United States Patent

Horan

[15] **3,639,788**

[45] **Feb. 1, 1972**

[54] **HIGH-IMPEDANCE POWER FOR ENGINE IGNITION AND EXHAUST-SYSTEM PARTICULATE REMOVAL**

[72] Inventor: **John J. Horan**, Willow Grove, Pa. 19090

[22] Filed: **Mar. 11, 1970**

[21] Appl. No.: **18,419**

[52] **U.S. Cl.**.....**310/8.1**, 123/148 BA, 315/55, 317/79

[51] **Int. Cl.**.....**H01v 7/00**

[58] **Field of Search**.....310/8, 8.1, 8.3, 8.7; 317/79, 317/81, 624.14; 123/148 BA; 315/55, 209; 313/128, 142, 143, 144

[56] **References Cited**

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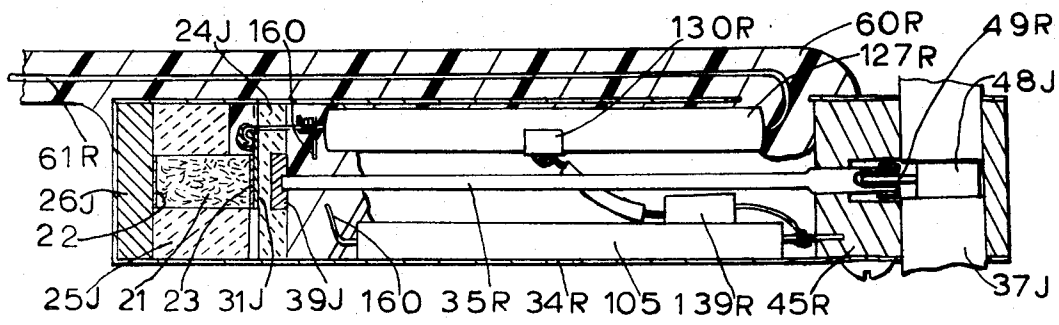
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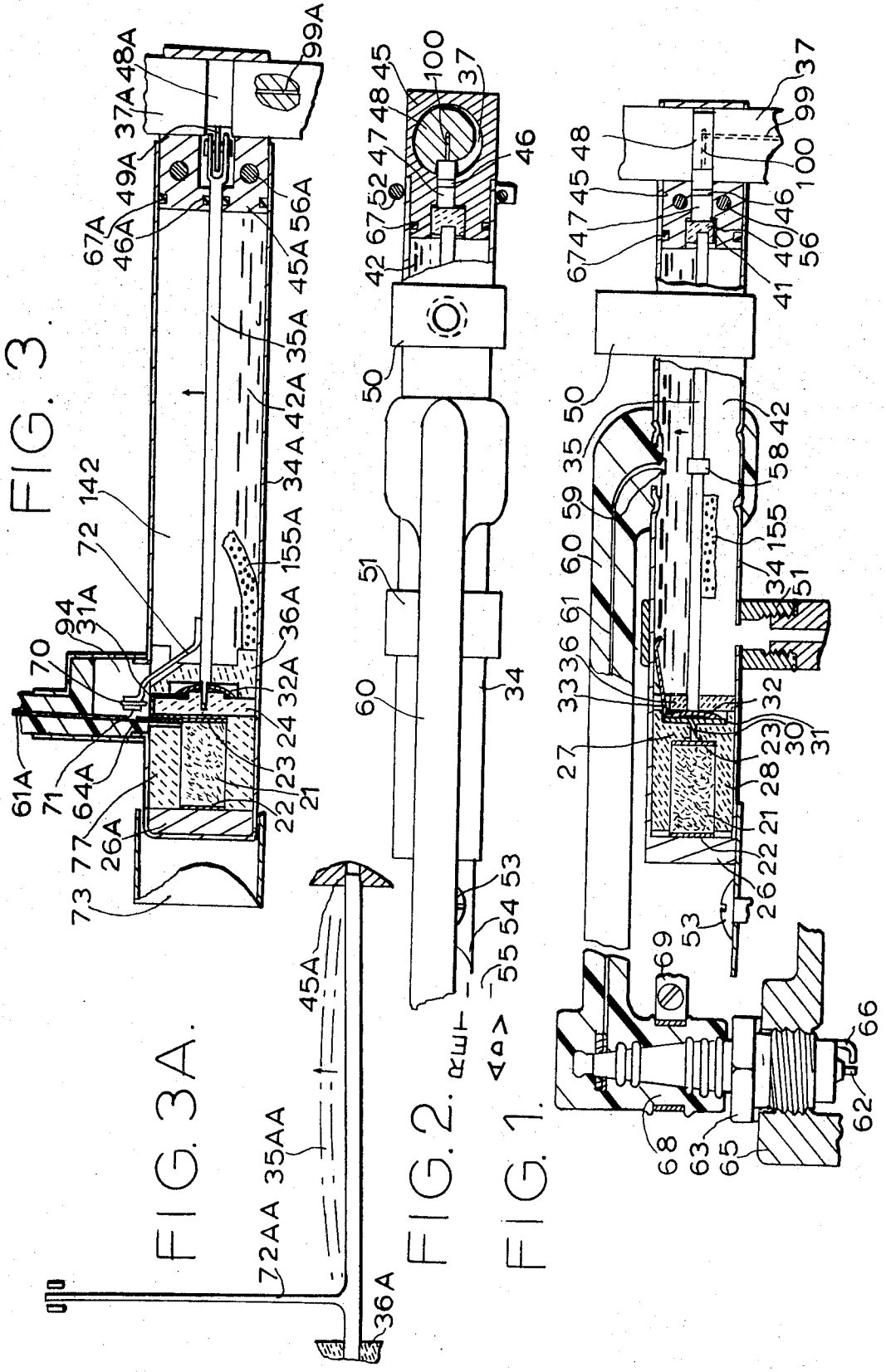
Primary Examiner—J. D. Miller
Assistant Examiner—Mark O. Budd

[57] **ABSTRACT**

This invention discloses unitary assemblies employing novel means for generation, via ferroelectrics, of timed engine-ignition impulses and of high-impedance impulses for removing particulate pollutants entrained in exhaust gases.

64 Claims, 55 Drawing Figures




FIG. 3.
FIG. 3A.
FIG. 2.
FIG. 1.

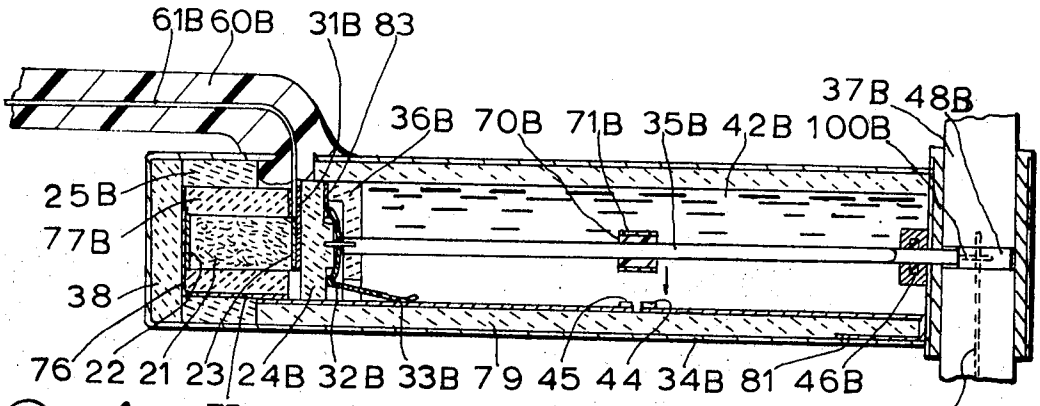
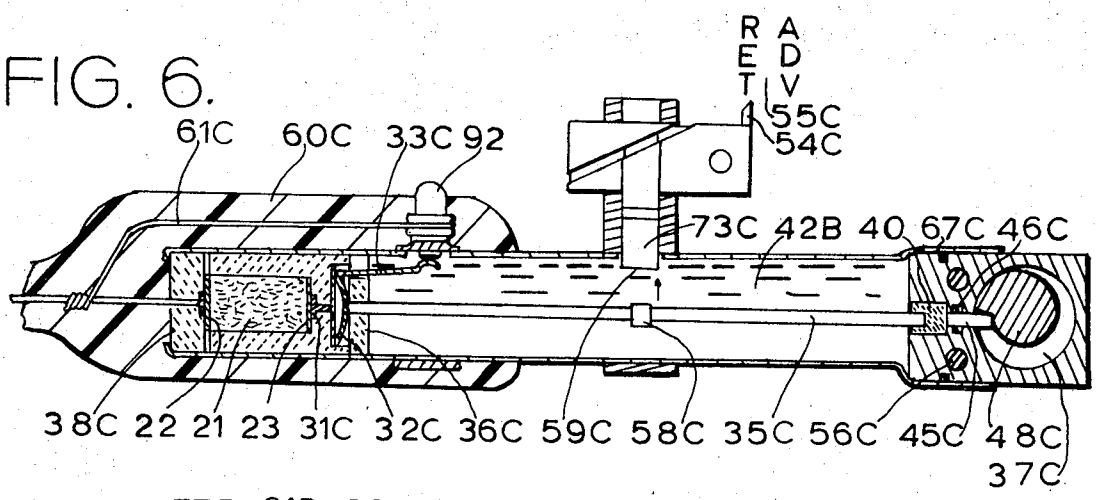


FIG. 4.

FIG. 6.



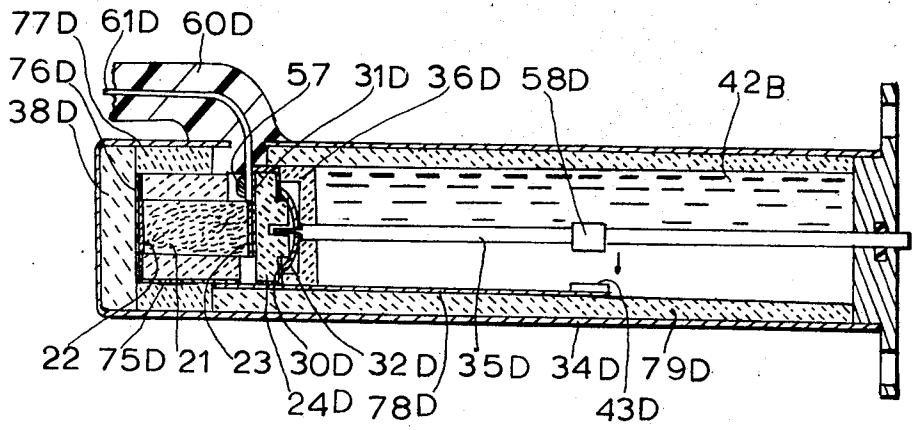


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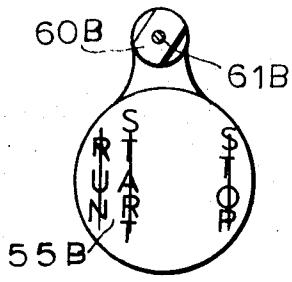


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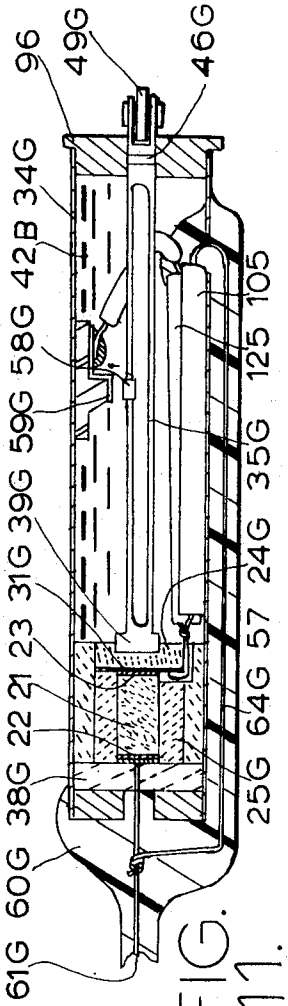


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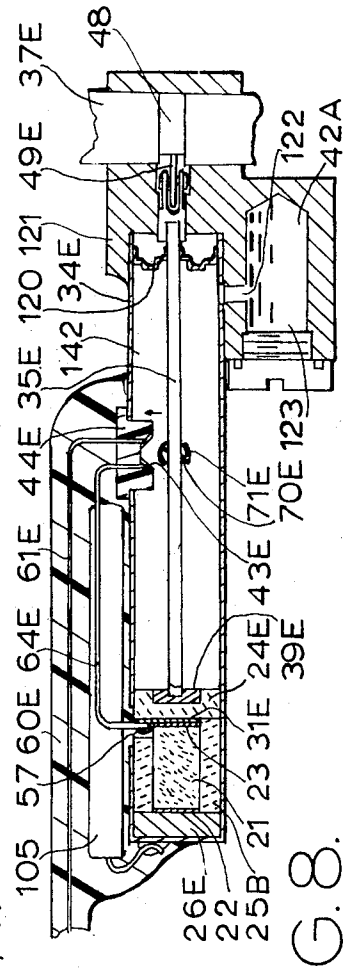


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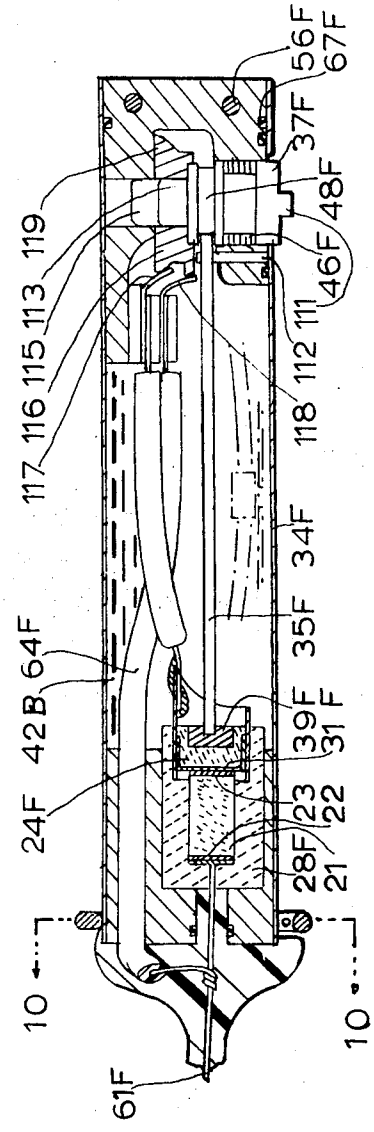


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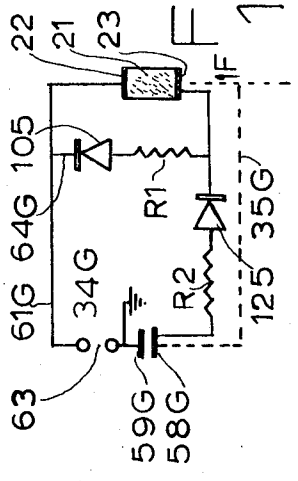


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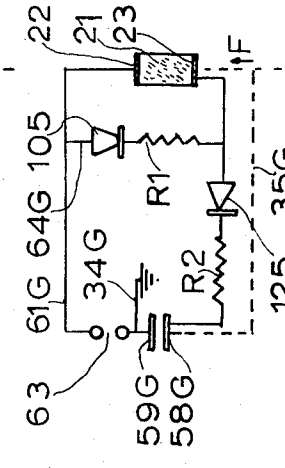


FIG. 12A.

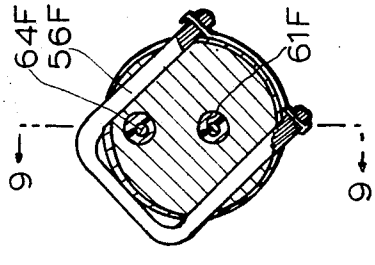


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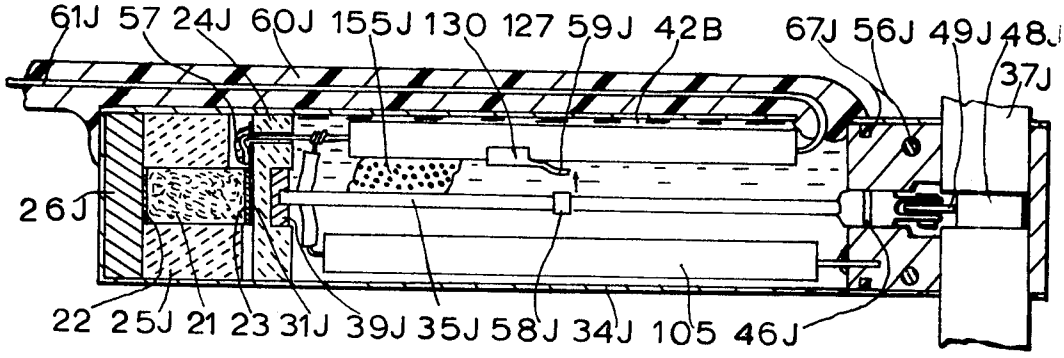


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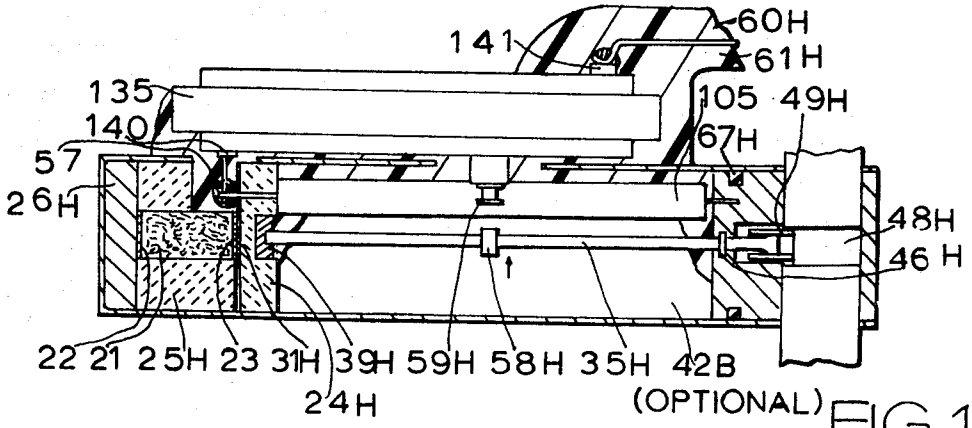


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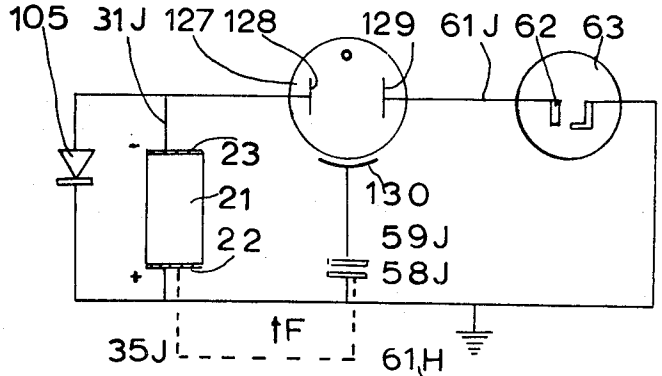


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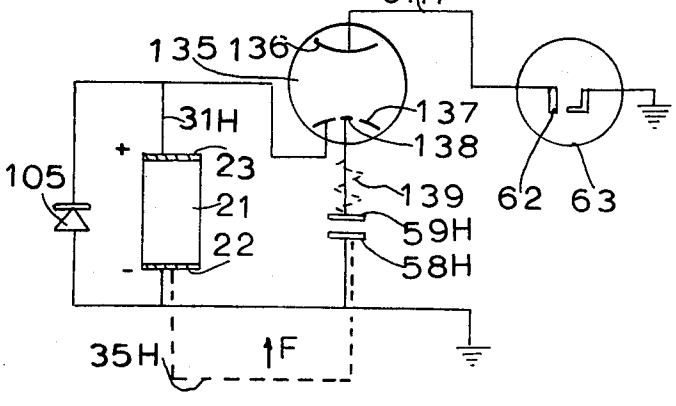


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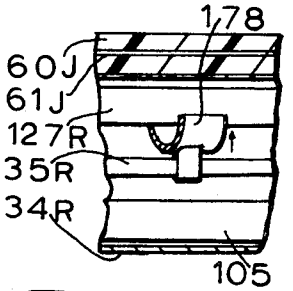


FIG.15A.

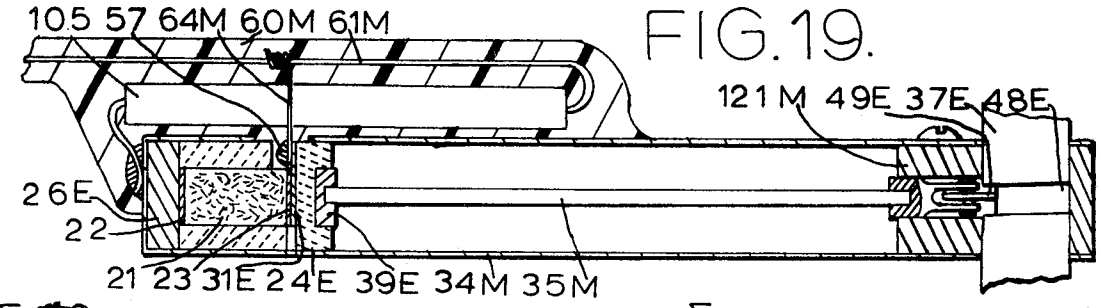


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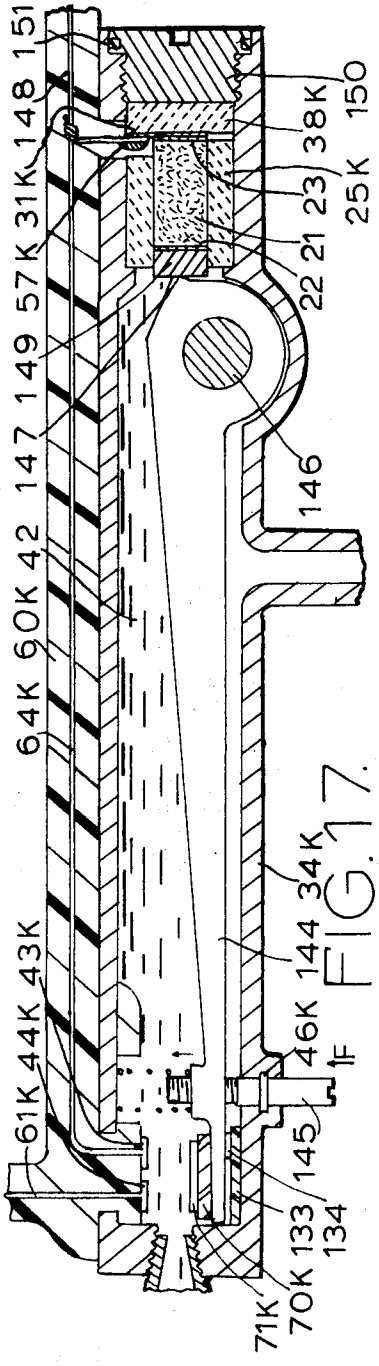


FIG. 17.

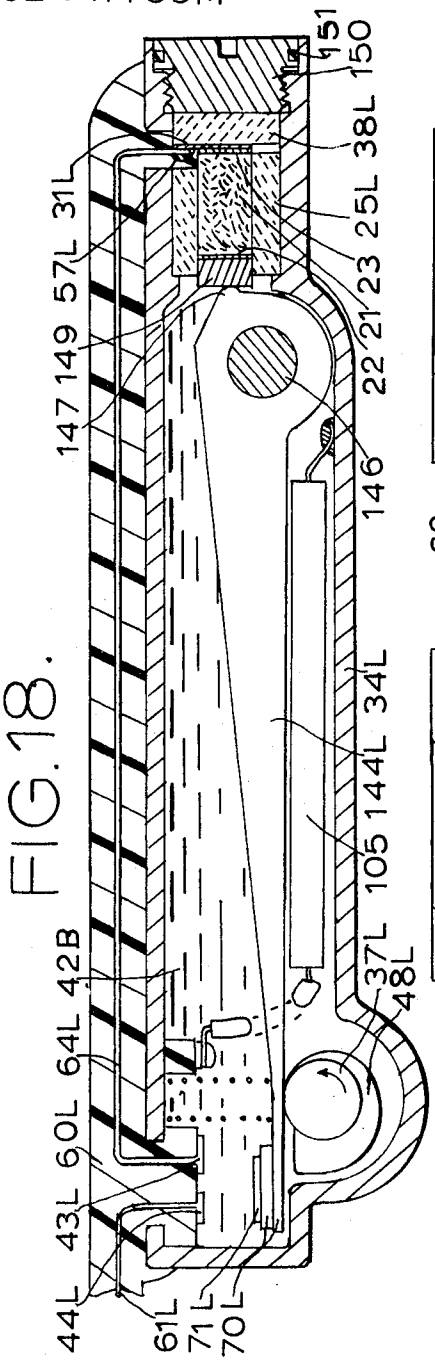


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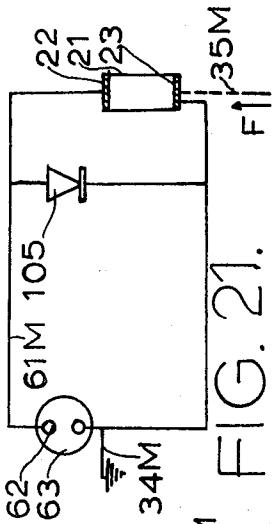


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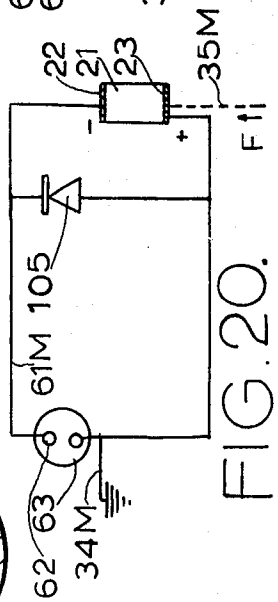


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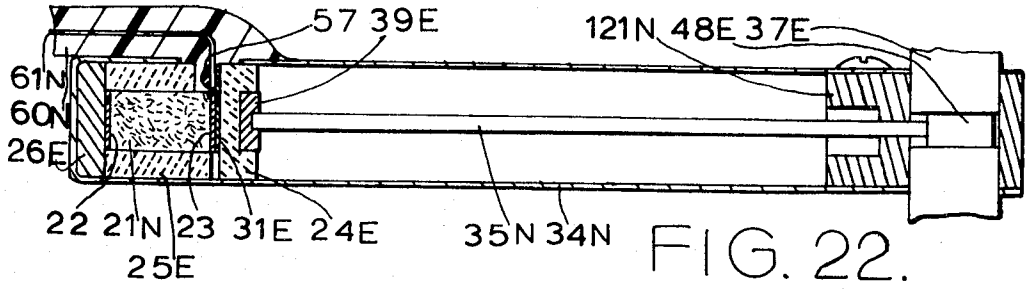


FIG. 22.

FIG. 23

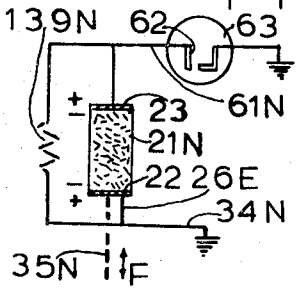


FIG. 24

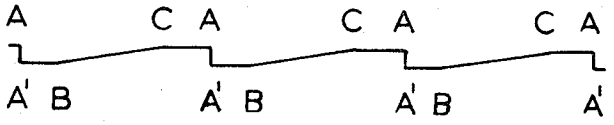


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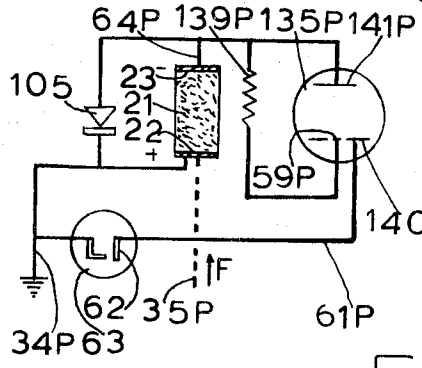


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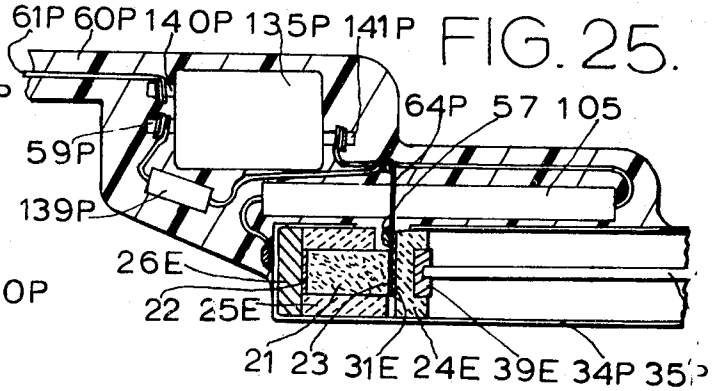
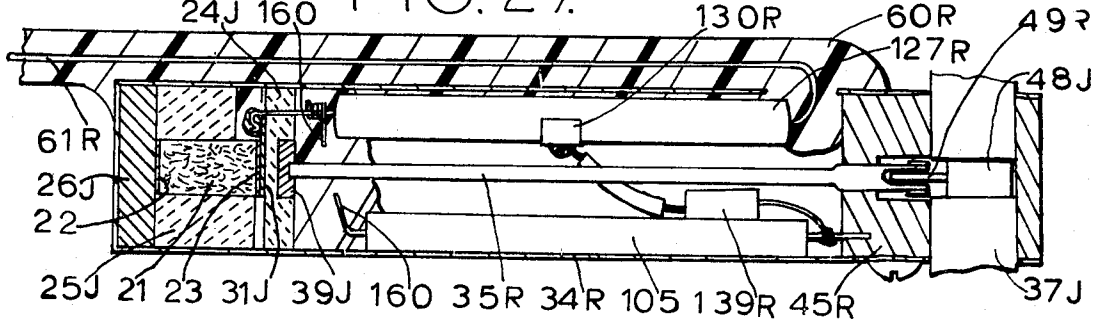


FIG. 27.



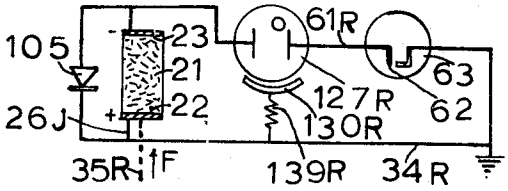


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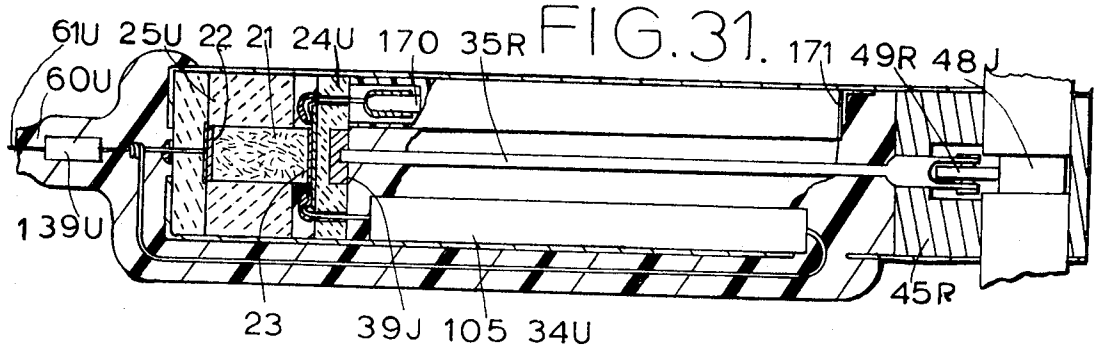


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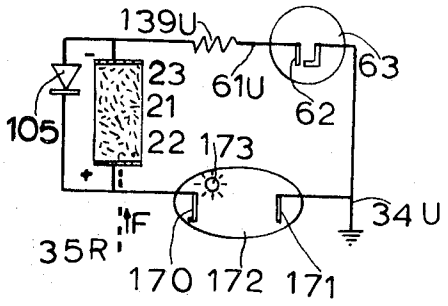


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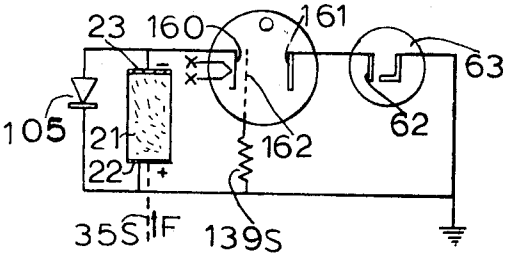
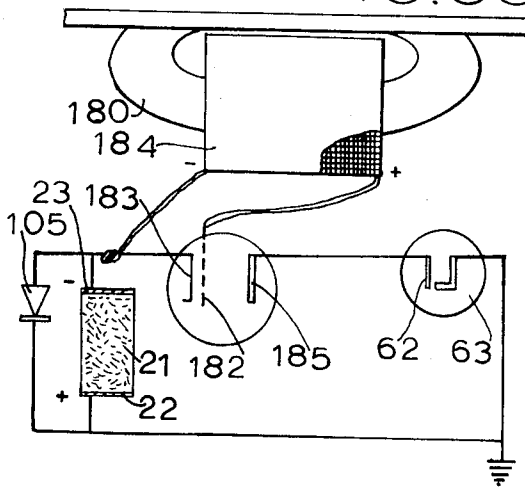


FIG. 29.

FIG. 30.

FIG. 33.



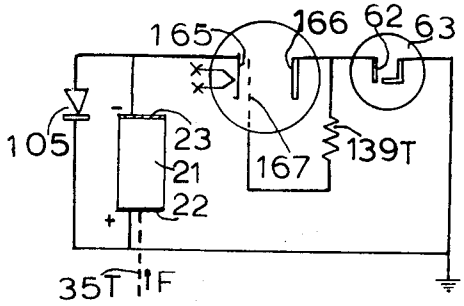
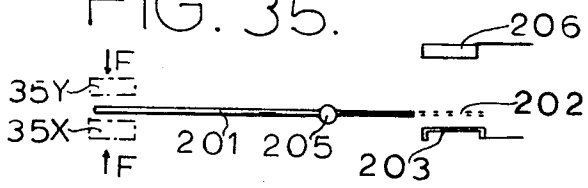


FIG. 35.



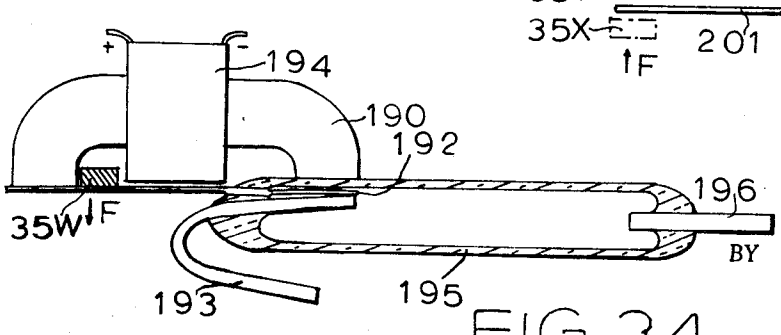


FIG. 34

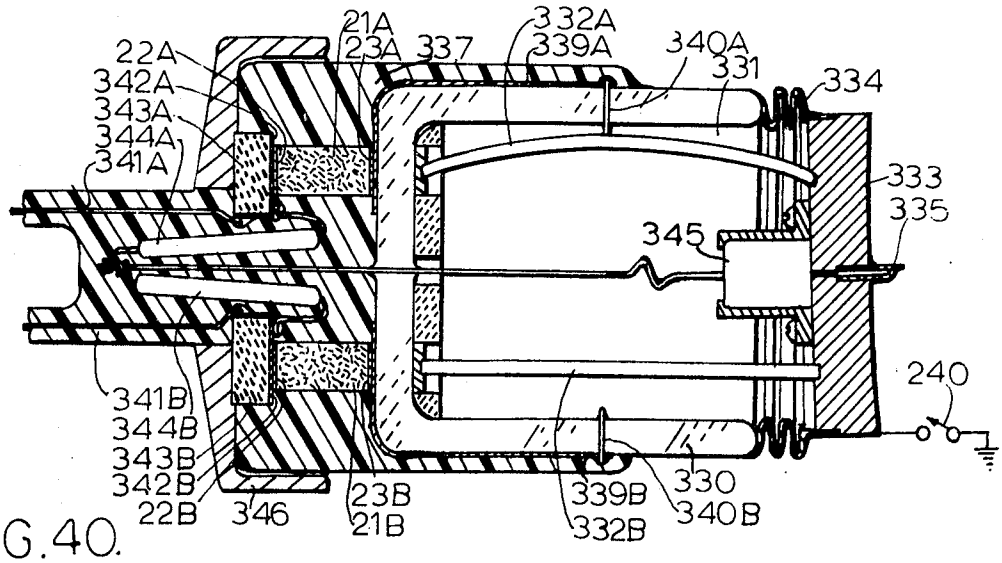


FIG. 40.

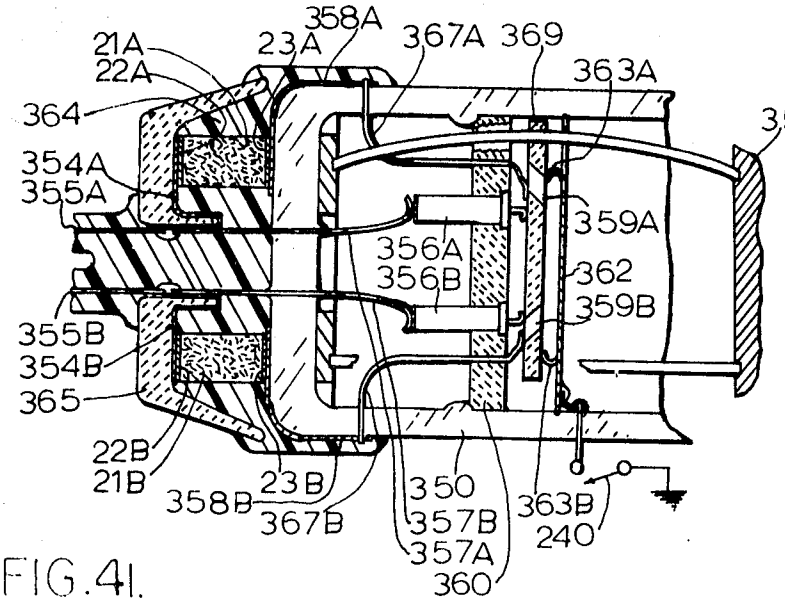


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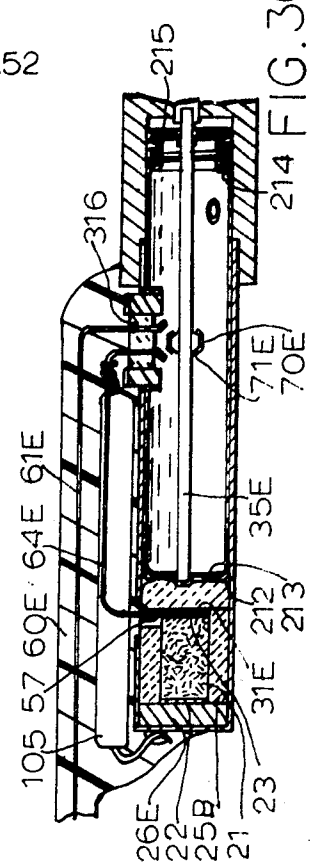


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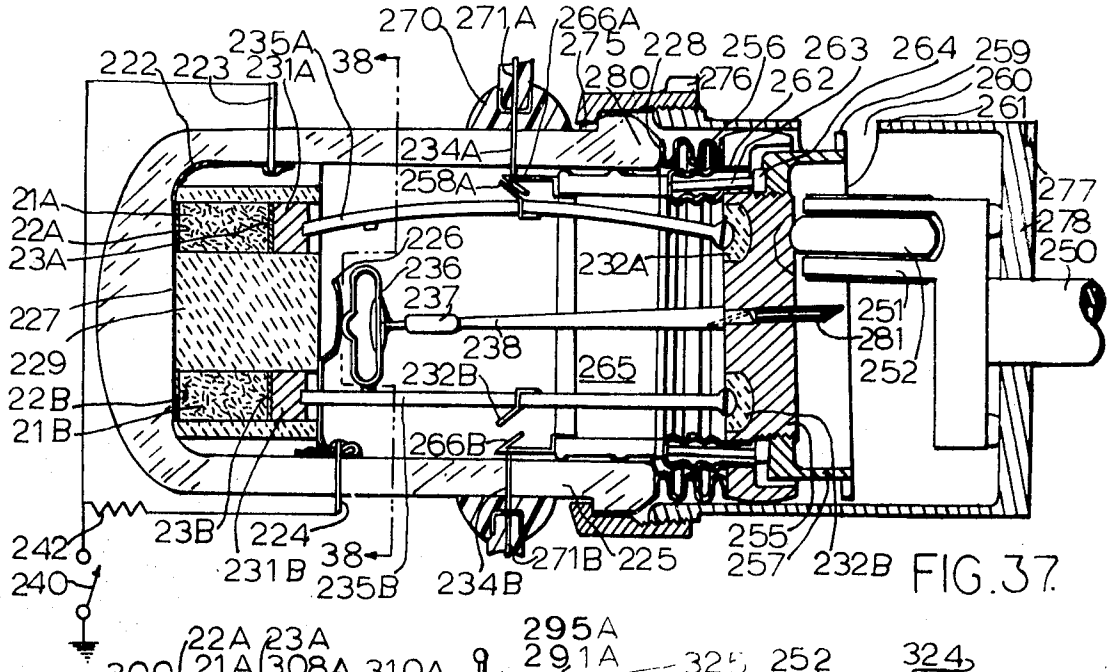


FIG.37.

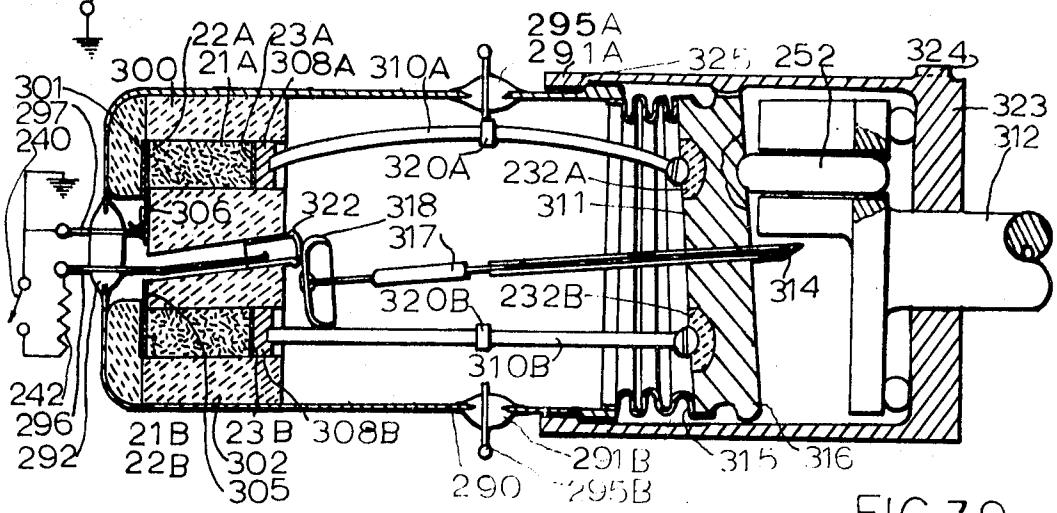


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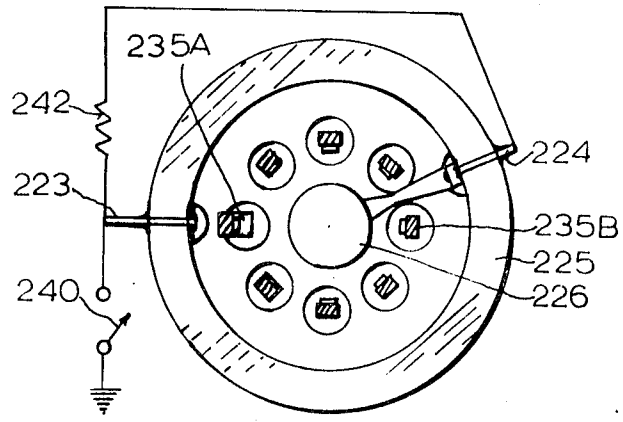


FIG.38.

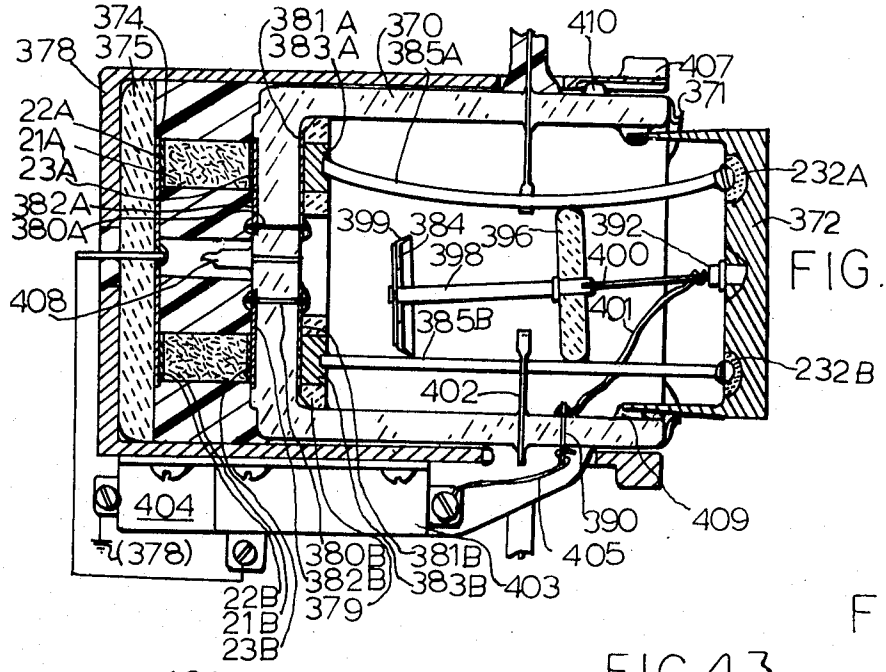
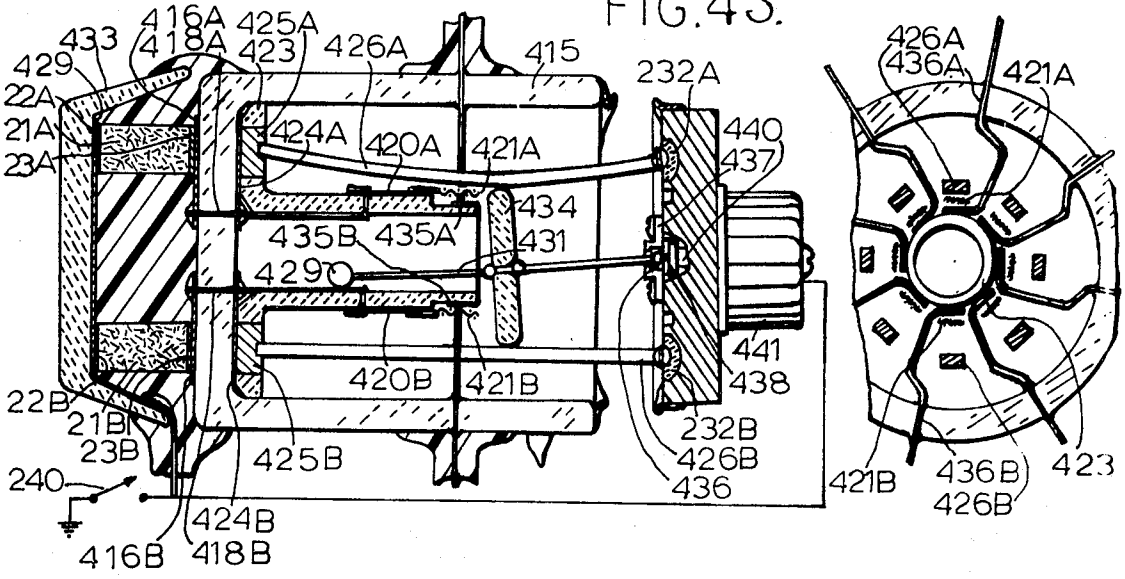


FIG. 42.

FIG. 44.

FIG. 43.



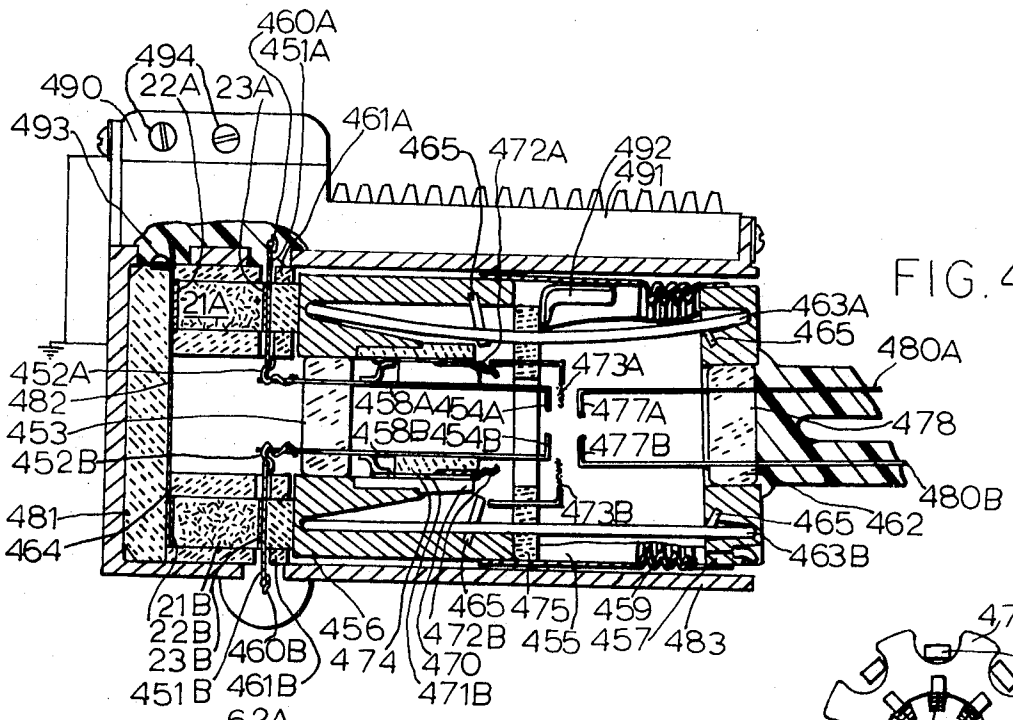


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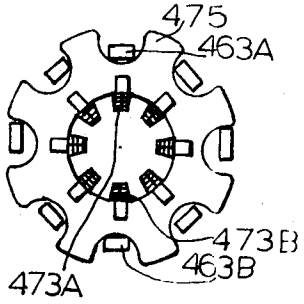


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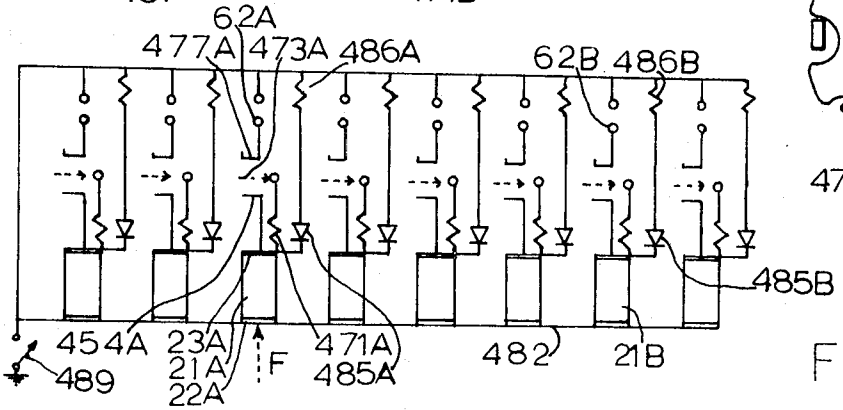


FIG. 47.

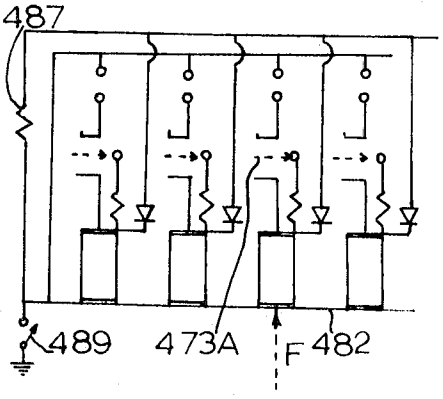


FIG. 48

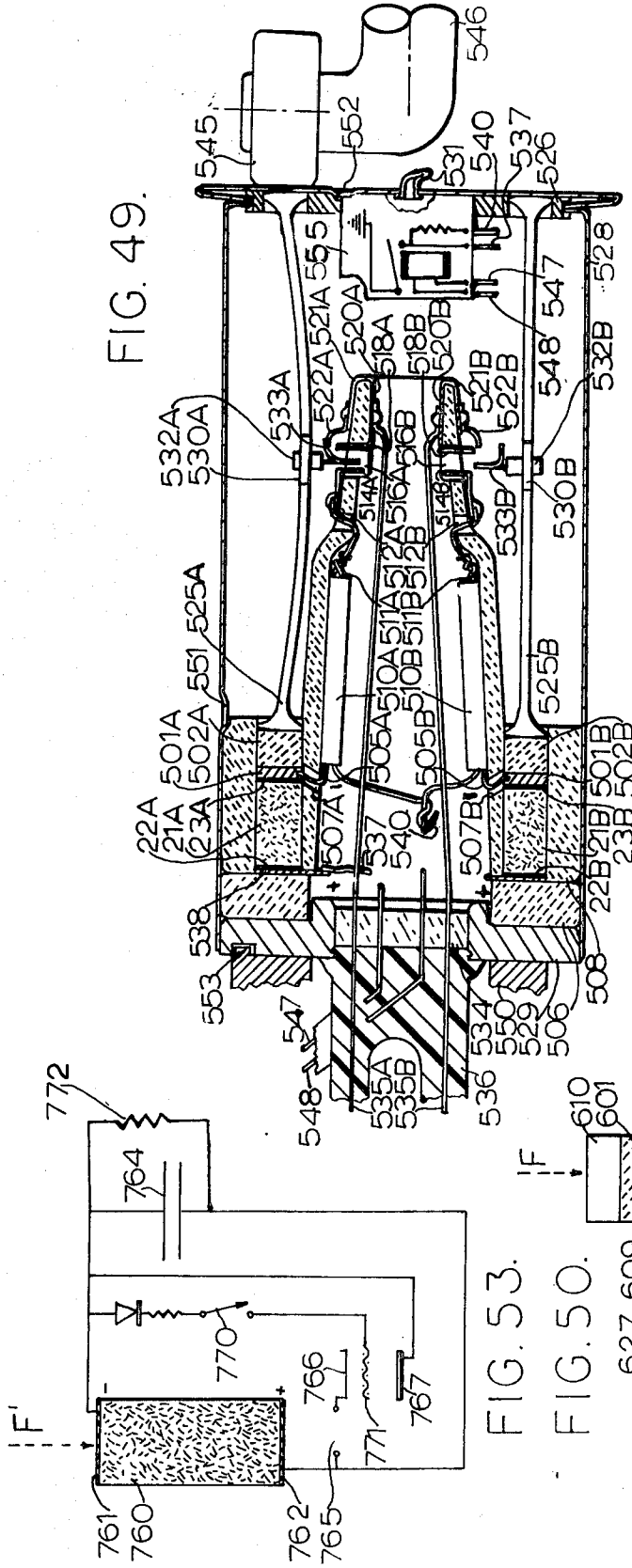


FIG. 49.

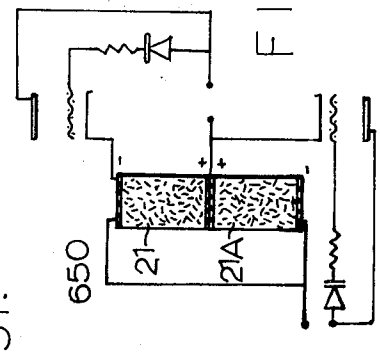


FIG. 52.

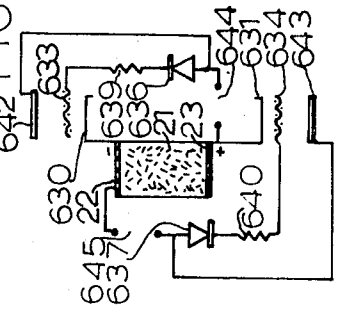


FIG. 51.

FIG. 53.

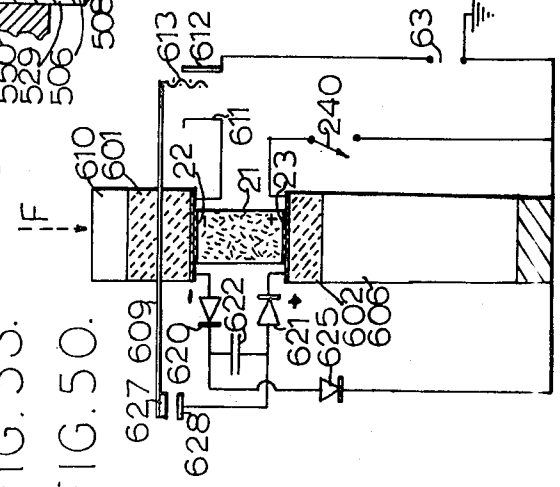


FIG. 50.

HIGH-IMPEDANCE POWER FOR ENGINE IGNITION AND EXHAUST-SYSTEM PARTICULATE REMOVAL

RELATED APPLICATIONS

U.S. Pat. No. 3,349,760 for "Engine-Ignition Systems and Components" was issued to applicant. This invention is a continuation in part of U.S. Pat. Nos. 3,430,080 for "Piezo-electric High-Voltage Alternators and Generators" and 3,444,850 for "Voltage-Generation Apparatus and Ignition Systems" and particularly of copending application Ser. No. 784,457, filed Dec. 17, 1968 for "Voltage Generation and Ignition-Timing Systems," wherein restriction among the claim groups was required by the examiner. That application issued on Aug. 11, 1970, as U.S. Pat. No. 3,524,084. Nonelected claim coverage is again being sought.

BACKGROUND OF THE INVENTION

The first patent listed above, among other disclosures, introduced the concept of piston timing of piezoelectric ignition systems. In the next, new means for stressing the transducer were introduced. In the third, I provided further stressing arrangements for limiting and controlling the application of force to the element and added further advances in the art of piston timing.

In the Background and Summary of the copending application, the shortcomings of the prior arts in both magnetic and ferroelectric ignition systems were discussed. Most ignition systems derive high-impedance energy in a highly wasteful manner by interrupting inductive circuits. Usually they consist of a group of interacting assemblies connected by wiring. Both the wiring interconnections and the many mechanical and electrical parts render them highly vulnerable to failure, especially in the presence of dust or moisture or when exposed to temperature extremes. They are limited in cyclic rate by the decreasing margin of time available for building up coil voltage between successive discharge impulses. Attempts to develop ferroelectric systems have not succeeded in displacing any magnetic systems in current engine manufacture.

SUMMARY OF THE INVENTION

In this and the copending application, I offer new ferroelectric systems that overcome prior difficulties in single and multicylinder ignition systems and have the additional capability of serving as power supplies for electrostatic particle separation from exhaust systems. In addition to the almost total elimination of mechanical friction achieved by the buckling-column mechanisms, I have introduced arc-submergence and electronic means for switching with greater energy-efficiency and reliability. I have also found and shown that one of the chief causes of failure of ferroelectric ignition systems has been the failure to recognize that the recovery impulse is an increment of high-impedance energy that must be delivered into a suitably matched load. Either open circuiting or short circuiting of this impulse in the manner of prior workers can result only in the kinds of capricious behavior that have prevented the adoption of ferroelectric ignition systems to date.

I have noted that catalytic combustors designed for completion of combustion of gaseous products exhausted by the engine are "poisoned" by particulates, which contain metals such as lead. The use of electrostatic particle collectors has been proposed. However, the cost of the kind of power supplies required for stepping up battery voltage to the level required by these devices is prohibitive. Fortunately, these ignition systems provide efficient energy conversion from mechanical to high-impedance electrical. Depending on various design parameters, either the squeeze or the recovery impulse of the transducers can provide the high-impedance output for ignition and either one may charge the particle collector. Thus, none of the high-impedance energy developed by the transducers needs to be wasted.

While mechanical energy may be stored in any elastic member, it is most easily handled by the buckling columns

because of their simplicity, load-limiting behavior, low-mechanical friction, and well oriented motions that they provide for timely actuation of ancillaries. Energy-delivery contacts, if simply mounted on elastic members, would arc prematurely as do ordinary series gaps, so all air and moisture should be excluded from gaps and switch points. Dielectric baths delay arcing and permit quick reduction of series impedance between transducer and spark-plug gap. "Soft" vacuums are also far superior to air; but their deionization time is often appreciable. "Hard" or high vacuums best resist premature breakdown and provide the most efficient reduction in impedance.

The overall output impedance, including series resistance and switching and timing means, as well as the spark-plug gap, must remain at maximum until the instant when a spark is desired, when the total impedance must fall to a level barely above that of the spark gap. The piston-switching means in the above patents did this but required modification of the spark plug and piston.

The principal new matter in this continuation in part relates to the enclosure of mechanisms suitable for firing multicylinder engines, together with the necessary rectifiers and switching means in vacuo. FIGS. 36–53 are new.

The apparatus described herein will coact with ordinary spark plugs without piston activation. The sudden changes in load impedance are accomplished in phase with cam motion, the switching of the impedance level being accomplished herein via various mechanical, electrical, and mechano-electrical triggering means.

The unitary assemblies disclosed herein for firing both single-cylinder and multicylinder engines may be easily installed or removed and can be mounted in whole on appropriate test apparatus. They can be coupled to appropriate cams or shafts having suitably phased motion. They will function in the wettest or dirtiest environments where conventional mechanisms would fail. They do not need to rely upon ionized combustion zones for carrying off the transducer recovery impulses. Even remote control can now be accomplished without switching in the atmosphere.

BRIEF DESCRIPTION OF THE DRAWINGS

Because the drawings are oriented primarily toward clarity of graphic presentation, the parts are not necessarily drawn to scale.

FIG. 1 is a sectional elevation of one form of the piezoelectric ignition control system employing a buckling column for energy storage and switching; and

FIG. 2 is a view from above of the principal portion thereof.

FIG. 3 is a sectional elevation of a variation of FIG. 1, in which the column serves to switch the firing voltage without itself being in the circuit; and

FIG. 3A is a structural variation of the column of FIG. 3.

FIG. 4 is a sectional elevation of a form of the invention disclosing a dual-phase dielectric and in which the switching is done on the ground-return side of the system, the release pulse being discharged via a load; and

FIG. 5 is a partly sectioned endwise view.

FIG. 6 is a sectional elevation of a variation upon FIG. 4 wherein the release pulse is dissipated via a lamp.

FIG. 7 is a sectional elevation of a variation upon the ground-circuit switching devices seen in FIGS. 4 through 6.

FIG. 8 is a sectional elevation employing rectifier means for leading off the release pulse, a plural-phase dielectric, and a variation upon the hot-line switching devices of FIGS. 1 and 3.

FIG. 9 is a sectional elevation illustrating alternative switching means and

FIG. 10 is a partly sectioned end view of the embodiment of FIG. 9.

FIG. 11 is a sectional elevation of a form of the invention having rectifiers paired back to back against a pole of the ferroelectric; and

FIGS. 12 and 12A are alternative schematic diagrams thereto pertaining.

FIGS. 13 and 14 are a sectional elevation and a circuit diagram of a form using a rectifier for carrying off the release charge and having a triggered spark gap for delivering the ignition pulse.

FIGS. 15 and 16 are a sectional elevation and a circuit diagram of a form like that of FIGS. 13 and 14, except that a triggered flash tube is used instead of a spark gap.

FIG. 15A resembles FIG. 15 except for the fact that the control or trigger electrode of the tube is physically movable.

FIG. 17 is a form that uses a lever in a dielectric medium in place of the buckling column but electrically resembles FIGS. 1 and 3; and it might alternatively resemble FIGS. 4 and 7 electrically with rerouting of the connections.

FIG. 18 is a form that uses a lever in a dielectric medium but electrically resembles FIG. 8. If the arm touched a spark gap, it would resemble FIGS. 13 and 14 electrically. It could resemble FIGS. 15 and 16 electrically with a further change from spark gap to triggered flash tube or could resemble FIG. 11 electrically if a rectifier is provided and switching is modified.

FIG. 19 is a simplification of FIG. 8, eliminating switching and dielectric fluid at some cost in performance.

FIGS. 20 and 21 are alternative schematic representations of FIG. 19.

FIG. 22 is a further simplification of FIG. 8, now eliminating the rectifier; and

FIG. 23 is a schematic representation of FIG. 22, while FIG. 24 shows the pattern of cam excursion most desirable with FIGS. 22 and 23.

FIGS. 25 and 26 are, respectively, a sectional elevation and a schematic of a unitary ferroelectric ignition apparatus embodying a rectifier and a triggered spark gap.

FIGS. 27 and 28 are, respectively, a sectional elevation and a schematic of a unitary ferroelectric ignition apparatus resembling that of the prior figures but employing a flash tube.

FIG. 29 continues the trend of the figures immediately preceding with a schematic diagram of an ignition apparatus employing a high-voltage thyratron.

FIG. 30 carries the design trend further with a schematic diagram of a similar apparatus employing a high-vacuum or "hard" tube.

FIGS. 31 and 32 are, respectively, a sectional view and a schematic pursuing the design trend of the six preceding figures except that a special kind of high-voltage diode is used.

FIG. 33 combines a detail of a magnetically timed variation of the ferroelectric ignition apparatus with a schematic of the complementary firing circuit.

FIG. 34 illustrates a further magnetically timed variation of an ignition apparatus.

FIG. 35 is a schematic illustration of a form of grid control for a ferroelectric ignition apparatus.

FIG. 36 is a sectional elevation of an apparatus like that of FIG. 8 but modified to enable the mechanism to be contained in a vacuum instead of a dielectric fluid.

FIG. 37 is a sectional elevation of a multicylinder version of piezoelectric ignition system, the switching mechanism again functioning in a high vacuum, and

FIG. 38 is a transverse section therethrough.

FIG. 39 is a sectional elevation of another multicylinder version employing a metallic housing instead of the glass one of FIG. 37.

FIG. 40 is a sectional elevation of another multicylinder version in which the transducers themselves are enabled to be placed outside the evacuated housing.

FIG. 41 is a sectional elevation of another multicylinder version, in which all switching is performed by a nutating member, the transducers again being outside the evacuated glass housing.

FIG. 42 is a sectional elevation of a fifth multicylinder version, again with an evacuated glass housing and external transducers.

FIGS. 43 and 44 are, respectively, a sectional elevation and a transverse cross section of a sixth multicylinder version, again in glass and with external transducers, but with ignition-impulse switching performed electronically.

FIGS. 45 through 48 are, respectively, an elevation of a multicylinder version with an evacuated metallic chamber and external transducers, firing-impulse switching again being electronic;

FIG. 46 is a transverse view of the control-grid arrangement on the nutating plate;

FIG. 47 is a circuit diagram for an 8-cylinder version; and

FIG. 48 shows an alternative circuit for a 4-cylinder system.

FIG. 49 is a sectional elevation of a multicylinder ignition system in an evacuated metallic housing, with enclosed electronic switching, rectifiers, and transducers.

FIG. 50 is a schematic diagram of a single-cylinder version having polarity-inversion, capacitor-storage, and impulse-combination features.

FIG. 51 is a schematic of a high-impedance single-element system in which both output polarities are electronically switched into separate loads.

FIG. 52 is a schematic of a system resembling that of FIG. 52 except that two transducers are arranged in mechanical series and electrical parallel.

FIG. 53 is a schematic of a system in which the squeeze impulse is delivered to a load such as an electrostatic precipitator without switching, only the recovery impulse being switched to fire a spark plug.

DESCRIPTION OF THE EMBODIMENTS

Referring now to FIG. 1, there is seen a unitary ignition system wherein element 21, preferably a cylinder of a high-dynamic-strain type of ferroelectric, such as is represented by the "PZT-4" formulation of polarized lead titanate zirconate, electroded 22, 23 at its opposite ends, is sandwiched between a metallic end block 26 and the base portion 27 of an inverted ceramic cup insulator 28, which has deposited conductors 30, 31 passing via a small hole through the base portion 27 and continuing to face outwardly from the remote surface of base portion 27. Conductor 31 makes contact with a hardened, prestressed metal spring switch 32, having an "oil-can" contour and a finger 33 that normally grounds electrode 23 and conductors 30 and 31 to the inside wall of tube 34, which forms the major part of the housing.

Buckling column 35 not only transmits to the piezoelectric via base portion 27 the compressive force it receives from push rod 47 but also serves as a conductor for the electrical charge that will be delivered by piezoelectric element 21 in response to that force. The source of energy is cam 48 contoured into shaft 37. At the right or camming end of column 35 it fits into a pocket in the insulating ceramic plug 40, which has a very slight venting groove 41 to permit reciprocal motion thereof in the liquid dielectric 42 with which tube 34 is filled. When the clearance is ample or the fluid is compressible no groove is needed. A wide variety of dielectric fluids 42 is available. These include the silicones, liquid or dual-phase hydrocarbons and fluorocarbons, etc. Pushrod 47 reciprocates in an axial opening in shaft adapter 45 and is sealed by O-ring 46. Shaft adapter 45 is retained in tube 34 by U-pin 56. The surfaces of cam 48 are lubricated by tiny oil vents 99, 100 drilled axially and transversely through shaft 37 and communicating with the extraneous engine.

When cam 48 rotates against the end of pushrod 47, column 35 first compresses switch 32, then delivers the compressive load via base portion 27 to ferroelectric element 21, which develops a high voltage between its face electrodes 22 and 23. The polarity of the voltage is the same as that of its original polarizing voltage which was impressed during manufacture. The element will function just as well if it is turned end-for-end, reversing the output polarity. When compressed, switch 32 flattens, lifting finger 33 off the tube wall 34, thus unshorting ferroelectric 21 so that it may develop and hold a high firing voltage under axial compression. Guide plate 36, which does not carry the column load, maintains alignment of column 35 and finger 33 and may be of ceramic or plastic.

For a column having an oblong cross section, as column 35 preferably does, the transverse deflection under axial load will be parallel to the short sides of its cross section and may be consistently predetermined in direction by various means, including the imposition of very slight, perhaps invisible, bend, kink, or other asymmetry anywhere along its length, by angling one or both of its end surfaces, etc. As cam 48 rotation proceeds toward maximum interference and compression and column 35 "bottoms" at its left end, it begins to buckle in the middle as its load arrives at and exceeds the ordinary columner load values. The midpoint contact 58 of column 35 moves upwardly under the influence of asymmetry built into the column in the direction of ignition contact 59, which communicates, via insulated 60 wire 61 conductor, with the middle electrode of spark plug 63. Insulation 60 is formulated of an elastomer that is resistant to heat and to attack by hydrocarbon solvents.

Since the left electrode 22 of element 21 communicates with ground via end block 26, tube 34, and either shaft adapter 45 and shaft 37 or screw 53 or an optional ground strap, the engine casting 65 continuously holds the ground electrode of spark plug 63 at ground potential. Thus, the making of contact between the midpoint 58 of column 35 and contact 59, which is a function of the phasing of cam 48 with the system axis, times the firing of spark plug 63.

In this first embodiment, the dielectric fluid 42 is the hydrocarbon engine fuel, which may enter tube 34 via conduit adapter 50. It departs via conduit adapter 51 on its way to the carburetor. These identical adapters have been sweat-soldered in place over tube 34. Thus any products of decomposition of the dielectric, caused by possible slight arcing at switch 32, finger 33, or contacts 58 and 59 are continuously flushed away via circulation of the fuel supply into the engine. The volume of any such products would be so exceedingly small that it might not be detectable by careful filtration. Danger of fuel explosion is absent once the tube 34 has been filled with fuel to the exclusion of air. If desired, tube 34 may be incorporated into the bottom of the fuel tank or into the carburetor, perhaps as the float tank, together with means for preventing accidental draining or a warning label with necessary instructions.

In FIG. 2, the rotation of cam 48 is seen to be clockwise. Therefore, counterclockwise rotation of tube 34 about cam 48 advances spark timing. The desired setting may be retained by tightening screw 53 at the outward end, with indicator point 54 positioned in the desired relationship to scale 55. Counterclockwise rotation of an appropriately designed cam will produce a similar effect.

Although wire conductor 61 may be conventionally terminated at the end of insulating cable 60 to slip onto the top of spark plug 63, the system is illustrated with a sealing elastomeric grip sleeve 68 for waterproofing the connection. Further protection may be gained by tightening clamp 69 over sleeve 68. By protecting the plug in this manner, and providing for engine breathing in the manners illustrated in the above-mentioned patents for wet engines, protection may be gained against immersion even in vigorously turbulent saline water. Where not immersed, sleeve 68, if used, would need to be made of a high-temperature elastomer.

Sawtooth cam 48 permits rapid release of pressure upon the ferroelectric 21 so that the full value of the weaker relaxation impulse, which as an opposed polarity, normally appears at the spark-plug electrodes while dense combustion and heavy ionization still remain in the engine cylinder, keeping the zone electrically conductive and able to drain off the secondary pulse while it is being generated. Roller cam followers, though normally advantageous, tend to modify cam kinematics and delay the release pulse, which, if used up in the combustion chamber, will get the system ready for another cycle but will otherwise interfere with subsequent cycles. The release pulse might be carried off via the ferroelectric itself, since it is not a good insulator, or by leakage elsewhere in the system during the relatively slow engine-starting cycles; but, for maximum reliability, both the squeeze and release mechanical cycles are best followed by immediate and virtually complete electrical discharge.

The conductivity of the ferroelectric may be increased further so that it will self-discharge between cycles and this will be done in another embodiment. However, at very low speeds and during manual starting, such a self-discharge property may be detrimental in that it may cause excessive energy to be robbed from the squeeze pulse, especially at higher temperatures, since the conductivity usually increases with temperature. Conversely, at maximum engine speeds and loads, the release pulse may not have enough time to drain completely, reducing the value of the squeeze pulse and possibly causing the engine to miss.

In this embodiment, the column 35—cam 48 relationship is such that, when the ignition pulse is switched into conductor 61, the dropoff portion of the cam contour then releases the compression load from column 35, which relaxes, allowing finger 33 of switch 32 to reestablish contact between conductor 31 and tube 34, and thus short circuit the release charge. Again, the dielectric fluid enables holding switch clearances at a minimum and keeping the assembly small.

As in most of the cases to follow, cam 48 and its shaft 37, or only the cam, may be designed to be an integral part of the ignition apparatus or alternatively of the engine.

The shape and structure of the column and of the tube, or counterstructure, make it economical to shield the entire ignition system against electromagnetic radiation during switching and discharge, as well as to exclude dust and moisture, the enemies of all ignition systems; and they further make it more convenient than ever to couple the ignition system with spark-advance controls and with shutoff means that operate by delivering the spark out of phase with the engine.

Referring now to FIG. 3, certain approaches alternative to those just seen will be observed. Element 21 is contained within insulating ceramic cylinder 77. The prestressed oil-can type of shorting switch 32A bridges temporarily between the fired-on conductive coating 31A, which covers the end of ceramic insulating plate 24, and column 35A. Column 35A is guided at the left by guide 36A and it has a pin 25 for holding switch 32A in place.

At the right, column 35A is sealed by O-ring 46A in shaft adapter 47A, which is secured to tube 34A by U-pin 56A. As the pressure in Column 35A builds up because of relative rotation of cam 48A on shaft 37A against cam follower 49A borne on the end of column 35A, the switch 32A flattens, disconnecting itself from conductor means 31A and thus disconnecting electrode 23 of element 21 from grounded column 35A. Wire conductor 64A, soldered on the underside of ceramic plate 24 to conductor 31A, leads upwardly into chamber 94. Hot-line conductor 61A travels to the center electrode of spark plug 63 (omitted here).

Grounded column 35A has arm 72 spotwelded to it near the left end; and arm 72 in turn carries at its tip insulated 70 contactor 71. When column 35A buckles, contactor 71 bridges between the aforesaid conductors 64A and 61A, delivering the ungrounded firing potential to the spark plug. As in the prior instance, the grounded side is continuous via end plug 26A, tube 34A, etc.

Timing adjuster 73, whose portion is responsive to the r.p.m. of the engine, via a governor or other auxiliary device well known to the art, may be moved perpendicular to the plane of the paper in order to advance or retard the timing.

FIG. 3 discloses another departure that is equally applicable to other embodiments herein. This is the use of a two-phase dielectric fluid, 42A, 142. Certain fluorocarbons and hydrocarbons, for example, boil at much lower temperatures than do silicones and other fluids generally used for removing heat from electronic equipment. In these fluids the transition to vapor 142 occurs well below the decomposition temperature and often below the boiling point of water. This fact permits such equipment to benefit from what is known as ebullient cooling, that is, by boiling, there being generally sharp in-

creases in the enthalpy of fluids passing to the vapor phase 142 (i.e., steam vs. water). The fact that the dielectric strength of certain of the relatively inert fluorocarbons remains at a useful level in the vapor phase accounts for the practicability of the ebullient cooling process in electronic equipment.

In these voltage-generation systems, however, we do not seek thermal protection per se. We seek, rather, to control engine timing, so we employ fluids of high-dielectric strength to suppress the tendency of high potential gradients to cause premature arcing between approaching switch contacts. Unfortunately, most of the best, safest, and most reliable dielectric fluids contain carbon as a chemical constituent of their molecular structure. As the contacts bearing high-relative potential approach very closely, even the strongest of dielectric fluids may tend to break down when the gap becomes sufficiently small. Even though the duration and the amount of current, and thus the total energy, are very small, the intensity of an electric arc is so great that a very tiny portion of the fluid may be decomposed. One of the final end products of decomposition is carbon, which may be partly in a conductive form. Given a sufficient cumulative concentration of such particles in a liquid, sparking will tend to occur earlier and earlier in the successive cycles of contact approach. Research has not yet developed fluids that have been proven to be wholly immune to this type of breakdown.

Although impurities tend to settle out, they may be kept in suspension by such vibration as accompanies the operation of an engine. The passage of an engine fuel through the apparatus, as in FIGS. 1 and 2, is one answer to the problem. Circulation of fluids other than fuels in the same manner but via external recirculating filters is another. With the aid of vibration, porous filter 155 made of a bonded-in-place fine elastomer, such as open-cell polyurethane foam, or even if allowed to float around in the medium, is another. Placing the foam where mechanical motion tends to circulate fluid is a practical expedient. Thus, the very fact that column 35A tends to buckle causes the fluid to acquire motion. Since the fluid possesses inertia, it tends to resist such motion, and while being displaced acquires kinetic energy of motion, thus forcing some circulation relative to filter 155, whether the filter is stationary or is attached to the column.

Another approach is to use one of the dielectric heat-exchanger fluids that has a high-vapor-phase concentration at low temperatures of operation. One of the most suitable fluorocarbon grades is FC-78, made by the 3M Company, which has an unusually low-boiling point and relatively high-vapor pressure. Instead of filling cylinder 34A with dielectric fluid, then, it may carry far less than half its capacity in the liquid phase 42A, the remaining volume above the liquid containing only the vapor phase 142 at variable pressures that depend on the ambient temperature but preferably several p.s.i., what might be termed a partial vacuum in the absence of air, which is preferably well sealed out.

Since the contacts are above the liquid level, such impurities as may be generated by arcing will drain down in the ever-condensing vapor produced by thermal differences within the chamber and along its walls, instead of remaining supported in suspension. And the presence of two phases assures that the same vibration that might disperse conductive particles in a single-phase dielectric now adopts the entirely new role of liquid circulator and washing means, whose effect may be further enhanced by foam filter 155 or other porous particle-trapping means, either fixed or mobile.

There are, of course, liquids which contain no carbon. Other requirements are that the liquids not ionize under any anticipatable conditions and that they not react chemically with the contacts or with other materials in the chamber. They must not decompose into metallic or other conductive particles. Preferably they should be nontoxic, nonflammable, and incapable of supporting combustion; but ideal properties may not be achievable.

FIG. 3A is illustrative of the fact that a wide range of structural variations of nonlinear force-transmission members is possible. The slender reed-switch extension 72 of member 35A has an excursion that is not necessarily in direct proportion to column deflection. If the contacts it may touch are yieldingly emplaced, it may move them. If not, its range of movement is limited by their presence; but the excursion of the middle of the column need not be significantly affected.

Referring now to FIG. 4, electrode 22 of ferroelectric 21 faces conductive coating 76, which has been fired onto insulating ceramic end plug 38. The conductive path leads via conductor 75, fired onto the exterior wall of insulating ceramic cylinder 77B to conductor 78 on the interior wall of elongated insulating cylinder 79, which may be of ceramic or plastic. Conductor 78 is interrupted at midlength of cylinder 79, where contacts 43 and 44 are slightly separated. Opposite them is insulated 70B shorting contact 71B on column 35B, the remainder of interrupted conductor 78 thereafter leading to conductor 81 on the outer wall of cylinder 79 that grounds to cylinder 34B. These conductors are generally glazed silver frits which have been fired onto the ceramics at elevated temperature. Less expensively coated plastics may be used wherever they are not located in a high-force zone.

The ceramic body 24B between column 35B and electrode 23 of the element 21 is quite different from the plain insulating plate 24 seen in the prior figure. Body 24B is made of a lossy barium titanate capacitor-type material so that there is both capacitance and resistive leakage between its opposite conductors 31B and 83. Switch finger 33B short circuits conductors 83 and 78 to ground via column 35B when the column is not loaded. When cam 48B on shaft 37B applies a load to column 35B, contact between the column and conductors 83 and 78 is interrupted by the flattening of the disc portion of switch 32B and the consequent detachment of its finger 33B from conductor 78.

Since electrode 23 is always in communication with the ungrounded center electrode of extraneous spark plug 63 (not shown), via conductors 31B and 61B in insulation 60B, when column 35B buckles in the predetermined direction of the arrow, with insulated 70B contact 71B shunting to ground the midway interruption of conductor 78, column 35B again times the spark as a function of its phasing with cam 48B.

In the end view, FIG. 5, it is seen that scale 55B may be engraved on the movable ignition system rather than on the stationary engine as heretofore.

Referring now to FIG. 6, there is seen an ignition system wherein the column 35C is continuously in circuit with the side of ferroelectric 21 which will become grounded when column 35C buckles so much in the direction of the arrow that its contact 58C completes contact with contact 59C of timing adjuster 73C. Column 35C is restrained laterally at its left end by ceramic guide 36C and at its right by ceramic plug 40 in shaft adapter 45C.

Timing contact 59C may be moved radially inward into the tube 34C to advance the spark timing as a function of the displacement to the right of the adjuster finger 54C. There is a stop position on the spark-advance indicator scale 55C, wherein the contact 59C is retarded by camming beyond the reach of buckling column 35C, as limited by the radial excursion of cam 48C. Engines may also be stopped by simply retarding or advancing the spark so much that it is badly out of phase with piston position.

The left-end electrode 22 of element 21 is seen to be continuously in series with spark plug 63 (not shown) via conductor 61C. It is also seen that, as long as column 35C is not under load and switch 32C is not compressed by it, the element 21 is shunted via finger 33C into neon lamp 92, through which all release pulses will be almost completely discharged down to a relatively negligible extinction value. When column 35C is loaded, finger 33C parts contact with bulb 92. Thus, most of the release-pulse energy passes into an energy-dissipating device, in this case the bulb 92, and is unavailable for arcing in the dielectric 42B. The maintenance of low-arcing potentials within the fluid reduces contamination by carbon or other breakdown products and enhances longevity of fluid 42B.

The lossy capacitor 24B of FIG. 4 and the neon tube of FIG. 6 are each examples of energy dissipating means, simple resistors and inductors also having value, provided that they are not afforded sufficient time in circuit to steal much energy from the squeeze pulse. Outside exposure of the tip of lamp 92, as seen in FIG. 6, may aid diagnosis of possible failures of system components. Except for the fact that the ground circuit is switched by column 35C, the structure of FIG. 6 bears some similarity to that of FIG. 1.

Referring now to FIG. 7, the mechanical termination of this system at the right includes a bolting flange 95 and an O-ring-sealed 46D projecting end 87 of column 35D. The conductive path from the left electrode 22 of ferroelectric 21 moves to the right in the manner of FIG. 4 via electrode means 76D and conductors 75D and 78D along inner wall of insulating cylinder 79D to contact 43D opposite the midpoint contact 58D of grounded column 35D. The right electrode 23 communicates with conductor 31D.

In the absence of columnar force, spring switch 32D short circuits the release charge of ferroelectric 21 via conductors 75D, 78D, 30D, and 31D. High pressure in column 35D flattens and opens switch 32D. It also isolates column 35D from direct communication with electrodes 22 and 23. As the grounded column becomes more heavily loaded and then begins to buckle in the direction of the arrow, its center contact 58 receives from contact 43D for delivery to ground the potential now existing at the left electrode 22 of element 21, causing the spark plug at the remote terminus (not shown) of conductor 61D to fire. Spark may be advanced or retarded by moving the assembly toward or away respectively from the approach to the end 87 of column 35D of an extraneous camming means.

Referring now to FIG. 8, column 35E is grounded at its right end and isolated electrically at its left end. It is permanently sealed at the right by flexible metallic diaphragm 160, which is welded to both column 35E and the inner end surface of housing 34E. The right end of column 35E is seated within and is guided by roller-type cam follower 49E, which in turn moves in a hole in block 161 under the action of cam 48E. Contact 71E at column midpoint is insulated by layer 70E beneath it. Contact 71E joins conductors 64E and 61E via contacts 43E and 44E when column 35E buckles under load.

There is no release switch in this embodiment. Instead, there is an encapsulated diode rectifier stack 105 having a very high-peak reverse voltage (PRV or PIV) characteristic, preferably on the order of about 25 kilovolts.

It was stated above in connection with another embodiment that the polarity orientation of the ferroelectric 21 was uncritical, as it is when the device is switched mechanically. That is still true of the version of FIG. 8. However, the rectifier polarity here should be so oriented with that of the ferroelectric 21 that the forward-current path of the rectifier will accommodate the energy of the release impulse but will block electrical energy transmission during the squeeze portion of the cycle.

The series of diodes that make up the stack rectifier 105 have a uniformly small conductive cross section area in order that rectifier 105 will have a very low-current capacity. It is not that a low-forward current capacity is particularly desired, although the energy transmitted is minute; it is that every reasonable precaution must be taken to keep the normal reverse-current conductivity at a minimum because of the relatively slow rate at which the high-firing voltage builds up in the ferroelectric 21 and because the firing energy itself is so small. Other things being equal, rectifiers able to conduct large values of forward current are generally less able to hold back some flow of reverse current.

Although it may be desirable that the individual diodes in rectifier stack 105 also be designed to have a low-initial transient reverse current, such as may result from the storage of minority carriers in the junction zones of the diodes and the necessity for sweeping them out, this appears to be of less consequence than the normal reverse current because, during the sweepout time, the voltage across ferroelectric 21 will not yet normally have been built up high enough to force much reverse current through the stack.

In FIG. 8 and some of the other subsequent figures, the use of rectifiers and other means either in place of or in addition to switching contacts reduces the amount of energy available for arcing and generating conductive impurities in the dielectric fluid. But FIG. 8 goes further in the effort to endow these systems with longevity. It departs from the single-chamber two-phase system of FIG. 3, replacing it with a two-phase system which is substantially a vapor-phase 142 system in the switching compartment within tube 34E. It carries the liquid phase 42A stored in the rechargeable lower antechamber 122 that is cut into block 121. Communication between compartments is via port 123. Leakproof welded diaphragm 120 assures against exchange of atmospheres which might otherwise be produced via the slight pumping action of O-ring seals. Diaphragm construction is, of course, also applicable to the other embodiments herein.

Referring now to FIGS. 9 and 10, although the column still delivers the force to ferroelectric element 21, it is not called upon to do the switching. Camshaft 37F is a part of this embodiment, being packed 46F against leakage and keyed 111 to be driven externally of an engine, to which it may be secured by suitable clamping means. Column 35F is prevented from moving laterally of the cam in a direction transverse to the paper by a pair of roll pins 112, the lower of which appears in the section drawing.

The square shanked portion 113 of shaft 37F below upper bearing 115 keys the grounded switch contactor 116 to shunt both contact fingers 117, 118, as seen in the drawing, and alternately once each revolution to ground the upper one 117. Grounding both at an appropriate instant while column 35F is unstressed short circuits the release charge developed in the ferroelectric 21. Grounding only contact finger 117, which leads from the right electrode 23 of the element 21, an appreciable part of a revolution later, as, for example, 180°, when the column 35F shall have become nearly fully bowed, completes the ignition firing circuit, since the left electrode 22 of the element 21 is continuously in circuit, via conductor wire 61F, with the middle electrode of spark plug 63 (not shown).

As seen in the phantom lines at the lower center of FIG. 9, the buckling column might again alternatively have been employed as in FIG. 5 to close the ignition circuit instead of using projection 119 and finger 117 for this purpose.

Referring now to FIGS. 11, 12, and 12A, the latter two are nearly identical schematic representations of FIG. 11. They differ only in that the polarity arrangement of the ferroelectric 21 in FIG. 12A is opposite from that of FIG. 12; so the polarities of rectifiers 105 and 125 are reversed between the schematics. Rectifier 105, seen in prior FIG. 8, is employed here in an identical manner. The distributed resistance in rectifier 105 and the conductors may again, as in FIG. 8, be augmented by other energy-dissipation means, including such as were shown in FIGS. 4 and 6 (24B and 92 respectively). This resistance is lumped as R–1 on the right of FIGS. 12 and 12A. The same is true of subsequent figures in which release-charge energy may be dissipated in conductors of small cross section or in discrete components included in the system.

Composite column 35G has a plurality of component members, all tending to bow outwardly a more or less equal amount at any given overload. Electrical contact is completed at only one point, however, via contact 58G.

Column 35G is tipped with an O-ring-sealed 46G roller cam follower 49G. Contact 58G triggers the discharge when it establishes a through connection via contact 59G between rectifier 125 and ground, represented by tubular housing 34G. Again in the ground line, as in other figures herein, there will be more distributed resistance, which is lumped here as R–2.

The requirements to be met by rectifier 125 differ markedly from those considered necessary in rectifier 105. The forward voltage on rectifier 125 is the same as the reverse voltage on rectifier 105; but it is only transiently applied to rectifier 125

at the instant when switch 58G, 59G is closed to complete the firing circuit into spark plug 63. Since the release charge appears as forward voltage on rectifier 105 it is conducted therethrough and dissipated as fast as the energy is allowed to flow by the lumped circuit parameters; so it never achieves a very high voltage value; and, since it is also the reverse voltage on rectifier 125, the latter does not need to withstand the high reverse voltage peaks imposed upon the former. This differentiation between the functions of the rectifiers is not intended to deny the use of a common rectifier type having characteristics high enough and well enough balanced for use in both applications.

Referring now to FIGS. 13 and 14, rectifier 105 is again employed to divert and dissipate the release charge of element 21, while barring the flow of squeeze energy. It is connected between the junction of right hand electrode 23 and conductor 31H, to the latter of which its lead is soldered at 57, and ground at the right. The distinctive novelty here is the triggered spark gap 135, which has a trigger electrode 138 in addition to gap electrodes 136 and 137, either of which can be oriented toward the element 21. These spark gap electrodes are hidden in FIG. 13, only the contact 59H, and terminals 140 and 141 leading to the respective electrodes being visible.

Energization of the trigger electrode 138 by the high-squeeze voltage of ferroelectric 21 causes an initial flow of current between that electrode and the one of opposite polarity, the ground side in this case. The resultant ionization which is localized causes the firing pulse to make the transit between the principal electrodes 136 and 137. A small-wattage resistor 139 or a sufficient value of distributed resistance in the conductors, including column 35H, is in series with the trigger electrode 138, so as to hold back current flow from the trigger circuit and compel the current to follow a preferential path of extremely low resistance (after ionization) between principal electrodes 136 and 137.

Because spark gaps of the type disclosed are usually made with large distances mutually separating the contacts and terminals 59H, 140 and 141 leading to the electrodes, it is more than usually practicable in this instance for contact 58H on column 35H to perform its switching function in air, particularly if dust can be prevented from settling on a shunting path. However, even in this case, I prefer the performance obtainable with fluid dielectrics.

Referring now to FIGS. 15 and 16, which likewise contain high-voltage rectifier 105 aligned to block squeeze pulses accumulating in ferroelectric 21 and to conduct release pulses, flash tube 127, preferably is of the elongated path type having a high-voltage arcover value, such as is seen in sparsely filled gas tubes. It has a third or trigger electrode 130 in addition to principal electrodes 128 and 129 that are concealed within the tube 127. The trigger electrode 130 need not necessarily be contained within the gas chamber itself. When it is located outside the glass envelope, as here, the current flow via contact 58J and trigger electrode 130 is negligible and there is a minimum of contact arcing. If desired, fluid may be dispensed with. The tube needs a deionization or recovery period after firing sufficiently brief to prevent premature conduction of the next subsequent impulse, even at high-engine speeds. Porous filter 155J is squeezed by deflection of column 35J, promoting limited cyclic circulation of fluid 42J therethrough.

FIG. 15A differs from FIG. 15 primarily in that trigger electrode 178 is movable. Of semicylindrical contour and having appreciable area and capacitance relative to the tubular flash tube 127R, it is mounted on column 35R and so oriented as to be deflected thereon into triggering position against the surface of the tube.

Referring now to FIG. 17, levers have been used for squeezing ferroelectrics heretofore, but without accomplishing the ends of this disclosure. Dielectric fluid 42 is a circulating hydrocarbon fuel, as in FIGS. 1 and 2, sealed in via O-ring 46K, located in an opening in housing 34K that admits adjustable threaded actuator pin 145. Pin 145 moves reciprocably in the direction of the arrow in response to an extraneous camming means (not shown). Lever 144 is displaced cyclically by pin 145. Lever 144 has an insulated 70K contact 71K on its inward face. Electrode 22 is grounded to lever 144 by hard metallic plug 149. Insulated 133 contact 134 is permanently connected (not shown) via extension conductor 143 (interrupted) to right-hand electrode 23 of element 21, which is, therefore, initially short-circuited electrically via plug 149, lever 144, and contact 134.

When pin 145 lifts lever 144 of contact 134, the short circuit is removed from element 21, whose last prior release charge had been drained to ground thereby. When lever 144 has advanced inwardly through the fluid 42 until cam 147 has fully squeezed element 21 via plug 149, insulated 70K contact 71K completes the circuit from grounded element 21 via conductor 64K and contact 43K to contact 44K and conductor 61K, leading to center contact 62 of the spark plug (not shown) to ignite the mixture in the combustion chamber.

Although advance and retard controls can be built in elsewhere, pin 145 itself may be moved either way, via its own thread, to advance or retard the spark. Plug 150, sealed by O-ring 151, has its outer surface threaded for adjustment of squeeze via ceramic disc 38L of the ferroelectric 21 at the right end of FIG. 17. It will be seen that this unitary ignition system is electrically similar to FIGS. 1 and 3. It would be electrically similar to FIGS. 4 and 7 if the interruption closed by the lever were between the ferroelectric 21 and ground, as, for example, if the lever arm 144 were insulated from an ungrounded ferroelectric and if an insulated contact on the advancing lever arm were to ground the element.

Referring now to FIG. 18, the lever-powered system resembles that of FIG. 8 electrically, with the same rectifier 105 similarly situated so as to block squeeze pulses. Rectifier 105 is in series between grounded tube 34L and contact 43L, as revealed by dotted-line interconnections. As in FIG. 17, contact 43L, at the end of squeeze motion by lever 144L, is directed via insulated 70L contact 71L to discharge element 21 into spark plug 63 (not shown) via conductor 61L.

This system can be converted to one electrically analogous to that of FIGS. 13 and 14 if contact 70L is made to touch the trigger electrode of a spark gap. It can be converted in the manner of FIGS. 15 and 16 if contact 70L completes circuit into the trigger electrode of a flash tube having a high-voltage arcover value. Or it could become electrically similar to that of FIG. 11, plus either FIG. 12 or 12A, provided that rectifier 125 is similarly wired in and if contact 70L is made to close the circuit from rectifier 125 to ground as do contacts 58G and 59G in FIG. 11. Generally speaking, most of the electrical circuits shown herein to be feasible with buckling column systems can be derived via levers and other devices for acquiring mechanical advantage. This fact does not negate the advantages characteristic of buckling column systems.

Referring now to FIGS. 19, 20, and 21, it is seen that, whereas FIG. 8 was a constructive elaboration upon preceding forms for performance improvement, a reversal of the elaboration trend may have some merit in certain applications where cost saving is paramount. Certain numerals in these figures now bear "M" suffixes instead of the letter "E" that was used to distinguish parts that had been modified for use in FIG. 8. In every case the M suffix indicates that the changes in the details were direct consequences of the simplification made here.

In this form, the high-voltage rectifier 105 remains in the system. However, the fluid dielectric and the switch are dispensed with. This change involves a distinct reversal of relationship among the ferroelectric 21, the rectifier 105 and the cam 48E. The reversal may be especially noted in FIG. 20, wherein the anode-cathode orientation of the rectifier is reversed so that it will be continuously conductive during the compression of element 21, the squeeze pulse thereby being completely drained. It is seen in an alternative form in FIG. 21, wherein the relationship between element 21 and rectifier is the same as in FIG. 20, but their common relationship to ground and to the center electrode 62 of spark plug 63 is now reversed also.

The effect is that the squeeze pulse no longer appears at the spark plug **63**; but the release impulse does. Firing now occurs later in the cam cycle, after dropoff, making it necessary to rephase engine and cam. The energy available for firing the spark plug is much less than when the squeeze pulse is utilized. The reduction in energy available at the spark plug may result in a lesser firing reliability, particularly under marginal conditions, unless certain steps toward compensation are taken.

Column **35E** may be stiffened to increase the load on the ferroelectric so as to increase both squeeze-pulse and release-pulse energy. Along with the heavier column cam **48E** may be given a greater rise and the diameter of the element and its length both may be increased to utilize the greater squeeze force without overstressing the element. Such changes will impose a still greater workload on rectifier stack **105**, which will already bear the increased electrical and thermal burdens of disposing of the stronger squeeze impulse. Such resistors as may be in series with rectifier **105** for handling waste power will likewise carry a heavier load. Thus, the conducting areas of the individual diodes in diode stack **105** must be greater for equivalent life. More energy will be wasted and more heat must be disposed of.

Because the potential developed during compression release is less than that of compression, the peak inverse voltage (PIV) requirement upon rectifier **105** will be lessened only if the gross polarizing potential has not been increased, though this is unlikely, because the element will probably have to be longer and thus require a higher polarization voltage so as to lift the release-pulse amplitude to the voltage level of the squeeze potentials utilized in other embodiments.

The fact that, when shorted or shunted, a ferroelectric has a lesser effective Young's modulus during compression than when open-circuited means that the element, size for size, will offer a less stiff reaction to the column during compression but will itself be mechanically stiffer during release by virtue of the effective open-circuiting of the diode stack. One might then expect it to develop a greater release impulse in a shorter interval than heretofore. This system requires that the element have maximum quality and minimum lossiness.

Because even the best ferroelectrics have some conductivity and, therefore, suffer some power loss via self-shunting, the elastic recovery of column **35M** and element **21** must not be impeded. One stop might be the elimination of roller cam follower **49E** in favor of a flat-ended or sharp-edged bottom surface of the column (as in FIG. **22**), so that the stress transition in the column will take place with maximum abruptness. Such a change will increase rubbing wear rates of column and cam and may require harder and more expensive alloys, finish, and heat treatment, together with first-quality, continuous lubrication Before the advent of the buckling-column principle, which is far less critical dimensionally and less wasteful of energy than were the former high-friction, high-wear-rate, lever and wedge systems, use of the compression release characteristic of the element would have greatly magnified the problems in way of reliability and longevity. The cam **48E** in FIG. **19** retains the sawtooth contour skin to those seen in plan in FIGS. **2** and **6**.

Referring now to FIGS. **22**, **23**, and **24**, there is a further simplification marked by further important though small changes in some of the retained parts, which, when modified for this embodiment, now carry the suffix "N." There being now no longer a rectifier, element **21** needs a means, illustrated in FIG. **23** as resistance **139N** for enabling discharge of the slowly built squeeze voltage while squeeze is increasing. Resistance **139N** may be a discrete resistor or its value may be distributed. It is shunted between electrodes **22** and **23** and has a value just sufficient to keep element **21N** discharging at a rate equal to that of input of squeeze energy. Resistance **139N** might preferably be a shunt resistance value built into a lossy transducer **21N**, were it not for the fact that lossy elements are much more susceptible to self-overheating and self-destruction at high-engine r.p.m. There is greater likelihood at high r.p.m. that a partial charge will remain on element **21N** when the cam dropoff point is encountered, causing precancellation of all or part of the release charge.

Full discharge of the squeeze impulse becomes easier to assure, especially when the engine has a wide speed range, if the cam, instead of having the simple sawtooth contour seen in FIGS. **2** and **6**, has the pattern defined in FIG. **24**, in which, after compression terminates its rise at C, the extended flat between C and A gives the element some time for discharge of its squeeze charge, prior to the instant of cam fall-off, designated as A—A'. A speedy release, maximized by the elimination of former roller cam follower **49E**, now enables fastest possible generation of a maximum-level release impulse, with the least possible time for resistance **139N** to rob some of the release energy being generated.

Through the cam may have a vertical dropoff as shown, the elastic recovery of column **35N** and element **21N** still take a little time; but the very low inertia of the slender column and its tendency to jump when released enables the stiff element **21N** to recover its uncompressed length the more quickly. Thus, if cheapness is the governing consideration, as in toys and toy engines, the system of FIGS. **22** and **23** will be the lightest in weight and cost the least, while still being functionable.

As in most other cases herein, cam **48E** may, at choice, be incorporated either as part of the voltage generating apparatus or as a part of the extraneous engine.

Referring now to FIGS. **25** and **26**, rectifier **105** is again engaged in blocking the transmission therethrough of electrical energy generated by piezoelectric **21** during the squeeze pulse; but it will shunt all release half-cycle impulses through itself and through any other resistive means that may be in series with it.

The principal electrodes **140P** and **141P** of high-voltage spark gap device **135P** form terminals of an ionizable gap in series between the ferroelectric **21** and spark plug **63**. Electrode **140P** is directly connected to the center electrode **62** of spark plug **63**, while the other principal electrode **141P** has the potential associated with electrode **23** of the ferroelectric. With current-limiting resistor **139P** interposed between electrode **23** of the ferroelectric and the trigger electrode **59P** of the spark gap device **135P**, the potential at electrode **59P** differs from the voltage magnitudes associated with the other two electrodes thereof under most conditions of energy flow, even the slightest. Thus, there is no need for a mechanical triggering switch associated with column **35P**, since at the calibrated column load value, trigger electrode **59P** can promote local ionization with respect to one or both of the principal electrodes **140P** and **141P**, following which the breakdown spreads through the gap between the principal electrodes and becomes general, without the waste of energy that would occur in a simple-series gap.

Referring now to FIGS. **27** and **28**, there is shown a unitary ignition system closely resembling the triggered flash device of FIGS. **15** and **16**. The difference lies in the omission of trigger electrode switch contacts and the substitution therefor of a permanent connection to a trigger electrode from the ground side of the circuit, though, alternatively, the trigger electrode may lead from the hot side. A current-limiting resistor **139R** is shown inserted between ground and the trigger electrode. Ordinarily a resistor will not be required unless the trigger electrode **130R** actually projects through the glass envelope. More than likely in such a case, other detail design parameters would need to be changed in order to keep the tube from flashing over prematurely into conduction at a lower voltage. In the case portrayed, the resistor has slight effect.

As indicated in the summary, it is desirable that there be a way of preventing the trigger electrode, when paralleled with one of the principal electrodes, from carrying current to the virtual exclusion of the other. In the case of the flashlamp, locating the trigger electrode outside the envelope constitutes a highly effective barrier to current flow. In a case of this type the trigger electrode may have an effect that is largely capacitive and effective primarily because of the precipitously changing waveform in the output of the ferroelectric. However, if the trigger electrode has good conductive access to the ionized plasma, the use of auxiliary means for restricting elec-

tron flow, such as a resistance, either discrete or distributed becomes necessary if the trigger electrode is not to usurp the function of one of the other electrodes.

Referring now to FIG. 29, the circuit differs from that of FIGS. 27 and 28 only in that the cathode 160 and anode 161, respectively, of a high-voltage thyratron now take the place of the principal electrodes of the flash tube, while the grid 162, with resistor 139S in series therewith, takes the place of the trigger electrode.

Referring now to FIG. 30, the tube is a high-vacuum type, built to withstand breakdown with high voltage between cathode 165 and anode 166. Grid 167 has been paralleled with plate 166, but with resistor 139T intervening to prevent current from the overloading and damaging the grid, as it would do in view of the relatively short distance and low impedance between cathode 165 and grid 167, as compared with the greater distance and impedance of the low-pressure path within the tube separating the anode or plate from the cathode.

When this "hard" tube begins to conduct, it ordinarily would deliver current primarily as functions of the geometry of the electrodes and the changing potentials on them. It need not shut off prematurely, however, because the first rush of cathode-anode current flow through the tube, under the triggering stimulus of the grid, lowers the tube impedance so drastically that the major portion of the potential gradient now appears temporarily across the sparkplug gap, causing the spark plug to fire and again steepening the gradient within the tube so as to drain the ferroelectric charge down to the combined extinction level at which it can no longer muster a sufficiently exciting potential to hold the two arcs in firing series. Cutoff occurs in the tube because of the negligible level of potential that the transducer can now hold across it, even though the fuel mixture probably has ignited and maintains ionization in the combustion chamber.

Referring now to FIGS. 31 and 32, several forms of 2-element tube 172 are compatible with the desired triggering function. The one shown is typical of one kind of high-voltage diode normally used as a relatively precise regulator. It becomes conductive when the potential between cathode 170 and anode 171 rises above the threshold differential for which the tube is designed. These tubes are normally polarized in that the cathode is made of or coated with an electron emitter and a low level of ionizing activity is maintained even in the absence of light by a small amount of strategically located radioactive material 173. It has a fairly sharp and generally constant level of potential difference at which the tube becomes conductive.

Referring now to FIG. 33, the gap between the pole faces of permanent magnet 180 is closed by the midportion of steal buckling column 35V. Finely wound copper coil 181 embraces the closed magnetic path. When column 35V buckles upwardly in the direction of the arrow, the path is broken and the sharp change in magnetic flux causes the coil to generate a half-cycle voltage surge which triggers the passage of the high-voltage impulse supplied by ferroelectric 21.

The circuit resembles those of FIGS. 28–30, except that grid 182 gets its positive triggering impulse via the coil instead of the ferroelectric. The negative side of the coil, like the negatively polarized side of ferroelectric 21, is connected to cathode 183.

When column 35V again relaxes between cycles, it will again close and bridge the poles of magnet 180, causing a second impulse in the coil, this time of opposite polarity. It will decay before arrival of the next triggering impulse. Thus, it is seen that the triggering signal may be derived via an energy-transfer medium other than voltage or mechanical force and that an appreciable, if very small, amount of such signal power can effect the transmission of stored energy.

Referring now to FIG. 34, this device also has a magnet 190 and a coil 194, which generates signal in a manner resembling the prior case; but the resemblance ends there. The flux closure path for magnet 190 includes a thin leaf or blade type of grid 192, made of soft iron or other highly permeable material and weakly sprung mechanically to barely touch cathode 193 at the end within tube 195. Although thickened and narrowed where it passes through the wall of compatible tube 195, the grid resumes its blade-type shape so as to fit against the flat pole face at the left end of magnet 190. Cathode 193 and anode 196 are part of a ferroelectric circuit which may resemble that of FIG. 33.

When the left end of grid blade 192 is in contact with the corresponding pole face of magnet 190, the right end of the grid is drawn magnetically upward toward the right pole face and slightly away from contact with cathode 193. But, when the middle of column 35W, seen here in transverse cross section, buckles downwardly in the direction of the arrow, it separates the left end of the grid 192 from the corresponding pole face of magnet 190, thus drastically reducing the flux in the blade and causing it to be mechanically sprung back toward cathode 193. The change in flux is accompanied by a voltage impulse in coil 194, the positive side of which has been connected to the grid and the negative side to the cathode 193. Electrical connections are omitted for clarity in FIG. 34.

As grid 192 springs back to touch cathode 193 within tube 195, the coil impulse is discharged, the slight resultant local ionization at the grid contact point triggering the discharge of the intense field imposed by the ferroelectric element (not shown) between cathode 193 and anode 196.

Tube 195 may be generally similar in nature to that of FIG. 32, except that the presence of grid 192 eliminates the need for very exacting and high-cost construction of the electrodes and precise location thereof, control over the placement of radioactive agents, gas content, etc.

Referring now to FIG. 35, it will be remembered that, in FIGS. 15A and 34, the discharge of energy has been triggered by physical movement of a control grid. Grids have been mechanically manipulated heretofore via levers passing through flexible seals in the walls of vacuum tubes. Thus, a mechanical member, such as a column, shown in phantom lines in optional positions 35X and 35Y, with directions of movement as indicated by respectively nearby arrows, may, for example, be placed against the remote end of such a lever, pivoted at a point in the tube wall, represented by 205, to move grid in either direction as may be desired between cathode 203 and anode 206. The grid 202 might be electrically connected to a point electropositive to the cathode, as in FIGS. 29 and 30, so as to trigger a discharge between the principal electrodes; or a grid resting on the cathode itself and electrically joined to it via a remote current-limiting resistor might be physically lifted therefrom toward the anode to fire the tube and release the spark energy from the ferroelectric.

Referring now to FIG. 36, the portion of the apparatus shown is like the corresponding part of FIG. 8, except for the elimination of the fluid 42A, 142 and of the antechamber below. Instead of inserting a liquid, a high, hard vacuum has been drawn in the inserted sealed chamber to eliminate the possibility of fluid breakdown into conductive components. The hard vacuum, like the fluids, permits contacts or electrodes having high potentials therebetween to approach each other more closely than normal atmospheric air, especially with water content, would permit, but for widely divergent reasons. Another significant difference is that, while dielectric fluid environments may require relatively good seals to keep fluid in and air out, the seal required to keep a hard vacuum within is of enormously superior quality.

Thus, in FIG. 36, the housing 212, corresponding generally to housing 34E of FIG. 8, is inadequate for vacuum retention. A subhousing, or inner housing, 213 has a flexible portion 214 that permits relative movement of the right end 215, which is welded to column 35E, as was the diaphragm of FIG. 8. The manner of function of the embodiment of FIG. 36 is otherwise like that of FIG. 8. Conductors 61E and 64E now enter the cylindrical cavity via a welded-in compression-type glass-metal fitting 316.

Referring now to FIGS. 37 and 38, there are seen axial and transverse cross sections of a piezoelectric ignition system and apparatus for multicylinder engines. For clarity, only two of the column-ferroelectric transducer pairs, 180° apart, are seen in FIG. 37 and in the similar sections of other ignition systems and apparatus seen hereinafter. It is understood that all other transducer-force member pairs that are not directly portrayed in these figures will be in intermediate positions.

The body 225 is a sturdy thick-walled vessel of a nonconducting material such as ceramic or glass, the latter permitting visual inspection of its vacuum-sealed interior. It is reasonable to perform the kind of glass-metal sealing shown, provided that the grade of vitreous material and the alloy are judiciously chosen for thermal-expansion compatibility, tungsten, platinum, and a branded alloy known as "Kovar" commonly being employed with different ranges of glasses.

Techniques for economizing on the quantities of the costlier metals are well known. Copper, too, has often been so employed, particularly in thin, flared edges thereof, such as the walls of bellows which have been preoxidized. The famous "Housekeeper" seal employed copper. Conductive silver frits, often proprietary, are most commonly employed with glass and ceramic compositions, which latter also are fired oxides and often contain glasses as part of their compositions. Silver is frequently applied thus for decorative purposes, attachment of electrical connections, and as the metallic constituent of conductive paths or tracks. Very thin films of gold and sometimes also of other metals are applied to such surfaces where a very slight conductivity is adequate and where corrosion may be a factor in the environment. Even nonmetallics have usefully conductive properties, among these being tin oxide and carbon films, which are frequently used as resistor compositions.

Conductive tracks will be seen repeatedly herein at electrical and mechanical interfaces between fired oxides and metals and for making electrical connections at remote points. Deposited resistors will be seen in other figures hereinafter. Silver frits are compatible with solder joints on ceramics. Many films are compatible with conductive epoxy cured terminals. Conductive tracks, such as 222, that may be applied either as films or narrow ribbons, may be seen herein terminating at pins, such as 223, or at buttons. Seals, such as 228, provide glass-metal junctures with flexible metallic devices.

Where glass and/or ceramics are required to perform rugged service, as in engines, to support heavy loads, such as the everyday loadings borne by ferroelectric ceramics, or to encounter occasional mild tensile stresses, it is usually discrete to provide generous cross sections of the brittle materials, as seen herein. Contrariwise, it is prudent to design metallic members that enter into glass sealing (other than compression seals, which will also be seen herein) to be as light in cross section as possible. Because of the limitations of the graphic arts, however, metallic members sealed to vitreous materials may often appear excessively heavy, or a pin will be shown that might better be fabricated as a very thin-walled tube.

It will further be understood that such conductive tracks, where seen in the drawings to underlie a ferroelectric transducer such as 21A or B and thus accept high loadings, may be laid into or fill up narrow recessed paths. The arts today provide a wide choice among techniques for avoiding stress peaks that might initiate localized mechanical failure of brittle materials.

The vessel or bottle 225 has at its bottom (the left end of FIG. 37) a circular array of cylindrical ferroelectric transducers 21A, 21B, etc., equal in number to the number of combustion cylinders in the engine with which it will be used. Each transducer may be conventionally electroded at both ends, as at 22A and B and 23A and B. Alternatively it may be provided with a very thin metallic or plastic electrode face that will accept a limited amount of localized extrusion and packing under initial loadings. Examples include soft metals or a vacuum-treated and nearly cured conductive epoxy applied over the conventional and sometimes rough silver-frit ends. Because a high vacuum will be drawn, conductive constituents with even moderate vapor pressures will be undesirable.

All of the transducers are snugly positioned in holes in insulating block 229, under individual metallic plugs 231A, B, etc., which are recessed at their right ends to accommodate the thrusting ends of columnar springs 235A, B, etc.

The transducers bear against at least a part of conductive track 227, which has an extension path leading up one side from the bottom to electrical junction with pin 223, which extends through the glass wall. Pin 224, also penetrating the wall, is soldered to grounding clip 226, which extends inwardly above block 229, affording a centrally located sliding surface for contact terminal 236 of insulated 237 nutating arm 238 to electrically ground columns 235A, B, etc., in succession. It is seen grounding column 235B in its turn, following completion by that column of a buckling cycle and at an instant when the opposite column 235A is now undergoing buckling in its turn. The normally open ignition switch is continuously closed to ground while the engine is running. Load resistor 242 provides a conductive connection between pins 23 and 24, its value being so chosen that the time constant of discharge of the release impulse of a transducer, which is a form of capacitor, will be under 20 percent of the interval between successive cylinder firings at maximum engine speed. Load resistor 242 may, of course, represent an electrostatic precipitator in an exhaust purification accessory for the vehicle powered by the engine. Such devices have a high impedance, behaving somewhat like a leaky capacitor. They are poorly suited for low voltage systems like those in motor vehicles, requiring costly and very inefficient power supplies. Piezoelectric devices, on the other hand, are extremely efficient and well suited to generation of high-impedance power. In this case, only that portion of transducer energy that would normally be wasted is utilized for the precipitator. It is that reversed polarity pulse, whose improper disposition in prior ignition systems has been responsible for so many kinds of failures that transducer ignition has never been commercially successful, that is not only being properly impedance-matched for the first time in the cases now pending, but is also herewith being applied usefully toward an additional objective, that of pollution elimination in exhaust systems.

Operation of this ignition system and apparatus is enabled by the rotation of engine timing shaft 250, which carries an eccentric arm 251, equipped with a roller 252 for deflecting tilting head 255 of the sealed assembly, the spring thrust between bottle 225 and tilting head 255 being provided by the aggregate loadings in columns 235A, B, etc. Spring bellows 256, affixed to bottle 225 by housekeeper seal (for example) 228, normally exerts a slight inward pull on tilting head 255 in order to maintain the columns in correct position after assembly and before evacuation. This effect is enhanced by the pressure differential against the evacuated assembly, which forces tilting head 255 snugly down against the ceramic insulating plugs 232A, B, etc., that provide seats for the right ends of columns 235A, B, etc.

As roller 252 rides around upon tilting head 255, it forcefully compresses the columns in order, thus causing each of these high-strength steel-spring members to buckle elastically outwardly, the direction of buckling being determined by any preselected form of asymmetry present in the design. For a regular column of rectangular (not square) cross section, only the two directions perpendicular to the longer sides are possibilities. A slight departure from absolute flatness of the left end or nonsymmetry at the right, or a nonsymmetry in metallic plug 231A, B, etc., or insulating plug 232A, B, etc., will predetermine the direction of buckling, which in this instance is to be outwardly.

The nature of the materials chosen for plugs 231A, B, etc., and 232A, B, etc., insures that columns 235A, B, etc., will always be at the immediate potential of the right-hand electrodes 23A, B, etc., of the respective transducers.

When column 235A buckles under pressure from roller 252, it transfers the charge from transducer electroded face

23A via intermediate contact 266A to pin 234A from its own midpoint contact 258A. Regulation of spark advance and retardation is made via an opening 260 in housing 261, that will admit an extraneous gear or rack for mating with the flange gear sector 259 of the rotatable spark adjuster 257 that rides a threaded (helical) path on tilting head 255. Small individual spring bellows 262 seal an array of 3 or 4 holes in tilting head 255 and admit spark-advance pins 263 that project from spark-advance ring 264 and thrust insulating ring 265 deeper into the cylindrical chamber within bottle 225. Thus, intermediate contacts 266A, B, etc., are brought earlier (or later) into contact with contacts 258A, B, etc., of buckling columns 235A, B, etc.

The outer ends of pins 234A, B, etc., are protected by an elastomeric band 270 having pockets 271 for admitting individual high-tension sparkplug leads.

Alternatively, band 270 and the necessary high-tension leads may be a molded and shielded one-piece assembly, which will further enhance the isolation of this system from other electrical systems, from moisture and weather, and from the transmission of electromagnetic interference that characterizes present-day automotive ignition systems. A metal cap over bottle 225 would complete the isolation.

The bottle, or body 225 and, hence, the whole system may be indexed with respect to the engine firing order by means of a lug or keyway 275 on flange 280. Other reasonable indexing sites include 276 and 277 on adapter 278, which may mate with the engine casting. Alternatively, flange 280 and the opening in the casting may together constitute a bayonet-joint assembly that applies a suitable column preload.

Referring now to FIG. 39, the body 290 is a metal can having openings 291A, B, etc., and 92, sealed by glass or ceramic buttons therein for permitting passage of pins 295A, B, etc., 296, and 297 for external electrical communication. The transducers 21A, B, etc., and their electrodes are unchanged from the prior embodiment; but electrodes 22A, B, etc., now bear against rigid ceramic pad 300 that spans the bottom of body 290. They are again disposed in a circular array. Such arrays can accommodate any convenient number of elements to match the number of cylinders in a given engine, from one to eight or more. Only the representative arrays that include transducers 21A and 21B will be discussed in this part.

Pad 300 carries conductive header 301, which contacts all of the electrodes 22A, B, etc., at the left of the elements. Insulating block 302 has holes to receive all elements and has a fired-on contact surface 305 at the end that bears against header 301. Block 302 also carries, soldered to conductive surface 305, a metal tab 306 which bears against pin 297, leading out of the end of body 290 via button 292, completing a common external connection to one pole of each transducer 21A, B, etc.

Metallic plugs 308 lie against the opposite electrodes 22A, B, etc., and 23A, B, etc., of elements 21A, B, etc., and provide perches for receiving columns 310A, 310B, etc., that bear individually upon them. The opposite ends of columns 310A, B, etc., bear against insulating plugs 232A, B, etc., which, like those seen in the prior embodiment, are seated in pockets in a tilting head 311, actuated by rollers 252, carried on timing shaft 312.

Tilting head 311 is sealably secured to body 290 by bellows 315. As in the prior case, arm 316, carried by tilting head 311, has an insulator 317, tipped by a lightweight flexible metallic contact terminal 318 that nutates within the circle of columns so as to carry off the recovery impulses of opposite polarity at about 180° after the firing impulse. As seen in FIG. 39, the firing impulse is being delivered by contact 320A on column 310A to pin 295A, which, again, is normally connected directly to a sparkplug.

The springy character of contact terminal 318 keeps it in communication with contact 322, against which elongated contact pin 296 is also in communication. Contact pin 296 leads to external impedance 242, the value of which is desirably chosen so as to remove and dissipate safely as external heat the high-impedance energy contained in the succession of transducer recovery impulses and thus protect all circuit components. Again, resistor 242 may represent an electrostatic precipitator element in an exhaust purification system. This external impedance is wired between pins 296 and 297. An ignition switch 240 closes pin 297 to the engine ground.

The assembly within body 290 is finally evacuated and heat sealed via tipoff tube 314. The flange at the right end of body 290 engages adapter 325, which is secured to bearing plate 323, which supports timing shaft 312. Gear sector 324 is cut on a flange of adapter 325 to permit spark advance and retardation control via pinion 321.

Referring now to FIG. 40, another ignition system assembly is seen. Bottle 330 is the principal part of the enclosure for evacuated chamber 331, sealed by tilt plate 333 and bellows 334, the tipoff tube being designated as 335. The ferroelectric transducers 21A, B, etc., are not enclosed within the vessel but instead are seated against its base from outside, where they are potted within an elastomer 364 that extends out over the sidewall of circular vessel 330, so as to protect and insulate conductor tracks such as 339A, B, etc., which carry charges that they have obtained from right-hand electrodes 23A, B, etc., of the transducers.

The transducer elements 21A, B, etc., are mechanically loaded in rotational succession by a timing-shaft roller (not shown) that rides upon the outer surface of tilt plate 333, delivering thrust via columns 332A, B, etc., to the respective transducers in the manner seen in prior figures. The wobbling of tilt plate 333 under pressure of the roller buckles the columns 332A, B, etc., in turn, causing their midpoints to close electrical-discharge circuits in sequence with their respective transducers via conductive tracks 339A, B, etc., and pins 310A, B, etc. The columns are continuously grounded at their right ends into tilt plate 333 as long as switch 240 is closed.

Hot leads 341A, B, etc., which are permanently connected to the sparkplugs, are soldered to conductive tracks 342A, B, etc., which lead to respective left-hand electrodes 22A, B, etc.

The recovery impulses of each respective transducer are carried off by respective rectifiers 344A, B, etc., whose leads are soldered also to respective tracks 342A, B, etc., on ceramic pads 343A, B, etc., the rectifiers having polarities aligned to carry the recovery impulses into massive resistor 345, which is secured to metallic tilt plate 333, serving as a heat sink at a location remote from the transducers. Resistor 345 may be replaced by an electrostatic precipitator element in the engine exhaust system.

Mechanical support for the left-hand surfaces of pads 343A, B, etc., is derived from a metallic clamping ring 346 which will be backed up by engine structure. Spark advance can be matched to the mechanical displacement, as by centrifugal force, of the timing shaft roller outwardly from the shaft axis, it being noted that a slight cupping of the right-hand surface of tilt plate 333 may be seen.

Referring now to FIG. 41, there is seen the major and distinctive portion of another ferroelectric ignition system assembly having an array of transducers 21A, B, etc., spaced equidistantly from the centerline and disposed outside of and with their right-hand electrodes 23A, B, etc., bearing against glass vessel 350, which is joined to tilt plate 352, as in prior instances, by a resilient structure that has been omitted for simplicity. The left-hand electrodes 22A, B, etc., of the transducers bear against conductive tracks 354A, B, etc., which lead respectively to the individual hot leads 355A, B, etc., that go directly to the respective sparkplugs and to the respective brush leads 357A, B, etc., that make contact with resistors 356A, B, etc., carried in insulating plate 360, which is slotted to allow clearance for radial movement of the midpoints of buckling columns 353A, B, etc. Plate 369 carries metallic switching inserts that cyclically connect leads 367A, B, etc., and, therefore, electrodes 23A, B, etc., to the fingers 363A, B, etc., of grounding plate 362 in their respective firing order and, half a cycle later, to resistors 356A, B, etc.

Referring now to FIG. 42, transducers 21A, B, etc., are spaced in a circle and have their right-hand electrodes 23A, B, etc., bearing against the bottom of glass vessel 370, which is joined to tilt plate 372 by bellows 371. The left-hand electrodes 22A, B, etc., bear against conductive plate 374, which lies against the surface of hard insulating ceramic plate 375, contained at the closed bottom of metal tube 378.

A set of conductive leads 382, making individual contacts with right-hand electrodes 23A, B, etc., leads to pins 380A, B, etc., passing through the bottom of glass vessel 370 for contact with another set of conductive leads 381A, B, etc. These last leads underlie metal plugs 383A, B, etc., which are retained by holes through the flange of ceramic plate 379, which keeps them axially aligned with the transducers. Plugs 383A, B, etc., accept the respective ends of columns 385A, B, etc., which have their right ends reacted by tilting plate 372, from which the columns 385 are insulated by ceramic buttons 232A, B, etc.

Columns 385A, B, etc., are arranged to buckle radially inwardly toward the centerline of vessel 370 when compressed in succession by tilt plate 372. As each is loaded, it flexes into electrical contact with a respective one of a ring of high-tension hooked contacts 402A, B, etc., that enter radially through the wall of vessel 370 from extraneous connections with respective sparkplugs.

Each column will have fully relaxed when the timing-shaft roller (not seen) reaches a point endwise of the column that is 180° away; but before it reaches that point it will already have begun to carry off the recovery impulse from its respective transducer. The arrangement for disposing of the recovery impulses accumulated in turn by the transducers during relaxation involves a nutating pendulum 384, retained via spring pin 400 at a constant depth below tilt plate 387.

The pendulum structure includes insulating plate 396, which is pushed into the nutation path by successively flexing columns 385A, B, etc., in order, as seen in FIG. 42, wherein column 385A is pushing plate 396 over against column 385B. From plate 396, a rigid pin 398 depends, terminating in a soft short-circuiting leaf 399, which thereby engages each column as the column returns toward its normally erect configuration.

The engagement of leaf 399 with any column 385A, B, etc., delivers the recovery charge that has accumulated on the respective transducer to the pendulum 384, which must now dispose of it. Pin 400 has been joined to wire 401 near the point where it joins the insulated compression fitting 392 projecting from tilt plate 372; and the remote end of the wire 401 is secured to grounding pin 390, which passes through a wall of vessel 370. Conductor 405 leads away from grounding pin 402 to one end of resistor 403, the other end of which has two connections. One enters relay 404 for connection across the secondary contacts thereof on its way to the vehicle ground, which is represented by metal tube 378. Tube 378 has a flange 407 adapted to constitute the male member of a bayonet joint, by means of which the entire device may be quickly attached to or removed from a cavity in an engine casting, the timing being advanced or retarded in accordance with the desired input rotation that the engine applies to the other half of the bayonet joint (not seen). The other connection from resistor 403 completes the ferroelectric circuit to header 374. The resistor 403 may be replaced by the collector plates in an electrostatic particle-collection device in the engine exhaust system.

Just as the tube 378 is index-matched to the engine, so the glass vessel is indexed to the tube 378 at 410 and to the tilting head at 409. The manner of joining such vessels to tilting heads has been shown hereinbefore; so bellows 371 has been largely cut away so as to keep the drawing simple. The same is true of evacuation techniques, tipoff tubes in both metallic and glass components being well known.

Referring now to FIGS. 43 and 44, there is seen a ferroelectric ignition system, again with the elements 21A, B, outside of and to the left of bottle 415, the right-hand electrodes 23A, B, etc., being positioned against the glass bottom that carries respective conductive leads 416A, B, etc., which are respectively connected to pins 418A, B, etc., passing through the glass, each lead terminating, via a grid resistor 420A, B, etc., in a grid 421A, B, etc.

Grid resistors 420A, B, etc., have a relatively high value, so they can deliver only a most minute value of power via the grids. They are coated like stripes on the external surface of ceramic support 423, the base of which has openings for positioning metal plugs 425A, B, etc., that support respective columns 426A, B, etc., over respective transducers 21A, B, etc.

Pins 418A, B, etc., are also connected, inside this vacuum chamber, to respective conductive leads 424A, B, etc., that deliver the charges that are accumulating on the respective transducers 21A, B, etc., to columns 426A, B, etc., via their underlying metal plugs 425A, B, etc. The columns, which will serve as anodes, are insulated from ground at their right ends by ceramic thrust pieces 428, fitted into recesses in tilt plate 430.

All of the ferroelectrics 21A, B, etc., are seen to have their left ends in contact with manifold header 429, which is coated onto and housed within ceramic cup 433. As each ferroelectric becomes mechanically loaded in turn by a timing shaft (not seen here) operating against tilt plate 430, its full charge is delivered to its column. As each respective charge rises to its full value, the column deflects inwardly toward the respective cathode 435A, B, etc., which terminates a respective hooked pin 436A, B, etc., that passes outwardly through the sidewall of bottle 415 to a connection with the center electrode of a respective sparkplug, the charge on the respective grid rises to virtually the same potential as that of the column or anode, increasing the flow of electrons from respective cathode 435A, B, etc., toward grid 421A, B, etc., and upsetting the more stable field that has existed until that instant between the column or anode and the respective cathode. This behavior causes the triode arrays to be successively discharged and drives down to a very low effective level the high value of impedance that has existed until that instant between the respective anode and cathode. Thus the voltage drop across the gap assumes a minimum effective level and the preponderance of potential is placed across the sparkplug gap which is in series with it. This makes it certain that the great bulk of the energy available in the transducer will be spent where it will be most effective. It will not be squandered, as in the prior art, at the connections and switch points, nor will it be allowed to heat up the transducer needlessly.

When the timing shaft roller departs from each loaded column in succession, they resiliently restore themselves to upright positions. Thus, the energy-wasting mechanical friction of prior art linkages is also a thing of the past. A reversed polarity charge now rises in the relaxing transducer 21A, B, etc. This charge appears at respective pins 418A, B, etc., in turn. Maximum values of these recovery impulses would be reached after the sparkplug has fired and the roller has traversed 180° from the firing position. In the prior art, if the recovery impulse is not allowed to decay in the transducer itself, thus heating it up, it is switched to ground. But since prior art systems did not include provision for matching the high-transducer impedance with the load impedance, that energy too had to go somewhere—into heat in the transducer itself and both heat and metal transport at switches and connections. The metal transport during both the firing and recovery impulses resulted in holding down the lifetimes of switching connections. Moreover, the fact that the recovery impulse is in this instance delivered to the load not instantaneously as in the past but over the much longer interval required for getting the energy through the resistive loading means; and this is another step toward system and component coolness and longevity. The recovery impulse is picked up by contact ball 429 as it nutates across the surfaces of pins 418A, B, etc. The ball 429 terminates spring shaft 431 and it is guided by the nutating motion of ceramic plate 434, whose path is generated by the succession of flexing columns 426A, B, etc.

Spring shaft 431 is retained at its left end by ceramic insulating pellet 436 carried in bracket 437.

Pin 438 leads from shaft 431 via insulated seal 440 into finned external resistor 441, in which the recovery impulse is converted to heat where coolant lubricant can be circulated against it. Resistor 441 is grounded to tilt plate 430.

Resistor 441 may be replaced by the particle collector means in an electrostatic precipitator installed in the engine exhaust system.

Referring now to FIGS. 45–48, this self-contained multicylinder ignition-system assembly has an array of transducers 21A, B, etc., disposed at equal distances from a centerline parallel to their individual axes, with their positively polarized terminals aligned to the right.

Each transducer 21A, B, etc., rests against and is thus connected at its left end which has a negative polarization, to a common thin-film header 482 that leads to vehicle ground via a switch or relay 490, represented in FIGS. 47 and 48 simply as a switch 489, though in a vehicle it would take the form of a relay (490 in FIG. 5), having a pair of screw terminals 494, enabling remote actuation via the vehicle power supply of this self-contained, self-generating ignition-voltage generator and distributor. The device, like several of the prior ones, is also a high-voltage power supply for electrostatic particle collectors and other devices requiring high voltage.

At the right end of the transducers 21A, B, etc., there are imprisoned against their positively polarized electrodes 23A, B, etc., respective thin metallic pads 451A, B, etc., tapered down at opposite ends for passage through radial holes in the annular ceramic ring 464, which may be of beryllium oxide for thermal conductivity. The inner ends are bonded to respective connecting wires 452A, B, etc. The outer ends are joined to respective pigtails 460A, B, etc., which deliver transducer potential to respective rectifiers 485A, B, etc. The rectifiers are hidden in fin-cooled energy-dissipation block 491 in FIG. 45 but are seen schematically in FIG. 47.

Wires 452A, B, etc., are in turn bonded to respective conductors 458A, B, etc., which pass through compression-sealed multipin insulator fitting 453 to respective anodes 454A, B, etc., contained in evacuated metallic chamber 455. Chamber 455 comprises a block 456 and a tilt plate 457, located at opposite ends and joined hermetically by flexible bellows 459, which is partly cut away to avoid the showing of excessive detail in the drawing. The bellows 459 affords limited freedom for relative movement between block 456 and tilt plate 457, which are quite similar in general configuration, the tilt plate 457 being much shorter axially.

Tilt plate 457 also has a multipin compression-sealed fitting passing therethrough. Column 463A, B, etc., are arrayed between block 456 and tilt plate 457 above their respective transducers 21A, B, etc., without any electrical contact to the columns. The columns 463A, B, etc., are prevented by radial pins from moving out of alignment with the respective transducers in the annular channels they occupy by radial pins 465 in block 456 and tilt plate 457. Block 456 and the columns confined thereby are insulated from the right-end electrodes 23A, B, etc., by ceramic pellets 461A, B, etc.

Block 456 carries in its central opening above fitting 453 a ceramic tube 470, which has current-limiting grid resistors 471A, B, etc., striped on the inner periphery thereof in an axial direction. The left end of each resistor 471A, B, etc., is connected by a respective short soldered lead to the respective long anode lead 458A, B, etc. To the respective right ends of these resistors 471A, B, etc., are soldered grid-switching contacts 472A, B, etc., which are firmly held in place by inserted ceramic or glass tube 474. The grids 473A, B, etc., are carried on insulative ceramic or glass nutator plate 475, which moves in a circular path without rotating under the urging of columns 463A, B, etc., which successively deflect inwardly toward the axis under axial force applied to each in succession by a rolling cam, not shown, riding upon the tilt plate, as long as the bottom of tubular housing 483 is firmly supported by extraneous structure of the engine.

Nutating motion of plate 475 results in each grid 473A, B, etc., being switched successively into energization by its respective grid contact 472A, B, etc., as it comes into alignment between its anode 454A, B, etc., and cathode 477A, B, etc.

The cathodes are connected directly to the center electrodes 62A, B, etc., in FIG. 47 of respective extraneous sparkplugs via compression-sealed fitting 478 and respective sparkplug hot leads 480A, B, etc.

The successive energizations of grids 473A, B, etc., trigger the successive passage between anodes 454A, B, etc., and respective cathodes 477A, B, etc., of the charges that build up in rotating order on the transducers 21A, B, etc., as described in the previous instances. Thus they enable the delivery of nearly all of the respective transducer energy to the sparkplug gaps, with very small current flow at the point of grid contact switching and with very small total energy loss in the high-voltage electronic switching means herein described.

The release of energy in this manner as a result of the almost instantaneous transformation of the impedance in each transducer loop from a value close to infinity to a moderate level permits energy flow across the anode-cathode gap with minimum heat loss at that point, with minimum metal transfer in the entire electrode zone of this electrode switching device, and with minimum heating up of the transducer and other ignition components at high r.p.m. rates of multicylinder engines. This efficient as well as innovative design concept assures long life of the system under severe service.

The discharge of the recovery impulse take place outside of the vacuum-switching zone so as to avoid any contribution of heat from this phase. The heat generated in the transducer itself by its recovery is small because there is no mechanical switching. The minute current level flows via respective rectifiers 485A, B, etc., as per FIG. 47, that are contained in fin-cooled energy-dissipation block 491, the rectifiers being always in circuit with the transducers but being so polarized as to bar transmission therethrough of the electronically switched firing impulses. The energy flows into resistors 486A, B, etc., also contained in the fin-cooled block 491. For adequate impedance matching, the resistance may be within a large plus or minus tolerance of the DC resistance value of the transducers 21A, B, etc. Presence of the resistors keeps the discharge going continuously during the recovery impulse at low-voltage levels, without the buildup that occurs during the firing impulse.

Ceramic insulator 481, carrying thereon electrical manifold header 482, which is a thin electrically conductive film, is preferably made of a thermally conductive oxide in order to carry away heat generated in the transducers. The electrically insulating feature could be eliminated in favor of a metal block if it were not desirable to provide an enabling switch 489, as seen in FIG. 47, or relay 490 for remote control. Besides reacting the thrust of the roller, housing 483 also serves as a shield against electromagnetic radiation of high-frequency spark energy.

FIG. 48 is similar to FIG. 47, except that half of the individual ignition firing loops have been omitted (As drawn, it would serve a 4-cylinder engine.); and all of the resistors of FIG. 47 have been eliminated in favor of common resistor 487 which serves as a common energy absorber connecting all rectifiers to ground.

As in other embodiments herein, resistors 486 and 487 may be electrostatic-particle-collection means forming part of an engine-exhaust purification system.

Referring now to FIG. 49, there is shown a general arrangement of a further improved ignition-system assembly for a multicylinder engine. As in the prior figures, only two of the ferroelectric elements 21A, B, etc., 180° apart, need to be shown.

In this instance, the right-hand electrodes 23A, B, etc., are polarized negative and the left-hand electrodes 22A, B, etc., are at the positive ends. Each element supports 2 pellets 501A, B, etc., and 502A, B, etc., the first being metallic in order to provide junctions for respective conductors 505A, B, etc., that pass toward the centerline through inclined transverse holes 507A, B, etc., in conical insulating body 508. Body

508 also spaces the transducers 21A, B, etc., which derive support from insulating ceramic or glass ring 506. Body 508 also provides support and spacing control generally for the other components that make up the assembly. If the body 508 is of ceramic material, the holes may be cut therein prior to a final high-temperature firing.

Conductors 505A, B, etc., then run toward the tip of the cone 508 behind respective rectifiers 510A, B, etc., which have a high PIV (peak inverse voltage) rating. Forward rectifier currents will be very low because the recovery impulse is drained continuously while the element is relaxing and the forward voltage also remains low because there is no buildup. This behavior is quite unlike that of the firing impulse which is stored until it is triggered into an extremely rapid discharge, via another route.

Conductors 505A, B, etc., emerge etc., behind the right ends of the rectifiers 510A, B, etc., for junctions with the respective leads 511A, B, etc., that emerge at the right ends of the rectifiers and provide for passage through the rectifiers of only the recovery impulses. The leads 505A, B, etc., continue from the junction through transverse holes 512A, B, etc., to bonded junctions with cathodes 514A, B, etc., on the outer slope of the insulating cone 508.

Cathodes 514A, B, etc., have activated surfaces extending transversely inward through the largest set of openings 516A, B, etc., which are squared off to permit anode plates 518A, B, etc., to be bonded directly upon the projecting legs of conductive tracks 520A, B, etc. These tracks extend to the tip of cone 508, where they conductively join high-resistance films 521A, B, etc., that have been deposited on the outer slope near the tip. At the lower ends of these high-value resistors 521A, B, etc., lightweight grid-switch contacts 522A, B, etc., are well bonded down upon both the coatings 521A, B, etc., and the insulative material of the body 508.

Next above the transducers 21A, B, etc., and pellets 501A, B, etc., come insulative pellets 502A, B, etc., of ceramic or glass. The columns 525A, B, etc., have their ends integrally mushroomed or flanged. Columns like those shown previously could have been used if a notched metallic pellet were positioned against ceramic pellet 502A, B, etc. The right ends of the columns are positioned in the holes of retaining ring 526 under the very thin, high-strength end wall 531 of elongated, cup-shaped, hermetically sealed metallic jacket 528. The evacuated assembly is tipped off at 531. The jacket 528 is bonded by any of the appropriate processes such as brazing or welding to metallic base 529.

Columns 525A, B, etc., differ again from prior columns in that each has a wide integral boss 530A, B, etc., at midlength. These bosses are pierced to carry insulative glass or ceramic pegs 532A, B, etc., from each of which there projects inwardly a small-diameter, flexible spring grid 533A, B, etc., having an upwardly turned leg that completes cyclic connection to the respective grid switch contact 522A, B, etc., when the respective column 525A, B, etc., is fully flexed under load, and the full squeeze impulse has been developed in the respective transducer 21A, B, etc., for firing a sparkplug.

The grid 533A, B, etc., having minimal inductance, immediately acquires via respective resistor 521A, B, etc., a potential virtually equal to that of the respective anode 518A, B, etc., and, because its distance from the respective cathode is only a fraction of the anode-cathode gap, it suddenly exerts a strong pulling authority upon electrons available at the latter. Electrons so dislodged from the cathode 514A, B, etc., find their way into the vicinity of the grid 533B, where they become susceptible to the pull of the anode. Because of the very high resistance of films 521A, B, etc., only an extremely minute current can pass therethrough, so the grid cannot draw the current flow its position would otherwise permit. The dislodged electrons move toward plate 518A, B, etc., ionizing a flashover path from cathode 514A, B, etc., and the impedance in the anode cathode gap is suddenly switched from a high value to a negligible one. In the vacuum, there is little heat generated and little metal transfer takes place, the discharge being quick, clean, and brief.

Whereas, in the prior embodiment, the conductors to the extraneous sparkplugs were linked to the cathodes, in this instance the sparkplug leads 535A, B, etc., have their conductively bonded junctures with the anodes 518A, B, etc., instead, via tracks 520A, B, etc. These leads pass outwardly through compression-type, multipin, glass-metal seal, which becomes part of base 529, and thence through molded-on elastomeric insulator assembly 536. If desired, assembly 536 and leads 535A, B, etc., may be shielded, thus completing the electromagnetic isolation.

Two additional leads 547, 548 pass inwardly via glass-metal seal 534, though one ungrounded lead would have sufficed. These leads are interrupted in FIG. 49 to provide room for reference numerals. They are the primary leads from an external voltage source that enables this ignition assembly to be internally grounded by means of the relay that is shown diagrammed on the surface of grounding block 555, into which the right ends of leads 547, 548 make entry. The second pair of leads entering grounding block 555 are 537 and 540, which have also been interrupted for the same reason at their left ends, where they issue, respectively, from transducer base collector ring 538 and from the common juncture of the left-hand rectifier leads.

Within grounding block 555, as diagrammed, lead 540 passes first through a load resistor that expends the energy in the transducer recovery impulses. Then it joins lead 537 at the point where the latter is connected to ground via the relay contacts.

The site for the load resistor, whose function is similar to that of resistor 487 in FIG. 48, is opportune. It is located next to the thin skin 528 of the assembly, where it may be cooled by the lubricant furnished by the engine to timing roller 545, carried on timing shaft 546. It is, of course, mechanically remote from the heat-sensitive transducers 21A, B, etc. The use of separate resistors for each transducer element, as shown in prior FIG. 47, is somewhat more efficient electrically but involves a more complex assembly.

With the very thin and hard metallic skin here involved, the end surface will flex locally under roller 545 to a much greater degree than heretofore. The fact that it does not merely tilt permits the loading and energy generation patterns of the transducers to be differentiated more sharply in sequence. The more rapid loading and discharge help to reduce the resistive losses in the individual elements 21A, B, etc., and, hence, the heat generated in them.

The rectifiers can be supported by their leads. Ordinarily, however, it is preferable to provide inserted bracketry that will hold them more rigidly. Such bracketry, which would not be particularly distinctive, has been omitted from the view to keep the drawing as simple as possible.

Also omitted are shims or inclined-plane adjustments for controlling the amount of squeeze and rotary adjustments for advancing and retarding the spark timing. Indexing indentations, such as 551 and 552, insure against internal misalignment; and the indexing means at 553 can provide both a positive alignment index and a site for a spark-advance input control.

Referring now to FIG. 50, there is diagrammed an ignition-system assembly configured for single-cylinder engines. When this system is arranged in multiple, as were the embodiments of FIGS. 37–49, it becomes equally applicable to multicylinder engines. No resistors are employed in the circuit, thus conserving energy and preventing the accumulation of heat. All of the energy contained in both the squeeze and recovery impulses is discharged in a single firing of the extraneous sparkplug 63.

The ferroelectric 21 and its electrodes 22 and 23 are similar to those seen in prior drawings, the upper electrode 22 being the one which has received the negative polarization. The transducer 21 is situated between strong insulating pellets 601 and 602, which may be of aluminum oxide. The lower pellet 602 perches on force member 606, which is seen to be grounded electrically and supported mechanically. Switch 242 is situated electrically between lower electrode 23 and

ground; but it could equally well intervene between anode **612** and sparkplug **63**.

The cathode **611**, grid **613**, and anode **612** must be enclosed in an evacuated chamber. It is very desirable that contacts **627** and **628** be similarly located in order that high voltage may be exchanged without premature arcing. All of the components (except sparkplug **63**) will be best protected if they are also located within a common, hermetically sealed and evacuated enclosure like those seen hereinbefore. Such an enclosure would desirably also include force-conforming wall means between slug **610** and the extraneous source from which force F is received. The energy-storage member **606**, or force member, may be any form of very stiff spring means, preferably metallic, such as a stack of Belleville washers or wave springs, a sturdy helix, or a buckling column. The cathode **611** grid **613**, and anode **612** may be configured in appropriate forms, including those seen in other figures herein.

Electrodes **22** and **23** are bridged electrically by a pair of rectifiers **620** and **621**, with polarity so oriented as to pass the transducer-recovery impulses and prevent passage of energy therethrough while the transducer is being squeezed. The rectifiers are linked by a capacitor **622**, preferably of the ceramic type. The recovery impulses are dumped into the capacitor **622** and stored there between squeeze impulses. The value of the capacitor is preferably an order of magnitude higher than that of the transducer so as to leave as small a charge as possible on the latter.

The excursion of spring **606** under force F during the squeeze impulse is sufficient to enable contact **627** on one end of electrically isolated arm **609**, which is fixed in upper pellet **601** to meet contact **628**, which is linked electrically to the left side of capacitor **622**.

The meeting of contacts **627** and **628** charges grid **613** negatively with respect to anode **612**, so that the nonconducting stability of the barrier gap between principal electrodes **611** and **612** is upset, thus triggering discharge between these transmitting electrodes of the squeeze impulse that has no accumulated in transducer **21** and resulting in delivery of the squeeze impulse to sparkplug **63**. Rectifier **625**, linking the positive side of capacitor **622** with ground, now enables capacitor **622** also to discharge itself completely via the ionized gap between the transmitting electrodes. Thus, all of the energy is delivered in optimum reenforced polarization to sparkplug **63** via anode **612**.

Upon release of squeeze force F, the capacitor **622** once again receives the recovery impulse which enables it to be ready to trigger the next discharge electronically.

Placement of two grids in this embodiment is feasible. One will be connected as shown and described. The other will be connected in the manner shown in FIG. **49**, enabling the grids to coact in discharging the impulse. Or they may act independently. It the two grids are assigned different timing settings, one or the other may be disconnected or disabled temporarily by magnetic or other stimulus, thus making it possible to avoid mechanical linkages for controlling timing. It will have been noted that while the grid potential in FIG. **49** was positive with respect to the cathode for initiating action on the cathode side, the grid **613** shown in FIG. **50** is negative and its initiating action is cathodic with respect to plate **612**.

Referring now to FIG. **51**, there is seen element **21** with both electrodes connected directly to respective cathodes **630** and **631** of separate electron arrays. Both of the respective grids **633**, **634** are linked by respective rectifiers **636**, **637** and resistors **639**, **640** to respective anodes **642**, **643**. When element **21** is squeezed under applied force F, the triode array **630**, **633**, **642** fires when the transducer potential reaches the design amplitude or when an open switch in series with any one of the triode elements is closed. Upon release of force F thereafter, the lower triode array **631**, **634**, **643** may similarly fire and deliver the lower amplitude recovery impulse. Since the recovery impulse has lesser amplitude, the geometry or other characteristic of the lower triode array must be arranged to allow triggering of the smaller impulse. The first triode array or the second may be used to fire a sparkplug. Either array may feed an electrostatic precipitator at the respective gap **644**, **645**.

Referring now to FIG. **52**, identical transducers **21** and **21A** are placed electrically in parallel and mechanically in series for actuation by force F. The positively polarized electrodes abut and the negative electrodes are linked by conductor **650**. Otherwise FIG. **52** resembles FIG. **51**.

Referring now to FIG. **53**, transducer **760** is large enough to enable its recovery impulse to have at least the same magnitude as the squeeze impulses of transducers **21** seen heretofore. Capacitor **765**, which represents an electrostatic precipitator, is fed with the output of the transducer during the application of force F'. As the precipitator collects particles, the plates lose charge, the behavior resembling that of a leak or resistor across the capacitor. This leak has been designated by a resistor **772** shunting the capacitor.

When force F' is suddenly released, transducer polarity is reversed and the triode array **766**, **767**, **771** may now energize whatever load is connected across gap **765**, which is seen to be in the cathode **766** leg of the transducer output. The energization may be automatic upon the achievement of firing potential or it may be delayed by, say, an ignition-timing switch **770** interposed in a conductor leading to one of the triode elements. This array provides the combination of an ignition-firing apparatus for a single-cylinder engine and a power supply source for an electrostatic collector unit of larger plate area per cylinder. The on-off type of charge received by the collector enables the interruption of the particle-collecting action and cyclical release of the particles to an appropriately cyclical scavenging means. Thus, the electrostatic collector plates can arrest the particles contained in the rushing exhaust gases and release them to another channel under centrifugal or blower force.

Like other apparatus represented in single-transducer figures herein, the apparatus of FIG. **53** may be arranged in multiple for use in multicylinder engines.

When there is a large collector-plate area in the exhaust purification system and where a lesser potential is adequate, the transducer **760** may be replaced by a plurality of shorter ones stacked atop each other. Such a configuration yields higher capacitance and a lower electrical impedance, the mechanical impedance being unaffected. Examples of stacked elements are disclosed in FIGS. **36–43** of my application Ser. No. 654,569, filed July 19, 1967 for "Resonant Energy-Conversion Systems." Obviously, the use of stacked elements must not be permitted to reduce the voltage of the ignition impulse output below the required level.

The use of a common source for high-impedance energy for both ignition and exhaust particle separation not only eliminate costly nonferroelectric alternatives but also keeps the purification system automatically regulated to the pace of the engine without need for controls. As shown in FIG. **53**, it does not matter whether the quantitatively greater energy supply is demanded by the ignition system or the particle-separation system, the transducer power supply can be detail designed either way. However, the ignition system will dictate the timing requirements.

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

Therefore, I claim:

1. Apparatus for generating and timing the delivery of high-voltage impulses to an extraneous high-impedance load, said apparatus comprising:

a stiff ferroelectric transducer having high-electrical and mechanical impedance, said transducer being polarized to generate said impulses between opposite electrical poles thereof when subjected to cyclically applied compressive forces between opposing surfaces thereof;

a pair of mutually insulated output conductive paths for such delivery,

said paths each being adapted for an electrical communication link between a respective one of said poles and said load;

a mechanism, including a reaction member and a force member, for transmittal of said forces against said surfaces,

said mechanism being aligned for coaction with an extraneous input source of mechanical energy,

said force member being configured and aligned to deform elastically and to store energy therein when said force is being transmitted therethrough,

the mechanical strain in said transducer being primarily a function of the compressive force delivered thereto rather than of the type of deformation occurring in said force member; and

switch means interposed in one of said paths in series with said load,

said switch means being aligned for conductive closure in response to elastic deformation of said force member.

2. An apparatus as in claim **1**, including also

high-voltage polarity-discriminating and high-impedance electrical energy dissipating means for diversion of reverse-polarity electrical energy generated in said transducer.

3. An apparatus as in claim **1**, including also

an auxiliary member of said mechanism constituting part of said switch means, said auxiliary member being movably responsive to deformation of said force member for conductively actuating said switch means.

4. An apparatus as in claim **1**,

said switch means being an electron device having a pair of transmitting electrodes separated by a barrier means.

5. An apparatus as in claim **4**,

one of said electrodes having been processed to promote electron emission therefrom.

6. An apparatus as in claim **4**, including also

a control-electrode means for disabling said barrier upon the application thereto of an appropriate triggering stimulus,

said force member being poised for alignment upon deformation thereof to force delivery of said stimulus.

7. An apparatus as in claim **4**,

said electron device including a switching aid that it normally nonconductive and interposed to isolate one of said electrodes,

said aid being poised for conductive actuation thereof responsive to elastic deflection of said force member.

8. An apparatus as in claim **7**,

said isolated electrode being a control electrode.

9. An apparatus as in claim **8**, including also

a high-value resistance interposed between said control electrode and one of said transmitting electrodes.

10. An apparatus as in claim **9**,

said one transmitting electrode being a cathode.

11. An apparatus as in claim **1**,

said force member being subject to elastic compression in the direction of force transmission therethrough.

12. An apparatus as in claim **11**,

said force member being subject to flexure during transmission therethrough of said compressive forces between opposing surfaces of said transducer.

13. An apparatus as in claim **12**,

said force member being configured as a column and being subject to elastic lateral buckling thereof during axial transmission of said forces therethrough.

14. An apparatus as in claim **13**,

the lateral flexure of said column being greater in magnitude than the axial compressive yield thereof when said force has risen to the value that enables said transducer to generate said impulse.

15. An apparatus as in claim **11**,

said force member having an elastic, nonlinear deformation characteristic for limiting the compressive force directionally transmissible therethrough against said transducer.

16. An apparatus as in claim **15**,

the ratio of force to deflection of said force member decreasing as the force being transmitted therethrough increases toward a level appropriate for generation of said impulse.

17. An apparatus as in claim **1**,

said force member being normally isolated electrically from said transducer poles.

18. An apparatus as in claim **17**,

said force member being conductively linked to one of said poles during said delivery.

19. An apparatus as in claim **1**,

said force member being continuously linked conductively to an electrode of said transducer.

20. An apparatus as in claim **1**,

at least a yielding portion of said force member being housed within a sealed enclosure,

said switch means also being enclosed therein.

21, An apparatus as in claim **20**,

said force member being located inside said enclosure.

22. An apparatus as in claim **21**

said force member being aligned to receive external force via a wall of said enclosure

said wall also being subject to yielding under said force.

23. An apparatus as in claim **20**,

said enclosure being subject to elastic yielding of a wall thereof under an externally applied mechanical force,

said yielding being aligned and coacting with the elastic yielding of said force member.

24. An apparatus as in claim **20**,

a wall of said enclosure intervening between said force member and said transducer.

25. An apparatus as in claim **20**,

said transducer also being positioned within said enclosure.

26. An apparatus as in claim **20**,

the space within said enclosure having been conditioned in contact to have a dielectric-breakdown strength much higher than that of the atmosphere.

27. An apparatus as in claim **26**,

said space being occupied by a dielectric fluid having average density and molecular weight significantly higher than the corresponding properties of air.

28. An apparatus as in claim **27**,

the fluid in said enclosure being at least predominantly in liquid phase.

29. An apparatus as in claim **27**,

the fluid in said enclosure being at least predominantly in vapor phase.

30. An apparatus as in claim **27**,

said enclosure having inlet and outlet ports for circulation therethrough of said fluid.

31. An apparatus as in claim **20**,

said enclosure having been evacuated to a low contained gas pressure.

32. An apparatus as in claim **20**,

said enclosure having been evacuated to a high vacuum.

33. An apparatus as in claim **20**,

said enclosure including metallic shield means in way of escape therefrom of electromagnetic radiation.

34. An apparatus as in claim **20**,

said enclosure constituting part of said reaction member.

35. An apparatus as in claim **20**,

said reaction member forming an enclosure for said force member and transducer.

36. An apparatus as in claim **1**,

one of said paths including a control electrode and a pair of spaced transmitting electrodes,
said transmitting electrodes being blocked from conducting by an intervening energy barrier,
the magnitude of said energy barrier being susceptible to variation responsive to relative motion of said force member.

37. An apparatus as in claim 1,
one of said paths including a control electrode and a pair of transmitting electrodes,
said transmitting electrodes being blocked from conducting by an intervening energy barrier,
the interaction between said control electrode and at least one of said transmitting electrodes being responsive to relative motion of said force member.

38. An apparatus as in claim 37,
the position of at least one of said electrodes being responsive to the deformation of said force member.

39. An apparatus as in claim 37,
at least one of said electrodes being supported upon said force member.

40. An apparatus as in claim 37,
the electrostatic potential upon at least one of said electrodes being responsive to the deformation of said force member.

41. An apparatus as in claim 37,
part of the energy received by an electrode arriving via a magnetic medium.

42. An apparatus as in claim 37,
including also mechanical switching means responsive to motion of said force member for electrically linking an electrode to said transducer.

43. An apparatus as in claim 1,
the mechanical response of said transducer to said forces being generally independent of the deformation contour assumed by said force member.

44. An apparatus as in claim 1, including also
means for inversion of electrical energy generated at opposite polarity by said transducer during cyclical release of said compressive forces and for in-phase combination of said inverted energy with said impulses.

45. An apparatus as in claim 44, including:
rectifier means aligned to divert electrical energy of said opposite polarity from delivery,
capacitor means for storing diverted electrical energy, and
switching means aligned to couple said stored energy into said impulses in polarity orientation therewith.

46. An apparatus as in claim 45,
said stored energy being injected via at least one electrode for triggering discharge of said impulses.

47. An apparatus as in claim 1
said switch means being in electrical series with said load.

48. An apparatus as in claim 47,
including means for time-phasing adjustment of conductive closure of said switch means.

49. An apparatus as in claim 1,
said load including an electrostatic precipitator adapted for particulate removal from the exhaust system of the engine supplying said energy.

50. An apparatus as in claim 2,
said means including an electrostatic precipitator adapted for particulate removal from the exhaust system of the engine supplying said energy.

51. Apparatus for generating and timing the delivery of high-voltage impulses to extraneous high-impedance loading means, said apparatus comprising:
a plurality of ferroelectric transducers polarized to generate said impulses between opposite electrical poles thereof when subjected to cyclically applied compressive forces between opposing surfaces thereof;
respective conductor means for delivery of said impulses from said poles to said loading means;
mechanical support structure for reacting respective surfaces of said transducers against said forces;
forcing means configured and aligned for deforming elastically and storing energy therein when force is being transmitted therethrough to respective transducers,
at least a deflecting portion of said forcing means being contained within a sealed enclosure; and
switching means conductively responsive to deflection of said portion and also contained within said enclosure,
said switching means being respectively interposed in said conductor means in series with said transducers.

52. An apparatus as in claim 51,
said enclosure having been evacuated to a high vacuum.

53. An apparatus as in claim 51,
wherein the forcing means comprises individual components for each respective transducer,
said components being arrayed for deflection in continuous sequence by an extraneous energy source characterized by relative movement in a predictable path.

54. An apparatus as in claim 51,
wherein the sequence of impulse delivery is enabled by the motion of an auxiliary member,
said motion being responsive to sequential motion of said components.

55. An apparatus as in claim 52,
said switching means being in accordance with claim 6.

56. The combination of apparatus as in claim 51
and energy dissipation means in accordance with claim 2.

57. An apparatus as in claim 52,
said enclosure including also an enabling switching means for completing an electrical connection to said apparatus,
and electrical communication means thereinto for enabling remote control of said connection.

58. The combination of a plurality of apparatus in accordance with claim 1, the force members thereof being in a sealed enclosure,
said force members being arrayed for deflection in continuous sequence by an extraneous energy source characterized by relative movement within a predictable path.

59. The combination in accordance with claims 32 and 58.

60. The combination in accordance with claims 6, 32, and 58.

61. The combination in accordance with claims 7, 32, and 58.

62. The combination of claim 61, including also a high-impedance electrical energy dissipating means for diversion of electrical energy not delivered as part of said impulses.

63. An apparatus as in claim 60, including also a member responsive with nutating motion to energy supplied by said source., said last member being an electrode support.

64. An apparatus as in claim 58, including also a member responsive with nutating motion to energy supplied by said source, said last member including a switching aid for diverting impulses of opposite polarity from delivery to said load.

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