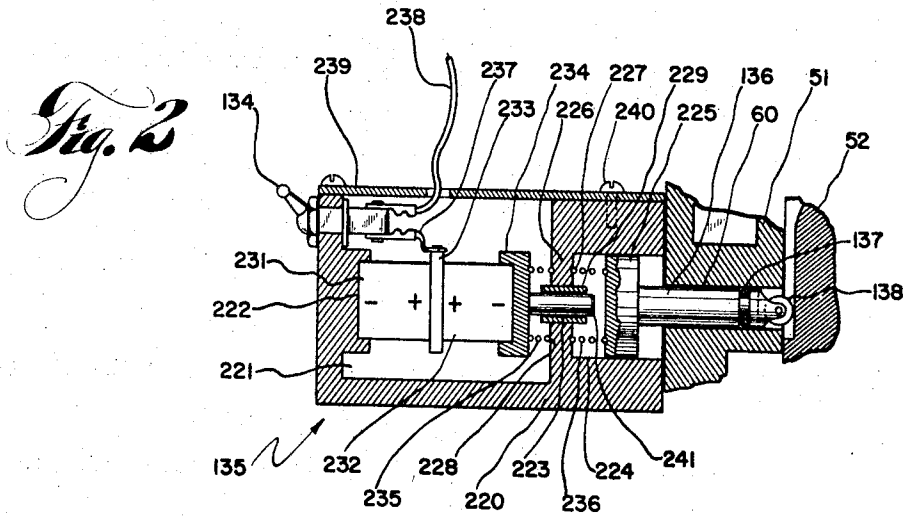
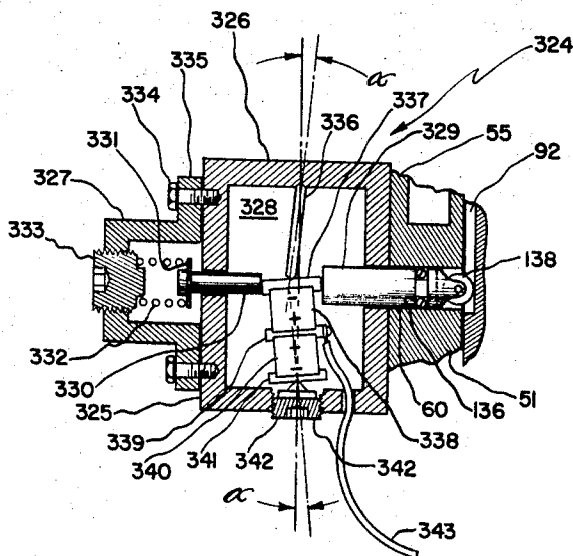


Fig. 3

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GENERATOR

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Original application May 16, 1958, Ser. No. 735,795, now Patent No. 2,959,159, dated Nov. 8, 1960. Divided and this application Mar. 16, 1960, Ser. No. 15,438
5 Claims. (Cl. 123-46)

This invention relates to internal-combustion engines of the free-piston type, and, particularly, to improvements in the ignition. This invention is a divisional application of copending application, "Free-Piston Internal-Combustion Apparatus," Serial No. 735,795, filed May 16, 1958, now issued as U.S. Patent No. 2,959,159 on Nov. 8, 1960.

Free-piston engines are those in which the reciprocating motion of this piston, or pistons, is not mechanically restrained by the conventional connecting rod and crank shaft. Although most of the multipiston free-piston engines have mechanical connections between the pistons to maintain the proper phasing between the pistons, the end positions of the piston stroke are not established by the mechanical connections. The end positions of the piston stroke are established on each engine cycle by the energy released to the work article or load that is being driven by the engine, the energies of the combination of the combustion process, and the resilient rebound system.

The present invention includes a piezoelectric generator adapted to be operated directly from the reciprocation of the free piston to generate an ignition potential simultaneously with the need therefor and at the proper time therefor.

A feature of the present invention is the way in which the elements of the piezoelectric generator are positioned with common poles in connection with a common terminal centrally positioned between the elements so that problems of electrical insulation are greatly reduced and the proper voltage is obtained to fire the igniter with minimum force being applied to the elements. Another feature of the electrical generator is its construction to provide individual electrical impulses at a precisely timed, rapidly repeating rate required for effective combustion control in the free-piston engine.

Briefly described, the piezoelectric generator is comprised of: a plurality of piezoelectric elements, each being mounted at an end of common polarity to a terminal; frame means for supporting at least one of the elements at an end of opposite polarity; resilient means supported by the frame means and stressing at least one element through at least one other of the elements against the housing; and means reciprocal in the frame means to change the stress in the elements producing an electrical potential between the terminal and the support means, equal to the combined potential generated in the elements.

In the drawings:

FIG. 1 is an elevational, partially sectioned view of a free-piston engine having the features of the ignition system of this invention;

FIG. 2 is a sectional, elevational view of an ignition generator which is a part of this invention; and

FIG. 3 is a sectional, elevational view of another form of ignition generator which is a part of this invention.

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Referring to FIG. 1, a free-piston engine 50 comprises a block or frame 51 and a free piston 52 reciprocal therein. The frame 51 is provided with an internally bored combustion cylinder 53 and provided in communication therewith is a coaxial greater-diameter compression cylinder 54 which is a part of the resilient rebound system.

Closing the compression cylinder 54 at the end opposite the combustion cylinder 53 is a base or mounting plate 55 fastened to the block 51 by suitable means, such as screws 56. The combustion cylinder 53 is provided with exhaust ports 57, intake ports 58, and cam follower bore 60 at spaced intervals along the cylinder wall 61 thereof. An exhaust manifold 62 encircles the combustion cylinder 53 having an annular form and cast integrally with the frame 51. Communication is provided between the exhaust manifold 62 and the combustion cylinder 53 by means of the exhaust ports 57.

An annular intake manifold 63 is also provided in the frame 51 at a position further removed from the head end of the combustion cylinder. Communication is established between the combustion cylinder 53 and the intake manifold 63 by intake ports 58.

At the head end 64 the combustion cylinder 53 is provided with ignition means 65, such as a spark plug. Centrally positioned on the axis of the combustion cylinder 53, at the head end 64, is the fuel nozzle 66 of a fuel injector, designated generally as 68.

An air inlet 86 is provided at one position in the intake manifold 63 and an exhaust outlet 87 is provided at one position in the exhaust manifold 62.

As shown in FIG. 1, piston 62 is constructed with a minor diameter portion 88 that is adapted to reciprocate in the combustion cylinder 53, being sealed with the cylinder walls 61 by means of piston ring 89. At the opposite end, piston 52 is formed in a greater diameter portion 90 which is adapted to reciprocate in a compression cylinder 54 and is sealed in connection therewith by means of the piston ring 91. A rod 94 is attached to the greater diameter portion 90 and passes through bearing surface 95 in the mounting plate 55. Rod 94 may be used as a connection for obtaining useful work from the free-piston engine 50.

The minor-diameter portion 88 is provided with a longitudinal cam groove 92. At one side of the engine 50 is located a generator 135 having a cam follower rod 136 adapted to reciprocate in bore 60. Cam follower rod 136 is provided with sealing means 137 within the bore 60, and carries, for freely rotatable motion, a generator cam follower 138. Cam follower 138 is adapted to roll in cam groove 92 of piston 52.

In the operation of free-piston engine 50, since there is no flywheel effect to keep the piston 52 reciprocating in the event that there is a combustion failure, i.e., misfire for one or two strokes, it is essential that the combustion system be reliable and closely controlled. Critical elements in the combustion cycle are the provision of an adequate ignition potential and the proper coordination of the timing of this potential with fuel and pressure conditions in the combustion cylinder 53.

The piezoelectric generator provided in this invention is conceived and constructed to provide these necessary elements.

Referring to FIG. 2, a generator, designated generally as 135, is constructed in a housing 220 that is attached

to the frame 51 by suitable means (not shown). Housing 220 is formed with an open chamber 221 having at one end a socket 222 and at the other end an aperture 223. The aperture 223 communicates with the bore 224. A hammer 225 is constructed to reciprocate in the bore 224, being guided thereby. Hammer 225 is provided with an integral projecting generator rod 136 which is constructed to reciprocate in cam follower bore 60 of frame 51.

Chamber 221 and bore 224 are separated by an annular flange 226 which is provided at opposite sides with annular groove 227 and 228, respectively, and which support, at the central aperture 223 thereof, a bushing or guide 229.

Piezoelectric elements 231 and 232 are disposed within chamber 221 and are assembled with an end of common polarity to a terminal 233. Element 231 is supported at the end of opposite polarity in socket 222. On the other side of the terminal 233 element 232 is fitted at the end of opposite polarity into an anvil member 234. Anvil 234 is provided with a projecting striker pin 241, which is disposed in bushing 229 and adapted to reciprocate therein. Resilient means, such as compression spring 235, is disposed between anvil 234 and flange 226 to assist in supporting anvil 234 and the elements 231 and 232. Another resilient means, such as compression spring 236, is provided between flange 226 and the end of hammer 225 to urge hammer 225 toward piston 52, and to keep follower 138 in contact with the bottom of groove 92. Terminal 233 is electrically connected at one end, by a wire 237 to a pole of switch 134. The other pole of switch 134 is connected by a lead 238 to the igniter 65, as shown in FIG. 1.

Generator 135 is provided with a cover 239 which is held in place by suitable means such as screws 240. In the operation of the piezoelectric generator, upon each follower or downstroke of piston 52, cam follower 138 drops into the deeper portion of groove 92 urged by spring 236 which presses against hammer 225. With switch 134 turned on to contact lead 237 with lead 238, upward movement of piston 52 forces generator rod 136 radially outward when cam follower 138 reaches a slope in groove 92. The speed of piston 52 is set so that when follower 138 strikes the slope in groove 92, the follower 138, generator rod 136, and hammer 225 are projected radially outward beyond the position shown in FIG. 2. Their travel is sufficient to strike an impact striker pin 241 of anvil 234. The force of impact upon anvil 234 momentarily subjects elements 231 and 232 to high compressive stress, thereby generating an electrical potential between housing 220 (frame 51, etc.) and lead 238.

After impact, spring 236 moves hammer 225 with generator rod 136 and follower 138 radially inward to the position shown in FIG. 7. On the next downward stroke of piston 52 the cam follower 138 again drops into the deeper portion of groove 92. The generator cycle is repeated as above described at once for each reciprocation of piston 52.

Among the advantages and features of generator 135 over similar units of the past is a single polarity construction. In connection with the free-piston engine, generator 135 provides a notable advantage of precise timing of ignition electrical impulses which is so necessary in operation of engines of this class.

In the generator 135 construction shown, the necessity for elaborate precautions to insure electrical insulation between the two sides of the line has been removed. With elements 231 and 232 positioned in contact with terminal 233 at their end of common polarity and supporting terminal 233 therebetween, there is no need for electrical insulation at either end of either element. There is therefore a notable advantage in manufacture of parts and assembly of units in the generator construction process. In addition, reliable trouble-free operation is provided.

The cam and follower operation of the generator 135

directly from the piston not only provides precise ignition timing but also provides for the utilization of a portion of the engine output that is directly for auxiliary functions. Generator 135 produces an electrical potential as a direct result of reciprocating motion. This is particularly advantageous when used in conjunction with the free piston engine 50 because reciprocating motion is the only type of motion provided by this engine. The rotary generator would require a complicated means of deriving rotary motion from the reciprocating action of the free piston.

A feature of the generator 135 is its compactness in comparison with conventional ignition generators for internal-combustion engines. This is a particular advantage when the engine is embodied in a portable hand tool as it provides increased ease of handling from both a maneuverability and a weight standpoint.

Another embodiment of a piezoelectric generator forming a part of the free-piston engine 50 of this invention is shown in FIG. 3. The generator 324 of this embodiment comprises a housing 325 constructed in two parts, a generator frame 326, and pre-stress adjustment member 327. Generator frame member 326 is fastened to engine frame 55 by suitable means such as screws, not shown, and includes a hollow inner chamber 328. The actuator rod 136 is disposed at one side of chamber 328 having an intimately projecting end 329.

A stress rod 330 projects into chamber 328 at the opposite side and is disposed and guided for reciprocal movement in housing 325 coaxially with the longitudinal axis of actuator rod 136. At the opposite end, stress rod 330 is provided with a shoulder 331 which is adapted to receive and center resilient means 332, such as a compression spring. Compression spring 332 is positioned on the end of an adjustment screw 333 which is threadedly engaged in housing member 327. Pre-stress adjustment member 327 is fastened to generator housing 326 by suitable means, such as screws 334, through flanges 335.

Compressed between opposite sides of housing 326 are a column 336, a fulcrum cap 337, a first piezoelectric element 338, a terminal plate 339, a second piezoelectric element 340, a bearing cap 341, and a pivot screw 342.

Fulcrum cap 337 is adapted at one side to receive one pole of the first element 338 and at the opposite side to receive one end of column 336 in a rockable knife-edge-bearing fit. Fulcrum cap 337 is rounded at each end and bears against the end surface of actuator rod 136 and the end surface of stress rod 330.

Column 336 is provided at each end with knife-edge bearing supports to permit slight pivotal movement with respect to its surface of engagement with the frame 326 and its surface of engagement with the fulcrum cap 337.

Terminal 339 is compressed between similar poles of the first element 338 and the second element 340, respectively, and is provided with a lead 343 for connection to igniter 65. The opposite end of the second element 340 is supported by bearing cap 341. At its other side, bearing cap 341 impinges on the knife edge of the upper element on pivot screw 342. The lower segment of pivot screw 342 is threadedly engaged in housing 326.

The length of column 336 and the stacked length of fulcrum cap 337, elements 338 and 340, plate 339 and bearing cap 341 are established greater than the distance between the opposite sides of frame member 326. In assembly, longitudinal axis of column 336 is inclined at an angle with a perpendicular to the axis of stress rod 330. The longitudinal axis of the stack members at the opposite side is also disposed in an angle with a perpendicular to the axis of stress rod 330. In assembled position, as shown in FIG. 18, the force of spring 332 produces compression in column 336 and elements 338 and 340.

Operation of the generator 324 is as follows: As the piston moves upward, cam follower 138 in groove 92 strikes the slope portion thereof and is projected radially

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outward. Outward movement of actuator rod 136 moves fulcrum cap 337 to the left along with stress rod 330 against the urging of compression spring 332. Movement of fulcrum cap 337 to the left increases the distance between the seat or column 336 in housing 326 and the seat or the opposite end of column 336 in fulcrum cap 337. The increase in the distance between these seats decreases the amount of compression in column 336 relieving the compressive stress on first and second piezoelectric elements 338 and 340. The reduction in the compressive stress in first and second piezoelectric elements 338 and 340, respectively, at a rapid rate, causes these elements to generate an electrical potential between opposite poles, and this potential is transmitted through leads 343 to the igniter 65 of engine 50.

Adjustment in the compressive stress in the piezoelectric crystals 338 and 340 may be made by turning adjustment screw 333 and pivot screw 342. Wear in the pivots may be compensated for in the same way.

The piezoelectric generators 135 and 324 provide a common advantage in construction in that a plurality of piezoelectric elements are combined with their common poles electrically connected to a common terminal to greatly reduce the necessity for electrical insulation in a device of this class. Also, the same compressive force or stress on the elements will produce twice the amount of energy of one element because the deflection for the two elements is twice that for one element. In addition, each of these generator embodiments provides a means of utilizing the reciprocal motion of the free piston directly, to generate the ignition potential necessary for combustion. It would be a serious disadvantage and complication if means were not provided with the engine 50 to generate the necessary ignition potential directly, as the reciprocal motion of the piston would have to be converted to rotary motion for use in a conventional electric generator.

The compactness and light weight of the generators 135 and 324 facilitates the portability and maneuverability of free-piston engine 50, and this is an important advantage when the engine is provided as either an impact tool, a saw, a pump, a compressor, a reciprocating electric generator or any other important application.

It will be understood, of course, that while the forms of the invention herein shown and described constitute the preferred embodiments of the invention, it is not intended herein to illustrate all the possible equivalent forms or ramifications of the invention. It will also be understood that the words used are words of description, rather than of limitation, and various changes, such as changes in shape, relative size, and arrangement of parts may be substituted without departing from the spirit and scope of the invention herein described.

What is claimed is:

1. A piezoelectric generator comprising: a pair of piezoelectric elements, each element being mounted at one end of common polarity to a terminal; a housing member supporting one of said elements at the end of opposite polarity in a rockable base member; a cap member positioned at the end of opposite polarity of the other of said elements and supported by support means including a rockable column member between said cap member and said housing member; a stress rod slidable in said housing member bearing against said cap member; and an actuator rod slidable in said housing member bearing against said cap member; resilient means positioned between said housing and said stress rod urging said stress rod against said cap member and compressively stressing said elements; and means moving said actuator rod against the urging of said resilient means to reduce the stress in said elements and to produce an electrical potential between said terminal and said housing member equal to the combined potential generated in both of said elements.

2. A piezoelectric generator comprising: a pair of piezoelectric crystals, each crystal being mounted at one end of

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common polarity to a terminal; a housing member supporting one of said crystals at the end of opposite polarity in a rockable base member; a cap member positioned at the end of opposite polarity of the other of said crystals, said cap member being supported by a rockable column member between said cap member and said housing member, the combined lengths of said column member, base member, cap member, and crystals being greater than the distance between opposite sides of said housing member; a stress rod slidable in said housing member bearing against one side of said cap member; an actuator rod slidable in said housing member and bearing against the side of said cap member opposite said stress rod; resilient means urging said stress rod against said cap member and wedging said crystals and column members in compression between opposite sides of said housing member; and means moving said rod against the urging of said resilient means to relieve the stress in said crystals and to produce an electrical potential between said terminal and said housing member equal to the combined potential generated in both of said crystals.

3. In a free-piston internal-combustion apparatus, a generator system comprising: a pair of piezoelectric crystals, each crystal being mounted at one end of common polarity to a terminal; a housing member supporting one of said crystals at the end of opposite polarity in a rockable base member; a cap member positioned at the end of opposite polarity of the other of said crystals, said cap member being supported by a rockable column member between said cap member and said housing member, the combined length of said column member, base member, cap member and crystals being greater than the distance between opposite sides of said housing member; a stress rod slidable in said housing member bearing against one side of said cap member; an actuator rod slidable in said housing member and bearing against the side of said cap member opposite said stress rod; resilient means urging said stress rod against said cap member and wedging said crystals and column member in compression between opposite sides of said housing member; a free piston having a longitudinal cam groove; a cam follower engaging said cam groove and connected to said actuator, moving said actuator rod against the urging of said resilient means on each reciprocation cycle of said free piston to relieve the stress in said crystals and to produce an electrical potential between said terminal and said housing member equal to the combined potential generated in both of said crystals.

4. In a free-piston internal-combustion engine apparatus, a generator system comprising: a free piston having a longitudinally cam groove; a plurality of piezoelectric elements, each being mounted at an end of common polarity to a terminal; frame means for supporting at least one of said elements at an end of opposite polarity; resilient means supported by said frame means and stressing said at least one element through at least one other of said elements against said frame; and reciprocal means in said frame activated by said cam groove on the free piston to change the stress in said elements producing an electrical potential between said terminal and said support means, equal to the combined potential generated in said elements.

5. In a free-piston internal-combustion apparatus, a generator system comprising: a free piston having a longitudinal cam groove; a pair of piezoelectric elements, each element being mounted at one end of common polarity to a terminal; a housing member supporting one of said elements at the end of opposite polarity in a rockable base member; a cap member positioned at the end of opposite polarity of the other of said elements and supported by support means including a rockable column member between said cap member and said housing member; a stress rod slidable in said housing member bearing against said cap member; and an actuator rod having a cam follower in contact with said longitudinal cam

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groove, said actuator rod slidable in said housing member bearing against said cap member; resilient means positioned between said housing member and said stress rod urging said stress rod against said cap member and compressively stressing said elements; and a cam follower attached to said actuator rod and in contact with said longitudinal cam groove to move said actuator rod against the urging of said resilient means to reduce the stress in said element and to produce an electrical potential be-

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tween said terminal and said housing member equal to the combined potential generated in both of said elements.

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