

May 20, 1969

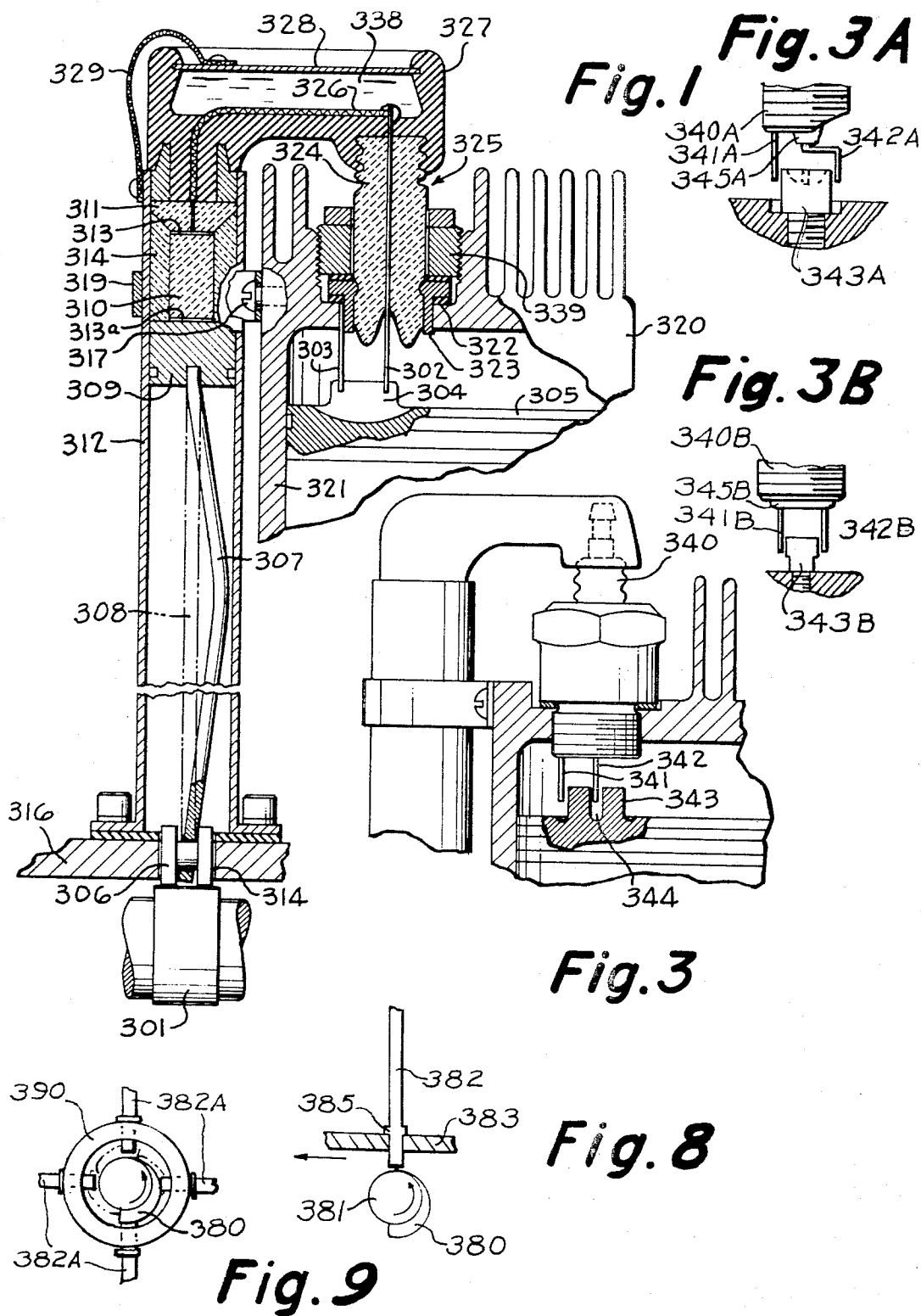
J. J. HORAN

3,444,850

VOLTAGE-GENERATION APPARATUS AND IGNITION SYSTEMS

Filed Aug. 8, 1967

Sheet 1 of 2



May 20, 1969

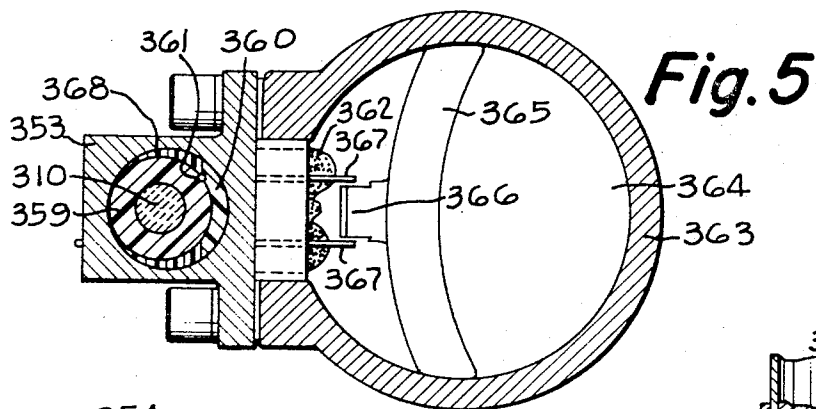
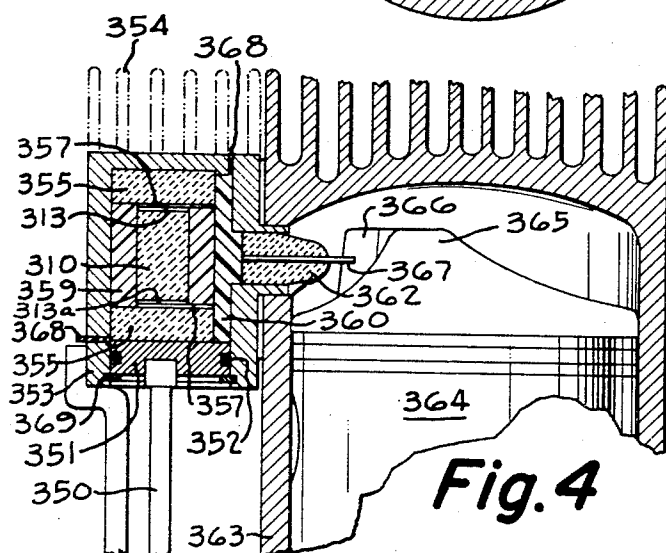
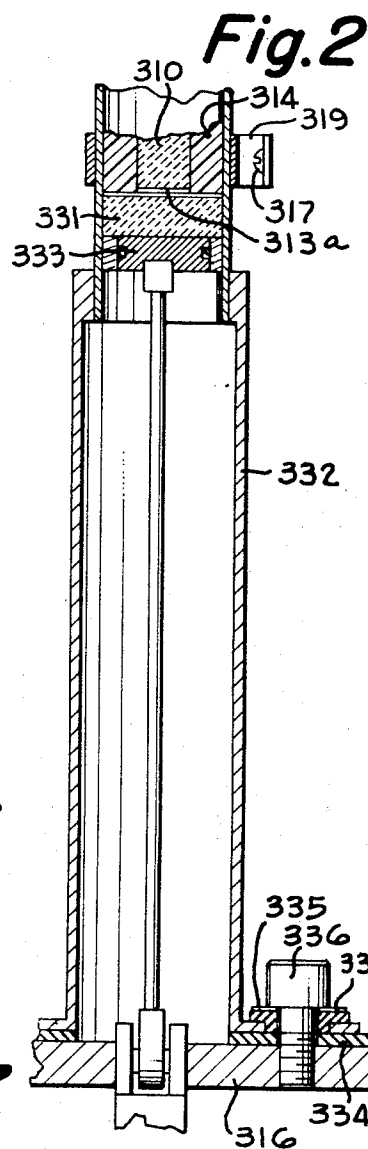
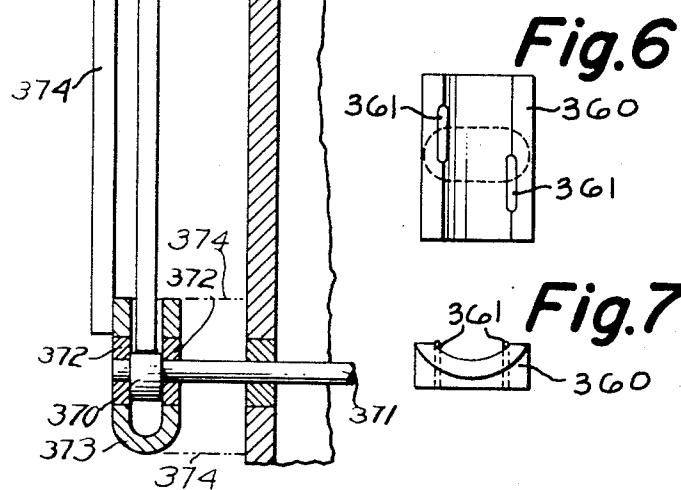
J. J. HORAN

3,444,850

VOLTAGE-GENERATION APPARATUS AND IGNITION SYSTEMS

Filed Aug. 8, 1967

Sheet 2 of 2



1

3,444,850

VOLTAGE-GENERATION APPARATUS AND IGNITION SYSTEMS

John J. Horan, 420 Quigley Ave.,
Willow Grove, Pa. 19090

Continuation-in-part of applications, Ser. No. 498,359,
and Ser. No. 498,549, Oct. 20, 1965. This application
Aug. 8, 1967, Ser. No. 659,095

Int. Cl. F02p 3/12; F02b 23/08

U.S. Cl. 123—148

18 Claims

ABSTRACT OF THE DISCLOSURE

This invention teaches simplified alternating voltage generators and ignition systems that are particularly applicable to ignition service in small internal-combustion engines, which generators utilize piezoelectric devices, cyclically compressed by force-limited means, for producing high voltages, the discharge of which may be timed by a piston or pistons.

Related applications

This application is a continuation in part of presently filed applications Nos. 498,359, now Patent No. 3,349,760 and 498,549, both filed October 20, 1965.

Background of the invention

Ignition systems for small engines are chiefly of the magneto type. These systems are complex and the parts are highly vulnerable to malfunction, putting the engine out of service or at least making its operation unsatisfactory. The malfunctions are particularly difficult for the user to diagnose and repair because the principal parts are most economically and most often hidden under the flywheel. Wet weather and other sources of moisture cause the functioning of these systems to become chronically erratic, especially in starting. For this reason, repeated but unsuccessful attempts have been made to design substitute systems, such as those employing ferroelectrics as voltage sources.

Description of the prior art

There have been two principal schools of thought as to how piezoelectric elements might be employed in such applications as ignition systems. According to one doctrine, the element is to be stressed by impact at the instant a spark is desired. The other school holds that, for maximum life, the brittle element should be squeezed gradually and that the high voltage generated should be conducted to the appropriate spark plug by an auxiliary timer or distributor. One manufacturer was persuaded to equip a small number of engines for a short time with one of these latter systems; but so many troubles were encountered that the attempt was discontinued.

In my prior applications Nos. 498,549 and 498,359, of which this application is in partial continuation, I have disclosed, among other advances, the actuation of piezoelectric via generically new devices for stressing them and inherently simple and accurate means for timing the discharge via the piston of the internal-combustion engine itself.

Summary of the invention

It is well known that elongated symmetrical structural columns to which a symmetrical axial load of critical magnitude may be applied will suffer instability and will buckle and belly outwardly at about mid-height while sagging axially, and will eventually collapse catastrophically if the load is further increased. Various formulae have

2

been credited to Euler, Rankine, Tetmajer, Johnson, and others for determining the critical load of columns. Most columns are, however, designed not to control the manner of collapse; they are designed to forestall such collapse under foreseeable conditions. Under most criteria, therefore, a column has failed its mission when it begins to show symptoms of collapse.

Columns are not designed to perform functions at their critical loads, the term "critical load" being of principal interest as a yardstick or criterion of the relative margin of safety or "safety factor," usually accepted as the ratio of critical load to working load.

The "failed column," provided that it has been made from homogeneous, high strength material and that no part thereof is stressed beyond the elastic limit of the material comprising it, finds another, though not commonly known or recognized as such, application in the design of the so called "buckling-column" spring. After a column has already buckled, and after the deflection has proceeded well beyond the so-called "region of instability," there is found a relatively linear range of deflection versus load, where the buckled column, in a high-strength material, now finds application as a biasing machine element or spring. Such springs, however, are not to be confused with ordinary "flat springs" made of curved sheet metal.

In this application, however, we are not interested in the ranges which the engineers, designers, and various artisans have found useful. We are, instead, most interested in using the so-called region of instability itself, where the character of column performance has so far made them unreliable and unwanted. At this point the column possesses the desirable characteristics of neither a structural column nor a spring.

However, if an elastic elongated column of high-strength material is subjected to an axial load above its critical load by an interfering machine member rather than by a gravitational force, the deflection of the column will proceed only to the point at which the interference is relieved. If the stress in the column has been below the yield value thereof, and if the interfering member thereafter passes out of heavily loading contact with the column, the elasticity in the material of the column will restore it to its prior erect shape unless further interfered with. If the original configuration of the column was slightly bowed or eccentric, in order that the direction of deflection might be predetermined, that configuration will similarly be restored. Such columns, or struts, need not be vertical; they may be horizontal or tilted in any useful direction. The actual values of load will be affected by taper as well as column cross-sectional area, and by the character of end support of the column, whether it is built into another member, whether it is ball-ended, etc.

Now very slight axial deflections, which need not exceed a few thousandths of an inch, permit development of nearly the maximum strength of which a small elastic column can be capable; yet, under the imposition of increasing deflection loads, the column will develop a relatively negligible increase of load, certainly a tolerable one. Thus a cam imposing only a very short axial squeeze of a few thousandths of an inch upon a column that stresses a piezoelectric at its other end to say 6000 or 7000 p.s.i. can double that deflection without sending the squeeze load up by more than a few hundred p.s.i.

To hold down the rate of wear upon cam and miniature column, they can be held out of contact most of the time required for the engine crankshaft or camshaft to make a complete revolution by means of an established clearance of a few thousandths of an inch. They may then be engaged by a shallow rise on the cam lobe for a few degrees of cam travel while the spark potential is quickly

generated and discharged. Intermediate cam followers, rolling or non-rolling, may, if desired, actually deliver the cam thrust to keep the relatively moving cam from laterally deflecting the end of the column.

Individual columns energizing separate piezoelectrics connected to spark plugs opening into different cylinders may be stacked close together, either parallel or radially arrayed in a carrier about a center. They may then be energized in succession by a single small rotating cam, affording a compact, low-cost ignition system for multi-cylinder engines which, incidentally, can be economically advanced and retarded by rotation or other movement of the carrier against or with the direction of relative cam rotation.

Brief description of the drawings

FIG. 1 is a partially sectioned elevation of one form of the invention.

FIG. 2 is a fragmentary, partly sectioned, view showing the manner in which a second form may differ from the first.

FIG. 3 is a fragmentary, partly sectioned, view showing a third form with additional differences, FIGS. 3A and 3B showing variations in spark plugs.

FIGS. 4, 5, 6, and 7, are, respectively, a partly sectioned elevation and a sectioned plan, together with elevation and plan views of one of the components of a fourth form.

FIGS. 8 and 9 are views applicable to FIG. 3, or, by substitution, to FIGS. 1, 2, and 4, showing alternative cam arrangements.

Description of the preferred embodiments

Referring now to FIG. 1, there is shown a piezoelectric ignition system assembly suitable for use with single-cylinder engines or for firing individual cylinders in multiple-cylinder engines. It will be seen to require no distributor. The system is complete as shown, from actuating cam 301 to firing electrodes 302 and 303, and including shunting portion 304 of piston 305. Cam 301 is shown in energization position, in which it raises roller cam follower 306, causing column 307 to buckle under compression out of its relaxed original position 308, shown in phantom outline.

Column 307 buckles because the motion of cam 301 is resisted at its upper end by conductive metal pellet 309, which in turn is blocked from upward movement by the presence of polarized ferroelectric ceramic slug 310 and rigid insulating ceramic button 311, which abuts the upper end of metal tube 312 as an end support to the slug 310. Since tube 312 has its lower end secured rigidly to guide-wall 316, which contains slot 314 for guidance of cam follower 306, the compression of column 307 is reflected in longitudinal tension in tube 312, which serves as a counterstructure.

Because all elements in the stressed array preferably have moduli of elasticity at least equal to that of the ferroelectric, which usually ranges between 8 and 12×10^6 p.s.i., and because the elongated column 307 has a high ratio of length to least transverse radius of gyration, the column 307 will begin to buckle and bulge out at about its midpoint (depending upon homogeneity and end conditions) in the plane of that radius.

It is characteristic of elongated columns that buckling sets in long before the member would fail in strict compression. If the material has a sufficiently high yield strength, like that of music wire and hardened spring steels, and if it is sufficiently slender, buckling may even proceed until a column is bent well over beyond any need in this service.

At values of compression below the critical load, the column will remain erect. Once this value is exceeded, however, the load/deflection curve develops a pronounced knee; and the rates of lateral deflection and axial deflection quickly increase. The maximum load that the column can carry may not immediately be reached; but doubling

the axial deflection once the column is perceptibly bent adds only a small percentage of additional load.

Thus a column having a $\frac{1}{8}$ " x $\frac{1}{4}$ " cross section has a least radius of gyration of about 0.036". If its length is 4", giving it a ratio $1/r_g$ of 110, it has a critical load that will stress a $\frac{3}{8}$ " diameter x $\frac{3}{4}$ " long lead-titanate zirconate element adequately to supply a firing voltage. If we should apply enough force to the actuating cam to cause the column to be perceptibly bent as viewed by the naked eye, the element will not be overstressed and will yield only a slightly higher ignition voltage. Thus the buckling column "spring" does not deliver more force than we intend to design into it. Cam deflections may be large enough to overcome tolerances or clearances elsewhere in the system, including customary non-uniformities in the length of the column itself. The one who repairs the device and exchanges one or more of the few components will not ruin the element because he had no force or clearance gages to check his own work, not even if he should lack any appreciation at all of such tools. With such ignition systems it ought not to be long before the high-dynamic-strain types of ferroelectrics become well known to the public as well as the professionals.

Because the columns can be designed to buckle as their loads reach their predetermined critical values, manufacturing and assembly practices become uncritical; they have merely to allow enough room for lateral deflection. Thus, there is no longer a need to strike the ferroelectric with a carefully measured and balanced blow to avoid the formerly alternative risks of dimensional difficulties; and, moreover, whereas the vigor of the blow was a hard value to divorce from direct dependence upon engine speed, we have a new force system not so dependent. There will no longer exist a risk of low ignition voltage consequent upon falling short a thousandth of an inch or so of the exact value of proper squeeze, as in the squeeze-lever types that develop enormous wear pressures at their little cam tips. The former risk of desensitization or fracture of the brittle and critical ceramic material when the cam tip descends an extra thousandth or two toward the ceramic is also gone.

The polarized ferroelectric material 310 is kept nicely isolated electrically in its housing by means of the sturdy ceramic insulating support button 311 perched upon its conductive surface electrode on its upper pole. Support button 311 is best made of material such as aluminum oxide that has both high dielectric strength and a physical strength in excess of that of the ferroelectric.

Glass may be used for button support 311 in place of aluminum oxide. There is also a surrounding sleeve 314, which may be made of glass, ceramic, or firm plastic. At the lower or grounded end, the piezoelectric 310 feels the upthrust of its lower support, metal pellet 309, which grounds to the wall of tube 312, the grounding conductor thereafter following the shortest path via holddown clip 319 to the upper part or head 320 of the firing chamber or engine cylinder 321, thence via metallic gasket 322 or directly into skirt ring 323 of spark plug 324 and into welded-on electrode 303. If the sleeve 314 is of glass or ceramic, as distinguished from plastics which have low Youngs moduli, it is preferably permitted to bear none of the thrust of pellet 309; otherwise too much energy will be wasted. The sleeve or a pellet should be longitudinally relieved in such event in order not to divert force from the ferroelectric. In order to prevent the possibility of resultant arcover of voltage via any clearance spaces, all such clearance space should be filled with a semi-liquid or solid elastomeric dielectric.

The ferroelectric 310 preferably has fired-on conductive metal surfaces 313 and 313a serving as pole electrodes. The upper electrode 313 of the ferroelectric makes contact with insulated conductor 326, which leads the high-tension voltage to the middle electrode 302 of the spark plug 325, passing downwardly through its ceramic body 324 into the firing chamber. When the conductor

326 is short as shown, it becomes practical and easy to mold on a waterproof rubber insulant 327, which protects the entire ignition system from environmental short-circuiting in any weather. Yet the ignition system may be deliberately short-circuited at will for stopping the engine by exerting slight pressure upon grounded molded-in spring-steel insert plate 328 at the top of the conduit and fitted over a structural void between conductors and wired 329 to ground. Such action temporarily reduces the gap between the two conductors viz: plate 328 in the grounded conductor and conductor 326, which constitutes part of the overall ungrounded conductor from ferroelectric 310 into the chamber via wall 363. By filling the gap in the conduit between plate 328 and conductor 326 with an optional dielectric fluid 338 harmless to insulant 327, the interval, the amount of bending of plate 328 and the size of the conduit may all be held at a minimum.

Other ways of stopping the engine may be employed at the designer's option. Another will be described hereinafter.

Non-rotating spark plug 325 is always aligned with conductive shunting portion 304 of piston 305 because of the keying effect of electrode 303, which requires that a small keyway be extended from the edge of the spark-plug mounting hole in the cylinder head. The flange of spark plug 325 is retained in place by a fastener such as the large diameter annular retaining screw 339, which threads into the tapped recess above the spark-plug opening.

Positive grounding of tube 312, the principal tensile or counter-structural means in this embodiment, to the upper end of cylinder 320 is accomplished by means of conductive strap 319, which is preferably fastened by screw 317 to the head portion in desirable proximity to electrode 303.

The system disclosed in FIG. 2 is similar to that of FIG. 1, except that the tube 332 is doubly isolated from any possibility of delivering any ground potential via its lower end. As may be seen, the lower electrode 313a of the ferroelectric 310 rests on dielectric ceramic 331, which intervenes between the ferroelectric and pellet 333. Isolation is completed via insulating plate 334, which, together with washers 335, separates tube 332 from contact with bolts 336, metal washers 337, and guide plate 316. When such structure is adopted, it becomes impossible for stray potentials to transit via the bearing and sliding surfaces of the engine.

Referring next to FIG. 3, a conventional type of threaded spark plug such as 340 may be employed with slight modification to its ground electrode 341, which is seen to be pointed downwardly, parallel to center electrode 342. Use of such a spark plug requires that the piston be so modified that appropriate alignment of its conductive portion will be assured regardless of the screwed-in orientation of the spark plug 340 and its electrodes 341 and 342. One way of accomplishing this is to configure the top of the piston with an annular boss 343, having a central hole 344 for clearing center electrode 342 and a radial thickness slightly less than the spacing between spark-plug electrodes 341 and 342. Rearranging the electrodes of FIG. 3 to space them equally from the spark-plug axis, the piston then being fitted with a single small solid (optional) boss coming up between the electrodes as in FIGS. 3A and 3B, the reliability may be further enhanced by greater exposure of one of the gaps.

In FIG. 3A, the metal shell of spark plug 340A and electrode 341A, directly secured thereto, are grounded and opposed to ungrounded electrode 342A, dog-legged where it emerges from porcelain insulator 345A to the right a distance from the axis of rotation equal to that of electrode 341A. The lower portion of the metal shell may optionally be relieved at the right as shown in order to maintain ground separation from the ungrounded electrode when this is rendered desirable by cumulative design parameters.

Boss electrode 343A is represented as a screw with a

cross-slotted head; but it may permissibly be a bolt or an integral part of the piston.

Proper tolerance control will assure the maintenance of a pair of spark gaps regardless of the rotational position of the spark plug when threaded into the cylinder head. The gaps will preferably be nearly equal; but this is not mandatory or critical since they are in electrical series and will have the same total gap and the same relationship of gap to voltage even though boss 343A may be off center to the right or left.

In FIG. 3B, both electrodes 341B and 342B of spark plug 340B are contained within the porcelain insulative body 345B and emerge from the bottom thereof equally spaced from the axis and from boss electrode 343B. Because initial costs will be lower if conventional production methods can be applied with minimum alteration to serve the new functions in new environments, these alternative forms of spark plugs were invented as answers to the problem of helping industry to span the disclosed technological jump in ignition-systems design.

Permissibly, as long as one spark-plug electrode is left free and ungrounded, the other may touch the piston. It will not last long though, unless it is especially designed to withstand the rigors of such repeated contact.

Referring now to FIGS. 4 through 7, there is shown an ignition system particularly well suited for coaction with pistons of two-stroke-cycle engines, as well as with four-stroke-cycle pistons having elevated portions. There is also shown a way of floating both piezoelectric poles off ground, the better to isolate the ignition and coact with spark plugs of the type disclosed in FIG. 3B.

Column 350 is similar to previously described columns. It pushes upwardly against steel pellet 351, which contains an O-ring 352 for sealing against the wall of housing 353, which permissibly may have cooling fins such as are indicated by phantom lines 354.

Resting upon pellet 351 is one of two identical insulating ceramic pellets 355 abutting opposite poles of ferroelectric ceramic 310. Preferably these pellets 355 will each have conductive electroding 357 oriented toward the conductive faces 313, 313a of ferroelectric 310 and leading generally toward the right as viewed in FIG. 4. However, the pressure may alternatively be exerted in a different direction, such as perpendicular to the axis of polarization of an element, in which the configuration will probably change and some efficiency will probably be lost. Insulating sleeve 359 separates ferroelectric 310 from contact at either end with housing 353. It will be noted that the centerline of pellet 351 does not coincide with the centerlines of the other pellet 355, sleeve 359, ferroelectric 310, or column 350, all of which are preferably aligned with each other.

The eccentricity accommodates relatively soft plastic or elastomeric insert 360, two additional views of which are seen in FIGS. 6 and 7. Insert 360 contains bent conductors 361, which lead vertically, one upwardly and one downwardly, from electroding 357 on the inward faces of ceramic pellets 355 toward the center plane of ceramic core 362, which is imprisoned in the nose of housing 353 that leads into the wall opening of cylinder 363 above piston 364. Reciprocating piston 364 is contoured generally conventionally for a two-stroke-cycle engine, with upwardly rising flow-guidance means 365 at its top. However, a small leftward extension 366 of the flow guide 365 has been straddle milled to clear and pass alongside electrodes 367 with appropriate small spark gaps interposed on either side. These electrodes 367, are, of course, aligned to abut respective conductors 361 and, by means of extension 366, to discharge ferroelectric 310 just before piston 364 reaches top-center position. They will discharge it again as column 350 relaxes when the cam lobe drops off sharply while piston 364 is still shunting electrodes 367, thus accomplishing a timely relief of the squeeze on the ferroelectric while the piston is still in a

position to benefit from a spark discharge in the event of a misfire.

A solidifying elastomeric filling is injected under pressure while in the plastic state, with a compressive load applied between pellet 351 and the top of housing 353. This procedure is followed in order to completely reject all contained air and fill all cavity areas. Similar material is appropriately injected into other systems described in this disclosure to avoid high-tension leakage. Such filling 368, if adhesive and strong, eliminates need for O-ring 352 and retaining ring 369, which would be used in the event that an oil or soft gel were the filler. Materials of desirable character include the polyurethane and silicone room-temperature-curing materials.

It will be noted that housing 353 and cylinder 363 are at no time exposed to the direct potential gradient from either end of ferroelectric 310. Thus, there is no current-discharge path through the engine except via the small shunting portion 366 of piston 364 during the brief instants of firing that occur near the ends of the compression strokes.

As in the other systems hereinbefore described, there is more than twin-ignition involved here. There is a further aid to engine starting in that a second pair of twin discharges occurs while the fuel-air charge is still in combustion position. The lower end of column 350 rests against cam 370 on shaft 371, which is permissibly slender because the cam 370 is supported by flanking bearings 372 fitted into pocket 373. The use of the buckling column 350 permits this light-weight assembly to be secured to firing chamber 363 alternatively, with very little regard for fussy tolerances, etc., that generally characterize devices containing ferroelectrics. If the engine 363 is coupled to the pocket 373, as indicated by phantom lines 374, the engine would then serve as the tensile counterstructure, a function which is otherwise performed by member 374, linking housing 353 to pocket 373.

Referring now to FIG. 8, it may be seen that it is very easy to shut off the engine by simply disabling, disengaging, or otherwise decoupling any part of either the compressive structure or the coupled tensile counterstructure, particularly if the mechanical system is allowed to go slack between energizations. This happens when the lobe 380 of the camshaft retreats from contact with the column 382, as seen in FIG. 8.

Guide 383, which holds the bottom of the buckling column 382 in alignment with respect to the camshaft centerline, is shown in the "on" position. To shut off the engine at any time, the guide may be moved a short distance laterally in a preferred direction, such as indicated by the arrowhead. When the column is so moved away from the cam lobe, it may tend to fall out of alignment unless protective measures have been taken, such as the placement of a shoulder 385, which rests on guide 383. The shoulder 385 also serves to prevent column 382 from riding continuously on the cam whether or not engaged to it. Alternatively, a spring could be used to bias column 382 off the cam lobe.

The quick dropoff seen in cam lobe 380 enables the ferroelectric element to be suddenly decompressed while the conductive portion of the piston is still opposite the spark electrode or electrodes, thus giving a second timely discharge.

Referring now to FIG. 9, a plurality of systems of this character can be driven by a single cam lobe 380. The ends of columns 382A, each equipped with a shoulder as discussed under FIG. 8, fit through openings in a ring guide 390, where each in turn is displaced by cam 380. Disengagement for shutting off the engine is accomplished by relative axial movement of either the ring guide 390 or the cam 380.

A limited measure of spark advance and retard is effected by a small amplitude of rotation of guide 390. Similar spark advance in FIGS. 2 and 4 is accomplished

by a supplemental guide moving perpendicular to the plane of the paper.

All of the columns 382 of FIG. 9 may optionally be arrayed in parallel or other desired array behind the first if respective lobes are provided for each as indicated by phantom lines 391.

Obviously now, certain features of one embodiment may be combined variously with others and with certain segments of old art; and they will stimulate imitation in configurations differing in unessential detail from representative showings herein, without departing from these teachings. My invention is not to be limited to specific forms disclosed. All of the equivalent approaches to the constructions, objects, and functions inferable by one skilled in the applicable arts are intended to be covered by the claims.

Therefore, I claim:

1. An apparatus for cyclically generating high-tension spark voltages, said apparatus comprising:

a structure, including a force-transmitting member and a polarized ferroelectric body in mechanical series on a common axis of compression, said member having been configured to have an elastic, force-limiting response to increasing compression along said axis, and a counterstructure longitudinally spanning said structure and having a tensile stress axis generally parallel to said axis of compression, said structure and counterstructure being mutually proportioned to admit coactively a cyclical cam adapted to develop opposite forces between said structure and counterstructure along said respective axes of sufficient intensity to generate said voltages across said body via cyclical compression and relief thereof.

2. An apparatus as in claim 1, the axial ratio of strain to stress in said member increasing non-linearly at higher stress levels.

3. An apparatus as in claim 1, said member being configured as a relatively slender column, said column being subject to incipient lateral elastic buckling at less than the maximum axial compressive force recoverably sustainable by said body when generating said voltages.

4. An apparatus as in claim 2, said body having two opposite poles, one of said structure and counterstructure including a housing enclosing said body and insulated from at least one of said poles.

5. An apparatus as in claim 4 comprising also: a spark plug having two mutually insulated electrodes projecting endwise therefrom; and a pair of electrical conductors, each of said conductors being joined at one end to an individual one of said electrodes and at the other end to a respective one of said poles.

6. An apparatus as in claim 4, the second of said poles being grounded electrically to said housing.

7. An apparatus as in claim 4, said housing also being insulated from the second pole, said apparatus having also a two-conductor, insulated, high-tension electrical wiring assembly emerging from within said housing, each of the conductors therein being electrically connected to a respective one of said poles.

8. An apparatus as in claim 7 comprising also: a spark plug having two mutually insulated electrodes projecting endwise therefrom, each of said electrodes being joined at its opposite end to a respective one of said conductors, the endwise projections of said electrodes being mutually spaced with a gap therebetween too great for spontaneous arc-discharge of said voltages there-

9

across within the compressed fuel-air mixture of an internal-combustion engine cylinder, whereby said discharge is enabled by the cyclical approach of a gap-bridging piston close to said projections, thus reducing the gap to a spacing well within the arc-discharge capability of said voltages.

9. An apparatus as in claim 4, said apparatus including a shunting portion, said shunting portion enclosing a structural void between two conductors connected to respective poles of said body, said void containing a fluid insulant sealed therein between said conductors, whereby the said shunting portion can be pressed to short-circuit said voltages.

10. An apparatus as in claim 2, including also means for decoupling at least one of said structure and said counterstructure from operative continuity with said cam and body in said apparatus, whereby said apparatus may be mechanically disabled.

11. An apparatus as in claim 2, including also a cam so adapted.

12. An apparatus as in claim 11, said cam having a sawtooth type of contour with a slow rise and fast dropoff, whereby said structure and counterstructure are displaced with a slowly rising force and said force is suddenly relieved after it has reached its maximum value.

13. An apparatus as in claim 11, said apparatus constituting part of an internal-combustion engine, at least part of said counterstructure sharing commonality with a structural component of said engine, the motion of said cam and the consequent generation of said spark voltages being coactively phased into the operation of said engine.

14. An apparatus as in claim 3 comprising also: a spark plug having a center electrode projecting endwise therefrom and an outer metallic shell insulated from said electrode;

an insulated cable electrically connecting said insulated pole to said electrode; and a second electrode conductively secured to said shell and also projecting endwise therefrom, said housing being electrically joined to said other pole, said housing and said shell being adapted for assembly to and grounding upon a metallic engine assembly for an electrical interconnection therebetween, the endwise projections of said electrodes being mutually spaced with a gap therebetween too great for the arc-discharge of said voltages thereacross within the compressed fuel-air mixture of such engine assembly,

whereby the cyclical approach of a gap-bridging piston close to said projections is required to reduce the gap to a spacing within the arc-discharge capability of said voltages.

10

15. An apparatus for cyclically generating high-tension spark voltages comprising:

a ferroelectric transducer having two opposite poles, said transducer being so configured and polarized as to deliver said voltages when compressed,

said transducer being part of an elongated structure, said structure also including a member in mechanical series with said transducer,

said member being characterized by a pronounced increase in the rate of elastic deflection thereof to increasing values of compressive force longitudinally applied to said structure below the maximum force recoverably sustainable by said transducer in generating said voltages;

and a counterstructure coupled in tensile opposition to said structure and spanning said structure longitudinally,

said counterstructure and structure being configured to admit coactively a cyclically camming device for applying said force longitudinally to said structure and a counterforce to said counterstructure.

16. An apparatus as in claim 15 comprising also:

a spark-plug portion having two conductors mutually insulated by a refractory material,

said conductors terminating in respective electrodes projecting at one end of said portion,

said electrodes being spaced apart with a gap therebetween too great for arc-discharge of said voltages thereacross when they are surrounded by the compressed fuel-air mixture of an internal-combustion engine,

at least one of said conductors being electrically continuous to one of said poles,

the other conductor being continuous to the other of said poles at least when said apparatus has been coactively assembled upon the metallic structure of such engine.

17. The combination of the apparatus of claim 15 and the said camming device.

18. An apparatus as in claim 15,

wherein said member is a relatively slender column subject to incipient lateral elastic buckling in response to an axial force less than said maximum force.

References Cited

UNITED STATES PATENTS

1,335,797	4/1920	Rohde	123—169
1,401,231	12/1921	Anderson	123—162
1,560,512	11/1925	Hirsch	313—128
2,040,919	5/1936	Caldwell	200—168
2,486,785	11/1949	Hutcheon	200—168 XR
3,211,949	10/1965	Slaymaker et al.	315—55
3,349,760	10/1967	Horan	123—162

LAURENCE M. GOODRIDGE, *Primary Examiner*.

U.S. Cl. X.R.

123—169; 313—128; 315—55