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(54) Title: BARREL-TYPE INTERNAL COMBUSTION ENGINE

(57) Abstract: An engine, e.g., a cam drive, barrel-type internal combustion engine, that includes: a main drive shaft defining a longitudinal axis; a sinusoidal main drive cam rigidly attached to the main drive shaft; a plurality of cam members that are in contact with the sinusoidal main drive cam and that are configured to follow the sinusoidal main drive cam, wherein rotation of the sinusoidal main drive cam corresponds to reciprocating linear movement of each of the plurality of cam members in a direction parallel to the longitudinal axis; for each one of the plurality of cam members, a pair of linear pistons disposed on opposite sides of the cam member for reciprocating linear movement within respective cylinder bores; and bearings disposed within the cylinder bores for maintaining the reciprocating linear movement of the pair of linear pistons within the respective cylinder bores in a direction parallel to the longitudinal axis.



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## **BARREL-TYPE INTERNAL COMBUSTION ENGINE**

### 5 Related Applications

This application claims the benefit of U.S. Provisional Patent Application Serial No. 60/702,023, entitled "Barrel-Type Internal Combustion Engine," filed July 23, 2005, the disclosure of which is hereby fully incorporated by reference.

### 10 Field of the Invention

The present disclosure relates to internal combustion engines, more particularly, the present disclosure relates to an improved cam drive, barrel-type internal combustion engine.

### 15 Background

Various types of internal combustion engines are well known in the art. The most common internal combustion engine is an Otto engine which utilizes pistons and connecting rods to drive a crankshaft. Rotary internal combustion engines, also known as "Wankel" engines, replace the reciprocating motion of the pistons by rotational or  
20 eccentric motion. The present disclosure relates to a so-called "barrel-type" internal combustion engine, a third family of internal combustion engines, in which combustion takes place in cylinders to move reciprocating pistons.

Like most internal combustion engines, barrel-type engines also convert combustion energy into rotational energy. Unlike the Otto engine, however, the barrel-  
25 type engine converts combustion energy to rotational energy without using a crankshaft. Instead, the linear motion of the piston is transferred directly into rotational motion through a sinusoidal-shaped main drive cam resulting in higher efficiencies, lighter weight

and less moving parts than conventional Otto engines. Mechanical power is transmitted from each piston through an associated cam driver/follower to the main drive cam mounted on the output drive shaft.

There are currently disclosed in the literature a variety of configurations of internal combustion engines of the cam drive barrel-type internal combustion engine. By way of example, reference is made to the U.S. Pat. Nos. 4,492,188 and 5,749,337, issued Jan. 8, 1985 and May 12, 1998 respectively. More recent disclosures, e.g., U.S. Pat. Nos. 6,694,931 and 6,526,927, both to Palmer, offered improvements in lubrication and cooling, valve operation and exhaust systems.

### Summary

Example embodiments of the present invention provide certain improvements in an engine, e.g., a cam drive, barrel-type internal combustion engine. An example embodiment of the present invention relates to an engine, e.g., a cam drive, barrel-type internal combustion engine, that includes: a main drive shaft defining a longitudinal axis; a sinusoidal main drive cam rigidly attached to the main drive shaft; a plurality of cam members that are in contact with the sinusoidal main drive cam and that are configured to follow the sinusoidal main drive cam, wherein rotation of the sinusoidal main drive cam corresponds to reciprocating linear movement of each of the plurality of cam members in a direction parallel to the longitudinal axis; for each one of the plurality of cam members, a pair of linear pistons disposed on opposite sides of the cam member for reciprocating linear movement within respective cylinder bores; and bearings disposed within the cylinder bores for maintaining the reciprocating linear movement of the pair of linear pistons within the respective cylinder bores in a direction parallel to the longitudinal axis.

The engine may include at least one thrust bearing and at least one shaft bearing for maintaining a position of the main drive shaft. Each one of the pair of linear pistons may include a piston shaft, the piston shaft having a finish for reducing friction experienced by movement of the linear piston shaft, e.g., a low wear coating.

5        In an example embodiment, the engine includes six pairs of pistons, each piston disposed within a respective one of twelve cylinder bores, wherein the cylinders are positioned in a generally circular pattern that is radially disposed around the main drive shaft. Mechanical power is transmitted from each one of the pistons to its respective cam member and from the respective cam member to the sinusoidal main drive cam being  
10    attached to the main drive shaft. Clearances between each one of the pistons and its respective cylinder bore may be about 1/1000 of an inch or less due to the linear movement of the pistons. At least one of the pistons and the cylinder bores may be made from one of ceramics, steel coated with ceramics, titanium coated with ceramics and silicon nitride.

15        The engine may also include an intake manifold including intake valves configured to supply intake air to respective cylinder bores and an exhaust manifold including exhaust valves configured to exhaust respective cylinder bores, the intake and exhaust valves being zero pressure intake and exhaust valves driven by piezoelectric actuators. The valves may be held in a pre-stressed closed position by a compressed spring. Advantageously, the  
20    exhaust manifold is made of a temperature resistant material such as aluminum, steel or high performance ceramic coated plastic. The engine may be configured such that a first one of the pair of pistons operates to produce torque, wherein the second one of the pair of pistons operates to perform a different task, e.g., compressing hydraulic fluids or pneumatics, etc.

An example embodiment of the present invention relates to an engine, e.g., a cam drive, barrel-type internal combustion engine, that includes: a pair of oppositely-disposed linear pistons configured to move linearly within respective cylinder bores via combustion within the respective cylinder bores; a cam follower mounted between the pair of linear  
5 pistons and configured for reciprocating movement in a longitudinal direction parallel to the linear movement of the pistons; a sinusoidal main drive cam on which the cam follower is mounted for rolling contact, the reciprocating movement of the cam follower imparting rotational movement to the sinusoidal main drive cam; and a main drive shaft rotatable about a longitudinal axis that is parallel to the longitudinal direction of  
10 movement of the cam follower and of the linear pistons within the respective cylinder bores, the sinusoidal main drive cam non-rotatably mounted relative to the main drive shaft, wherein the engine is configured such that a first one of the pair of linear pistons operates to produce torque, wherein the second one of the pair of linear pistons operates to perform a different task.

15 Still further, example embodiments of the present invention may relate to, e.g., barrel-type IC, engines having one or more of the following features:

- a. Cam drivers/followers made from, or coated with, wear resistant material such as silicon nitrite.
- b. A sinusoidal cam with various cam shapes, dimensions and material  
20 properties based on cost limitations or performance requirements such as torque, fuel type or speed. Cam materials may include alcoat, steel, Timken 3311, maraging steel or silicon nitrite.
- c. Cam driver/followers designed to minimize friction and prevent piston rotation.

- d. Linear guidance bearings for the piston rods within the engine for reduced internal friction.
- e. Piston rods with low wear properties either by super-finishing and/or by using low friction coating such as "Alcoat".
- 5 f. Temperature resistant material within the cylinders such as ceramic cylinder sleeves.
- g. Pistons without piston rings with low piston/cylinder clearance, e.g., with clearances of less than 1/1000 inch, resulting in low side loading, low friction and low wear.
- 10 h. Interchangeable pistons based on price selection criteria, with the material selection ranging from aluminum, titanium, ceramic or steel based on price and power requirements.
- i. An oil-cooling system with oil circulation through outer periphery of the engine block.
- 15 j. Zero pressure intake and exhaust valves driven by piezoelectric actuators;
- k. Power recovery from the high temperature exhaust.
- l. High voltage plasma ignition system.
- m. Piezoelectric driven, low pressure, scalable fuel injectors.
- 20 n. Adjusting the engine fuel injection based on measurement of NO<sub>x</sub>, O<sub>2</sub>, soot and unburned HC in engine exhaust.
- o. A multi-fuel engine which uses a fuel viscosity to determine the fuel properties or type.

- p. Total electronic engine control, including fuel injection, ignition and valves, responsive to both rotary drive position and linear piston position.
- 5 q. The engine control system to be self-optimizing with the multi-variable-dependent system tuned to achieve an optimum stoichiometric ratio.
- r. Utilizing selected pistons/cylinders for auxiliary or ancillary operations. Pistons and cylinders can selectively operate as hydraulic or pneumatic pumps or can provide compressed air for the  
10 other cylinders, and thus perform as a linear supercharger.
- s. Control wires hardwired into engine block.
- t. A self-starting engine having low starting torque. Low starting torque is achieved by reducing the overall friction in the engine and by eliminating the intake and exhaust valve resistance.
- 15 u. Linear electric generator for controlled production of power.
- v. A control system that can selectively be operable in either two-stroke or four-stroke mode.
- w. A built-in rotary generator/motor for hybrid operation or “limp home” function.
- 20 x. Selective firing of the pistons and selective braking by utilization of the electronic control valves on the intake and the exhaust.
- y. Use of the improved cam driven axial vector engines in various applications including refrigeration, compressors and generation of electricity.

Additional advantages will become apparent from the description which follows, taken in conjunction with the accompanying drawings.

#### Brief Description of the Drawings

5           FIGS. 1a and 1b are cross-sectional views of the engine according to an example embodiment of the present invention;

          FIG. 2 is a perspective view of the sinusoidal cam, piston rods and drive shaft of the engine in FIGS. 1a and 1b;

          FIG. 3 is an exploded view of the sinusoidal cam, piston rods and assemblies;

10          FIGS. 4a and 4b are cross-sectional views depicting the oil circulation components;

          FIGS. 5a, 5b, 5c and 5d depict various views of the air intake and exhaust ports and the zero pressure intake and exhaust valves;

          FIGS. 6a, 6b and 6c are cross-sectional views of the piezoelectric actuator for the  
15   intake and exhaust valves;

          FIG. 7 is a timing diagram of a 4 stroke cycle;

          FIGS. 8a, 8b, 8c, 8d, and 8e depict various views of the piezoelectric fuel injector;

          FIG. 9 is a block diagram of the engine ignition system;

          FIG. 10 is a block diagram of the engine control system of an example  
20   embodiment of the present invention; and

          FIG. 11 is a fully assembled, cut away drawing of the engine, according to an example embodiment of the present invention.

### Detailed Description

In the drawings and in the description that follows, the term “proximal”, will refer to the end linearly and radially closest to sinusoidal cam or the main drive shaft. The term “distal”, in linear direction, will be the end away from the sinusoidal cam and in a radial direction, will be the end away from the main drive shaft.

FIGS. 1-3 show the basic components of the cam driven barrel-type internal combustion engine according to an example embodiment of the present invention and will be used to explain the basic operation of the engine.

FIGS. 1a and 1b are cross-sectional views of the engine. Pistons 1 are attached to the distal ends of each linear piston shafts 2. The linear piston shafts 2 are held in place by two linear support bearings 3 located proximally from the pistons 1. The cam driver/followers 4 connect the linear piston shaft 2 to the main drive cam 5. The main drive cam 5 is in rigid communication with the main drive shaft 6 which is supported within the engine body 7 with thrust bearings 8 and main shaft bearings 10.

Two sets of linear support bearings 3, mounted in the engine body 7, provide support for each linear piston shaft 2. Rotation of the main drive cam 6 creates linear motion of the cam driver/followers 4, linear piston shafts 2 and their pistons 1. The movement of the pistons 1 within the cylinder sleeves is limited to linear motion by the linear support bearings 3.

FIG. 2 shows the main drive shaft 6, the main drive cam 5 and the linear piston shafts 2 with pistons on the distal ends and the cam driver/followers 4 in communication with the main drive cam 5. The cam driver/followers 4 are made from, or coated with, wear resistant material such as silicon nitride. The main drive cam 5 can be made from various wear resistant or hardened materials such as aluminum coated with Alcoat, steel, Timken 3311, maraging steel or silicon nitride.

The shape of the main drive cam 5 can vary to provide different power profiles.

More torque can be generated by the addition of more lobes to the cam. Changes can be made to the profile to better accommodate the pressure applied to the main drive cam 5 by the proximal movement of the piston 1 during combustion. Different shapes and  
5 dimensions result in new power profiles and each cam profile is optimized for the specific application. For example, an engine powering a generator requires the delivery of constant speed and torque while an engine powering an automobile requires torque on acceleration.

The main drive cam 5 and cam driver/followers 4 are made with tight tolerance so that they are in constant communication. Position of the main drive shaft 6 is maintained  
10 with thrust bearings 8 and main shaft bearings 10 and position of the linear piston shafts 2 are maintained with two linear support bearings 3. Internal friction and component wear is reduced by submerging the main drive cam 5, its bearings, the cam driver/followers 4 and the linear support bearings 3 in lubricating and cooling oil.

Wear of the linear piston shafts 2 at the linear support bearings 3 is reduced by  
15 super-finishing the portion of the linear piston 2 shaft supported by the linear bearings 3. Linear piston shafts 2 may also be coated with low wear coatings such as Alcoat.

Movement of the cam driver/follower 4 on the main drive cam 5 creates forces that are not linear with the linear piston shaft 2. In a typical barrel-type internal combustion engine, the piston 1 and linear piston shaft 2 would attempt to buckle or rotate. Although  
20 the movement of the piston in the cylinder sleeve 9 is parallel to the cylinder sleeve wall 11, the forces acting on cam driver/follower 4 are not linear. To address the angular forces, and to reduce the tendency for the piston 1 to buckle or jam in the cylinder sleeve 9, a gap is desirable between the cylinder sleeve wall 11 and the piston 1. In conventional arrangements, piston rings sealed the gap, acted as a seal between the combustion chamber

and the crankshaft and prevented combustion from blowing into the crankcase and prevented oil from entering the combustion chamber.

Movement of the pistons 1, within the cylinder sleeves 9, is restricted to linear motion. Radial movement is restricted by the linear support bearings 3 and rotational movement is restricted by the cam driver/followers 4. Limiting the movement to linear movement allows for extremely tight clearances between the piston and the cylinder sleeves to 1/1000 of an inch or less. The pistons 1 and cylinder sleeves 9 may be manufactured to zero tolerance, assembled and clearances are produced by moving the piston within the cylinder sleeve 9.

By providing tight clearances between the cylinder sleeve 9 and the piston 1, and by restricting the piston 1 to linear movement within the cylinder sleeve 9, piston rings may be eliminated. Elimination of piston rings may allow the pistons 1 and cylinder sleeves 9 to be made from a variety of temperature tolerance and wear resistant materials such as ceramics, steel coated with ceramics, titanium coated with ceramics or silicon nitrite.

FIG. 3 shows an exploded view of the main drive shaft and piston assemblies. A piston 1 is attached to the end of each of the six linear piston shafts 2. Each manifold 12, mounted on each end of the engine, contains 6 cylinders.

Cooling and lubricating the engine is accomplished by a closed loop oil circulation system, as shown in FIGS 4a and 4b. Oil is pumped by oil circulation plungers 13 directly to the gearbox 14 and lubricates the main drive cam 5, cam driver/followers 4 and the linear support bearings 3. Oil is then circulated to the piston head 15 and around the cylinder sleeve 9 to collect the heat from the engine. The oil then passes through a plurality of outer oil cooling passages 16 where heat is dissipated by the finned outer engine surface 17. The cooled oil returns to the main drive cam via the cool oil return

point 18. Separation of the gearbox and combustion chambers keeps gearbox oil cool and clean.

The closed loop cooling and lubrication system eliminates the need for a separate cooling system or an external cooling systems radiator. Using a single fluid eliminates the need to isolate fluids and removes the possibility of system contamination, as in conventional water cooled, oil lubricated engines.

FIGS 5a-5d show various views of the intake and exhaust manifold and valves. Intake air 21 is supplied to the cylinder 22 by two valves located proximally to the main drive shaft. Exhaust air 23 is exhausted in a distal direction to the exhaust manifold. Exhaust manifold is made of temperature resistant material such as aluminum, steel or high performance ceramic coated plastic.

The intake and exhaust valves utilize zero pressure intake and exhaust valves 24 driven by piezoelectric actuators. Each valve is held in a pre-stressed closed position by a compressed spring 25. The valve body 26, as shown in FIGS. 5c and 5d, opens by sliding over a stationary valve guide 27. In the closed position, cylinder pressure is applied to the valve body 26 which is in communication with the ceramic valve seat 28. Internal cylinder pressure is transferred to the ceramic valve seat 28 which holds the valve in position. Little downward force is required to hold the valve in position.

In the open position 31, as shown n FIG. 5d, the valve body 26 provides little resistance and air can flow on in or out of the cylinder virtually unrestricted.

Power or energy can be recovered from the high temperature exhaust either by conventional methods, such as turbochargers, or by other unconventional methods such as electric generation, steam generation or a cooling compressor.

Two ignition ports 32 are located between the intake and exhaust valves. A high voltage plasma ignition system provides a plasma spark which generates high energy for

ignition. The air within the cylinder is excited setting the stage for ignition. Ignition delivers between 20 and 60 kilovolts in 50 microseconds which results in a larger combustion area. In addition to the plasma ignition, the engine is capable of sparkless ignition by achieving compression ratios up to 20:1.

5 As shown in FIG 5b, two intake valves 29 and two exhaust valves 30 are used for each cylinder. Each valve is actuated by a piezoelectric actuator that moves the valve body distally. The open valve provides little resistance and air can flow in or out of the cylinder virtually unrestricted.

Each valve is driven by piezoelectric actuator 40 as shown in FIGS. 6a, 6b and 6c.

10 The travel of the piezoelectric stack 41 is transferred through a two stage linear hydraulic transmission. The first piston 42 is in communication with the piezoelectric stack 41. The first stage of the transmission 43 converts the 0.045 mm of movement of the piezoelectric stack 41 and the first piston 42 to 0.481 mm of travel on the second piston 44. The second stage of the transmission 45 converts the .481 mm of travel of the second piston 44 to 5.2

15 mm of travel on the third and final piston 46. The available force at the third piston 46 is equal to 138 N.

The fluid contained within the hydraulic chambers 47, 48 of the piezoelectric valve can either be hydraulic oil or fuel, provided the fluid is not compressible.

Referring to FIG. 6a, the following parts are shown:

|    |     |                        |
|----|-----|------------------------|
| 20 | 501 | main body              |
|    | 502 | center body            |
|    | 503 | upper inner seal       |
|    | 504 | upper outer seal       |
|    | 505 | piston 1, piezo driven |
| 25 | 506 | piezo actuator         |
|    | 507 | piezo adjustment cap   |
|    | 508 | adjustment screw       |

- 509 upper cap
- 510 lower transmission piston 2
- 511 lower piston seal
- 512 upper bleeder screw
- 5 513 lower plug
- 514 lower seal
- 515 lower seal cap
- 517 lower piston 3

10 Fuel is injected into the combustion chamber with piezoelectric driven, low pressure, scalable fuel injectors 50, as shown in FIGS 8a-e.

Referring to FIG. 8a, the following parts are shown:

- 81 inject needle piston
- 82 inject lower piston
- 15 83 inject body lower
- 84 o-ring
- 85 injector upper body
- 86 translation piston
- 87 piezo member
- 20 88 wire cradle, side
- 89 wire connector, male
- 810 wire cradle, side
- 811 piezo retaining sleeve
- 812 piezo end cap
- 25 813 o-ring
- 814 locknut
- 815 o-ring
- 816 lower needle sleeve, swaged
- 817 needle guide spacer
- 30 818 upper needle sleeve
- 819 o-ring
- 820 piezo member

821 disc spring

Fuel is supplied from a common rail supply at 85 PSI through fuel inlets 51 on each side of the injector 50. Fuel can be supplied at pressures as high as 200 Bar. The piezoelectric element 52 both compresses the fuel and injects the fuel into the combustion chamber 53. Fuel can be injected into the combustion chamber 53 at pressures up to 7500 PSI.

The fuel injector 50 is actuated by applying an electrical voltage to the piezoelectric element 52. Referring again to FIG 8, the translation piston 54 is in communication with the piezoelectric element 52. Application of a voltage between 0 and 150 VDC causes in the expansion of the piezoelectric element 52 results in the translation piston 54 traveling 65 microns when full voltage, or 150 VDC, is applied. The translation piston 54, with a diameter of 12 mm, compresses the fluid in the upper fuel reservoir 55. The hydraulic force acts upon the 5 mm diameter injection needle piston 56 displaces the injection needle piston 56 373 microns at full voltage. When power is removed, the injection needle piston 56 is closed by high force wave springs 57.

The piezoelectric element 52 can actuate at frequencies between DC and 20 KHz, Applying a high frequency to the piezoelectric element 52 creates a very fine atomization of the fuel making a more complete combustion possible. For example, at low speed, such as 100 RPM, a high atomization of the fuel can be achieved by producing 300 injections for each combustion cycle. At high speed, such as 2000 RPM's, 20 KHz injection frequency corresponds to 15 injections of fuel per combustion cycle.

Engine fuel injection volumes and injection frequency can be adjusted based on measurement of NO<sub>x</sub>, O<sub>2</sub>, soot and unburned HC in engine exhaust.

Engine operation is controlled by a Digital Signal Processor (DSP) 60 as shown in FIG. 10. The DSP 60 is capable of measure all aspects of engine operation. In FIG. 10 the

DSP 60 measures fuel temperature 61, pressure 62 and consumption 63, linear encoder position 64, rotary position 65 of the main drive shaft, emissions 66, oil temperature 67 and engine airflow 68. Control of this engine is fully electronic and any necessary measurement would be measured and received by the DSP 60. For example, the addition  
5 of a fuel viscosity sensor (not shown) to measure the viscosity of the fuel allows the engine to use any combination of diesel, JP5 or JP8.

The DSP 60 also controls all devices. In FIG. 10 the DSP 60 provides control signals to the piezoelectric actuator intake valve 69, the piezo actuator exhaust valve 70, the piezo actuator fuel injector 71, plasma ignition 72 as well as all power conversion and  
10 generation 73. All devices on this engine may be controlled by the DSP 60.

The DSP 60 determines the control and performance of the engine. Control and engine performance are dependant on a multitude of variables. The control system adjusts the system performance in an effort to achieve an optimum stoichiometric ratio, in order to maximize combustion efficiency. Variables that can be adjusted include the start of fuel  
15 injection, frequency and amount of fuel injected and the closing and opening of the intake and exhaust valves.

Total electronic control allows the engine to operate in different modes. Different modes involve eliminating combustion, opening and closing of valves and utilizing the low internal resistance of the engine. For example, the engine can coast by opening of the  
20 valves and eliminating combustion. Since very little power is required to maintain speed, the DSP can also selectively fire cylinders to maintain speed. The DSP can also selectively close to produce resistance and stop the engine.

The DSP can also switch between 4 and 2 stroke operation. This is accomplished by adjusting the timing of the intake and exhaust valves and the timing of the fuel

injection. By switching to 2 stroke operation the engine generates significantly more power.

Another mode of operation utilizes pistons and cylinders for auxiliary or ancillary operations. Pistons and cylinders can selectively operate as pumps or can provide compressed air for the other cylinders and perform as a linear supercharger. The DSP continues to control combustion and power generation in the remaining cylinders while the pistons and cylinders being utilized for auxiliary or ancillary operations are driven directly from the main drive cam. The DSP provides control for the auxiliary or ancillary operations.

Utilization of pistons and cylinders for other functions is highly efficient. For example, in a typical supercharger operation, a supercharger belted to the drive shaft supplies compressed air to the intake valves. The belt and pulley arrangements results in large losses and cannot be easily disengaged. By utilizing one or more pistons and cylinders as a linear supercharger, power is delivered directly from the main drive cam to the piston. When the supercharger is not required, the valves are opened and the majority of the load is removed from the engine.

The ability to selectively open and close valves and the low internal friction allow for the engine to be self-starting. Piston position should not be determined by the rotary position of the main drive shaft, instead the piston position may be determined by a linear encoder mounted on the linear power shaft. The DSP determines which piston is in the proper position for combustion, fuel is injected into the cylinder and ignited by the plasma ignition. The engine requires very little starting torque due to the low internal friction, due to the elimination of piston rings, and eliminating the intake and exhaust valve resistance.

Referring again to FIG. 1, example embodiments of the present invention may further provide for multiple methods of generation electrical power. A built in rotary

generator/motor (not shown) can be mounted to the back side of the engine. As a generator, the engine can produce both rotational power and electrical power. The engine can also be driven by the electrical generator by switching leads and converting the generator into a motor. This allows the engine to operate as a hybrid engine or operate in a “limp home” function and drive the main drive shaft 6. Even a small generator operating as a motor can effectively drive the engine since the motor has very little internal resistance when the DSP opens the valves.

As an alternative, one or more of the pistons can operate as linear electric generators for production of electrical energy. In this configuration, a magnet mounted the piston rod passes through windings of a generator located around the piston rod. Electrical energy is produced when the piston is actuated. The piston can be driven by reversing the windings and using the windings and the magnet as a linear motor.

It is contemplated that this improved cam driven axial vector engines can be used in various applications including refrigeration, compressors and electric generator, etc.

It is contemplated that a single engine could supply multiple sources of energy. For example, the main drive shaft provides rotational energy, an internal generator provides electrical energy, and selected pistons and cylinders provide hydraulic energy.

An example embodiment of the present invention may further provide for control wires to be hardwired into engine block.

As set forth herein, the barrel-type internal combustion engine, according to various exemplary embodiments of the present invention, may provide many numerous advantages compared to conventional engines of this and other types. Generally, the engine may be an internal combustion engine with, e.g., 12 cylinders and, e.g., 6 pistons. The horizontally oriented cylinders are positioned in a generally circular pattern that is radially disposed around the output drive shaft. Mechanical power is transmitted from the

piston to the piston cam roller and from there to the sinusoidal main cam, mounted on the output drive shaft.

The mechanical power transmission is aligned /supported by shaft roller bearings. The direction in which the main drive shaft lies is parallel to the direction of the piston movement, thus eliminating the need for a crankshaft. This allows the pistons to travel in true linear motion, thereby eliminating the need for piston rings and the accompanying cylinder-side loading. Additionally, this eliminates the friction that results from conventional piston rings and the accompanying cylinder-side loading, which may reduce engine efficiency, causes premature wear-out and leads to component failure.

With its six double-ended piston, twelve-cylinder configuration, along with any one or more of the various other features described herein, the engine may provide improvements in efficiency and power. FIG. 11 is a fully assembled, cut away drawing of the engine, according to an exemplary embodiment of the present invention.

The engine may have a multitude of applications. For example, with its torque band and light weight, the engine may allow for truly hybrid electrical and hydraulic vehicles. In addition, each cylinder has a piston at both ends, making it possible to operate the engine such that torque is produced only at one end of the engine. Thus, in some example embodiments, there is provided an arrangement in which the pistons at the other end of the cylinder may be used to carry out other tasks, such as compressing (single or multiple stage) hydraulic fluids or pneumatics or electrical power generation for various applications; such as propulsion of a vehicle, pumping irrigation water, or acting as a dedicated power generator for home and industrial applications.

The engine may employ materials that, e.g., improve its performance, while still providing the engine to be manufactured and assembled at relative low costs and high volume. For example, the engine may utilize materials that provide for a lightweight construction, such as, e.g., 6061-T6 aluminum alloy. In addition, the engine may employ ceramic pistons and cylinder sleeves, a high-performance tool steel for cam and drive shaft, high-performance tool steel cam followers for power transmission, high-performance linear bearings for power piston support, high-performance plastics for exhaust manifold. Also, the engine may employ control electronics modular surface mount electronics.

With respect to its linear power transmission, mechanical power is transmitted from the piston to the piston cam roller and from there to the sinusoidal main cam mounted on the output drive shaft. Mechanical power transmission is aligned / supported by shaft roller bearings and piston rings may be eliminated, thus providing linear operation with no side loading. High-performance coatings may also be employed to further reduce friction on bearing surfaces, providing, e.g., less wear, increased reliability, increased efficiency, etc.

The engine may also provide advantages by employing, e.g., a zero backlash gearbox. For example, linear guide bearings may provide for dose tolerance on piston-to-cam power transmission. Linear bearings may be immersed in oil bath for maximum lubricating / cooling efficiency. A closed oil system may be employed for cam power transmission. The arrangement may provide for the minimal thermal breakdown of synthetic oil, as oil is segregated from inner hot cylinder walls or hot pistons. Also, separation of the gearbox and the combustion chambers may help keep the gearbox oil cool and clean. An internal plunger pump may be employed for lubricating / cooling supply pressure. Also, cam rollers and cam may be immersed in low- temperature, high-

performance synthetic oil bath. The gearbox may be sealed with redundant high-temperature Viton oil seals.

The cooling and lubrication arrangements of the engine, according to various exemplary embodiments thereof, may also provide for advantages. For example, the engine may be cooled and lubricated by high-performance synthetic hydraulic oil. Oil is pumped by the internal plunger pump from the gearbox to the piston head and around the cylinder sleeve to the oil sump. The oil is then pumped through the integral heat exchanger returning the cooled oil to the gearbox. Advantageously, the plunger pump lubricating/cooling system returns the cooled oil and sprays the cam for maximum lubrication/cooling during power transmission. In an example embodiment, the direct coupled oil plungers circulates the oil at 64 GPM at 2000 RPM achieving optimal cooling/lubrication. The engine, according to various example embodiments thereof, may also provide for advantages via its electronic fuel injection arrangement. For example, the engine may employ multiple fuel types, e.g., diesel, JP5, JP8, etc., that are direct injected and atomized via piezo-electric high-frequency particle separation. The injected fuel is atomized into billions of nano-particles per second for superior combustion. This progressive low-pressure method of fuel injection creates maximum control of fuel charge injected. The atomization duration and frequency may be constantly regulated by the electronic control system to dynamically optimize the stoichiometric ratio of fuel-to-air for maximum power output, fuel economy and clean combustion. In addition, multiple smaller injections of fuel per combustion cycle further provide advanced control.

The engine, according to various example embodiments thereof, may also provide for advantages via its electronic ignition. In an example embodiment, electronic capacitive discharge/plasma ignition is utilized to assure highly efficient combustion of the

fuel charge. The ignition is advantageously controlled by an electronic engine management system providing variable compression based upon fuel/environmental feedback. For example, ignition may be timed off an optical encoder installed on the main drive shaft. The electronic engine control system interprets the encoder output, firing the  
5 cylinders in the appropriate sequence. Such an arrangement may provide maximum control during start up and combustion cycles, virtually eliminating engine knock. Furthermore, the cathode may be embedded in the head while the anode may reside in the piston head, thus enabling the conventional sparkplug to be eliminated.

The engine, according to various example embodiments thereof, may also provide  
10 for advantages via its electro-hydraulic valve control. For example, the intake and-exhaust valves may be electro-hydraulically actuated for maximum engine control. The valves are actuated by pressurized fuel. Fuel is pressurized by a piezo-ceramic pump system and is directed via piezo-electric hydraulic valves to open and close the intake and exhaust  
15 valves. Piezo-electric actuation permits valve actuation within 500 microseconds, creating an extremely flexible engine control. The electro-hydraulic valve control, coupled with a suitable electronic control system, enables starting the engine without a starter motor and can convert part of the engine to a fluid pump, air compressor or as a power generator. The unlimited valve control allows for the opening of the intake and exhaust valves during minimal load scenarios thereby eliminating additional resistance and improving fuel  
20 economy by selective firing.

The engine, according to various example embodiments thereof, may also provide for advantages via its starter-less operation. For example, the precision of the zero-backlash gearbox and elimination of piston rings may result in minimal friction in the engine. This reduction of friction may allow for starter-less operation. The elimination of

piston rings provides low turning resistance, enabling engine starting via electronic selective firing of the cylinders. To start the engine, fuel pressure is built via a piezo-electric pump. Upon reaching a desired pressure, the engine control system may determine the position of the cylinder via a linear encoder. Once the engine position has been  
5 determined, the electronic control system creates combustion in the best-positioned piston, closes the intake and exhaust valves, injects fuel, and ignites the fuel via the electronic ignition system. The electronic engine control system commences sequential firing and increases the amount of fuel injected based on the amount of air compressed inside the combustion chamber. The amount of intake air is measured in the feedback loop by an  
10 airflow sensor. This enables control of the piston speed by controlling the compression on the opposite side of the double-ended cylinder. As a result, very low pulse-free idle (< 5 RPM) speeds are achievable.

To summarize, the engine may include some or all of the following features or provide some or all of the following advantages: electronic control; digital signal  
15 processor (DSP based); electronic valve control; electronic fuel injector control; electronic throttle control; sensor feedback; dynamic engine mapping; optimal efficiency; multi-fuel operation; remote diagnostics / interface; serial, Ethernet, CAN (J1939); glass dashboard / gauge cluster; and a tamper-proof design.

In addition, the engine may have many different applications. For example, the  
20 engine may be employed in military applications, ultra-efficient electrical power generation, automotive and transportation sectors, industrial, e.g., fixed and mobile, diesel-electric locomotive, small engine applications including maritime craft, recreational vehicles, pumping and compression applications.

In addition to the ultra-high efficiency electrical generator capabilities, the engine  
25 may provide AC load management, selective piston firing based upon sensed AC load,

lowest cost / kilowatt hour, multi-fuel design especially attractive to, e.g., military, developing or third world nations, may provide significantly reduced weight / size. Also, non-historic vehicular installations may be provided by the engine . Still further, the engine may provide a broad product range, e.g., 7.5 kW, 15 kW, 25 kW, 50 kW, 100 kW, 5 200 kW and 1 MW and/or combination units. The engine may be employed for power generation / hydraulics, power generation / air compressor, etc. The relatively low part count of the engine may provide the engine to be produced in large numbers, e.g., at high volume.

It will be understood that various modifications may be made to the example 10 embodiments disclosed herein. Therefore, the above description should not be construed as limiting, but merely as exemplary embodiments. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

What is claimed is:

1. An engine comprising:

a main drive shaft defining a longitudinal axis;

a sinusoidal main drive cam rigidly attached to the main drive shaft;

5 a plurality of cam members that are in contact with the sinusoidal main drive cam and that are configured to follow the sinusoidal main drive cam, wherein rotation of the sinusoidal main drive cam corresponds to reciprocating linear movement of each of the plurality of cam members in a direction parallel to the longitudinal axis;

for each one of the plurality of cam members, a pair of linear pistons disposed on  
10 opposite sides of the cam member for reciprocating linear movement within respective cylinder bores; and

bearings disposed within the cylinder bores for maintaining the reciprocating linear movement of the pair of linear pistons within the respective cylinder bores in a direction parallel to the longitudinal axis.

15 2. The engine of claim 1, further comprising at least one thrust bearing for maintaining a position of the main drive shaft.

3. The engine of claim 1, further comprising at least one shaft bearing for maintaining a position of the main drive shaft.

4. The engine of claim 1, wherein each one of the pair of linear pistons includes a  
20 piston shaft, the piston shaft having a finish for reducing friction experienced by movement of the linear piston shaft.

5. The engine of claim 4, wherein the linear piston shaft includes a low wear coating.

6. The engine of claim 1, wherein the engine includes six pairs of pistons, each  
25 piston disposed within a respective one of twelve cylinder bores.

7. The engine of claim 6, wherein the cylinders are positioned in a generally circular pattern that is radially disposed around the main drive shaft.

8. The engine of claim 1, wherein mechanical power is transmitted from each one of the pistons to its respective cam member and from the respective cam member to the sinusoidal main drive cam being attached to the main drive shaft.

9. The engine of claim 1, wherein a clearances between each one of the pistons and its respective cylinder bore is about 1/1000 of an inch or less.

10. The engine of claim 9, wherein at least one of the pistons and the cylinder bores is made from one of ceramics, steel coated with ceramics, titanium coated with ceramics and silicon nitrite.

11. The engine of claim 1, further comprising a closed loop oil circulation system.

12. The engine of claim 11, wherein the closed loop oil circulation system comprises oil circulation plungers for pumping oil to lubricate the sinusoidal main drive cam, the cam members and the bearings.

13. The engine of claim 1, further comprising an intake manifold including intake valves configured to supply intake air to respective cylinder bores.

14. The engine of claim 13, further comprising an exhaust manifold including exhaust valves configured to exhaust respective cylinder bores made of a temperature resistant material.

15. The engine of claim 14, the intake and exhaust valves being zero pressure intake and exhaust valves driven by piezoelectric actuators.

16. The engine of claim 15, wherein each valve is held in a pre-stressed closed position by a compressed spring.

17. The engine of claim 14, wherein the exhaust manifold is made of a temperature resistant material.

18. The engine of claim 17, the temperature resistant material being one of aluminum, steel and high performance ceramic coated plastic.

19. The engine of claim 1, wherein the engine is configured such that a first one of the pair of pistons operates to produce torque, wherein the second one of the pair of  
5 pistons operates to perform a different task.

20. The engine of claim 19, wherein the different task includes compressing at least one of hydraulic fluids or pneumatics.

21. An engine comprising:

a pair of oppositely-disposed linear pistons configured to move linearly within  
10 respective cylinder bores via combustion within the respective cylinder bores;

a cam follower mounted between the pair of linear pistons and configured for reciprocating movement in a longitudinal direction parallel to the linear movement of the pistons;

a sinusoidal main drive cam on which the cam follower is mounted for rolling  
15 contact, the reciprocating movement of the cam follower imparting rotational movement to the sinusoidal main drive cam; and

a main drive shaft rotatable about a longitudinal axis that is parallel to the longitudinal direction of movement of the cam follower and of the linear pistons within the respective cylinder bores, the sinusoidal main drive cam non-rotatably mounted  
20 relative to the main drive shaft,

wherein the engine is configured such that a first one of the pair of linear pistons operates to produce torque, wherein the second one of the pair of linear pistons operates to perform a different task.

22. The engine of claim 21, wherein the different task includes compressing at  
25 least one of hydraulic fluids or pneumatics.

23. The engine of claim 21, further comprising at least one of a thrust bearing and a shaft bearing for maintaining a position of the main drive shaft.

24. The engine of claim 21, wherein each one of the pair of linear pistons includes a piston shaft, the piston shaft having a finish for reducing friction experienced by  
5 movement of the linear piston shaft.

25. The engine of claim 24, wherein the linear piston shaft includes a low wear coating.

26. The engine of claim 21, wherein the engine includes six pairs of pistons, each piston disposed within a respective one of twelve cylinder bores.

10 27. The engine of claim 26, wherein the cylinders are positioned in a generally circular pattern that is radially disposed around the main drive shaft.

28. The engine of claim 21, wherein mechanical power is transmitted from each one of the pistons to its respective cam member and from the respective cam member to the sinusoidal main drive cam being attached to the main drive shaft.

15 29. The engine of claim 21, wherein a clearances between each one of the pistons and its respective cylinder bore is about 1/1000 of an inch or less.

30. The engine of claim 29, wherein at least one of the pistons and the cylinder bores is made from one of ceramics, steel coated with ceramics, titanium coated with ceramics and silicon nitrite.

20 31. The engine of claim 21, further comprising a closed loop oil circulation system.

32. The engine of claim 31, wherein the closed loop oil circulation system comprises oil circulation plungers for pumping oil to lubricate the sinusoidal main drive cam, the cam members and the bearings.

25 33. The engine of claim 21, further comprising an intake manifold including intake valves configured to supply intake air to respective cylinder bores.

34. The engine of claim 33, further comprising an exhaust manifold including exhaust valves configured to exhaust respective cylinder bores made of a temperature resistant material.

5 35. The engine of claim 34, the intake and exhaust valves being zero pressure intake and exhaust valves driven by piezoelectric actuators.

36. The engine of claim 35, wherein each valve is held in a pre-stressed closed position by a compressed spring.

37. The engine of claim 34, wherein the exhaust manifold is made of a temperature resistant material.

10 38. The engine of claim 37, the temperature resistant material being one of aluminum, steel and high performance ceramic coated plastic.

39. The engine of claim 21, further comprising bearings disposed within the cylinder bores for maintaining the reciprocating linear movement of the pair of linear pistons within the respective cylinder bores in a direction parallel to the longitudinal axis.

15 40. The engine of claim 39, wherein a gap between a shaft of the piston and the inner surface of the cylinder bore is without seals.

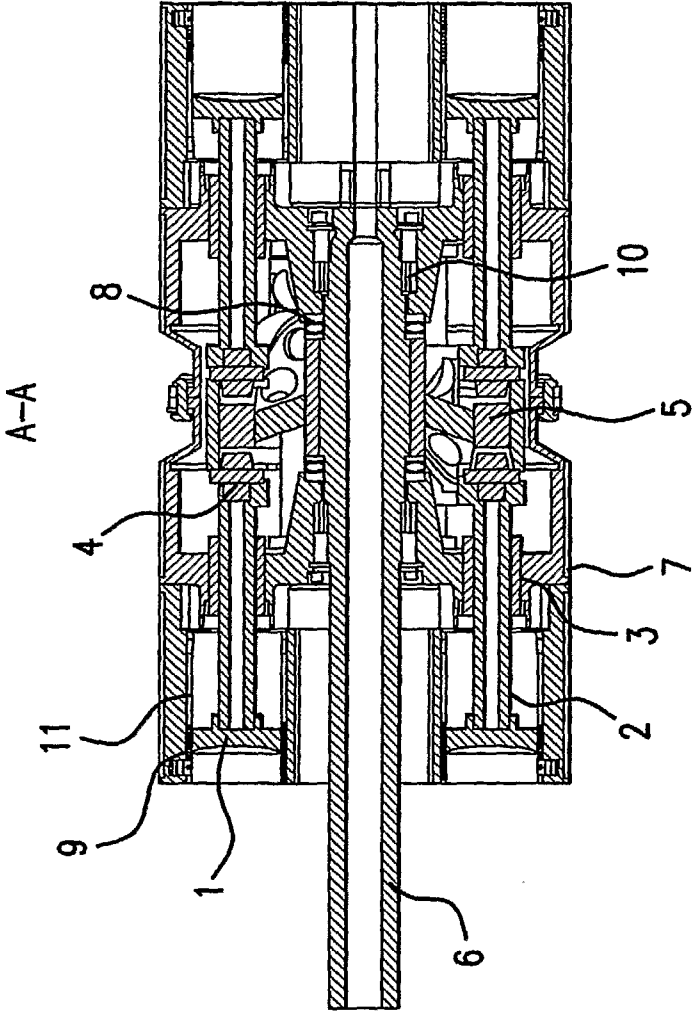


FIG. 1b

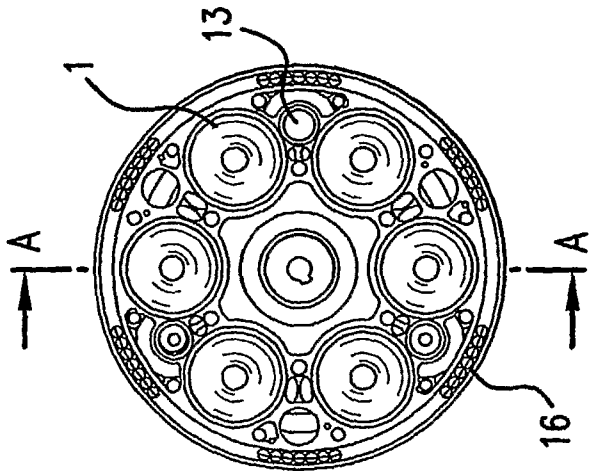
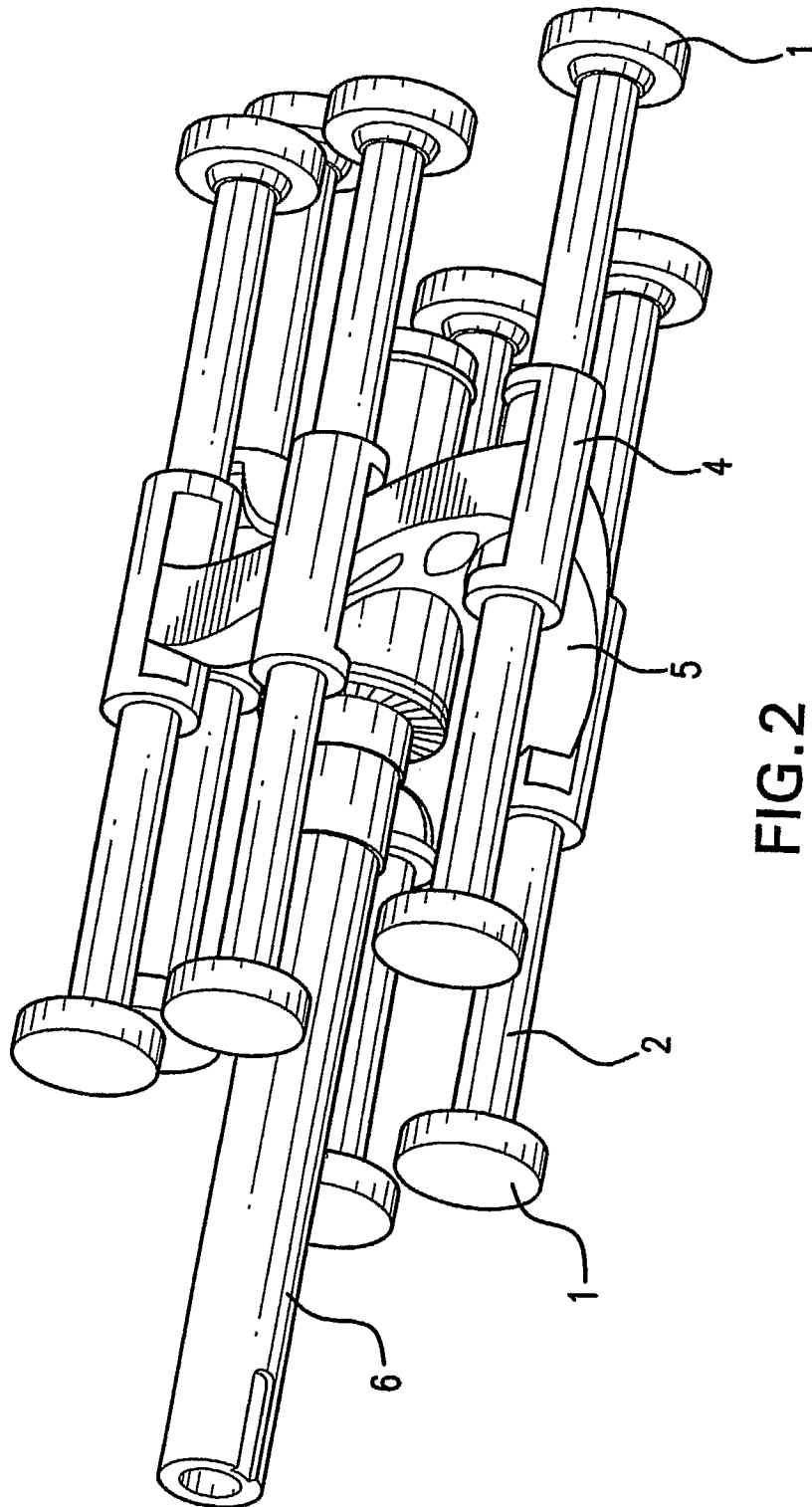


FIG. 1a



**FIG. 2**

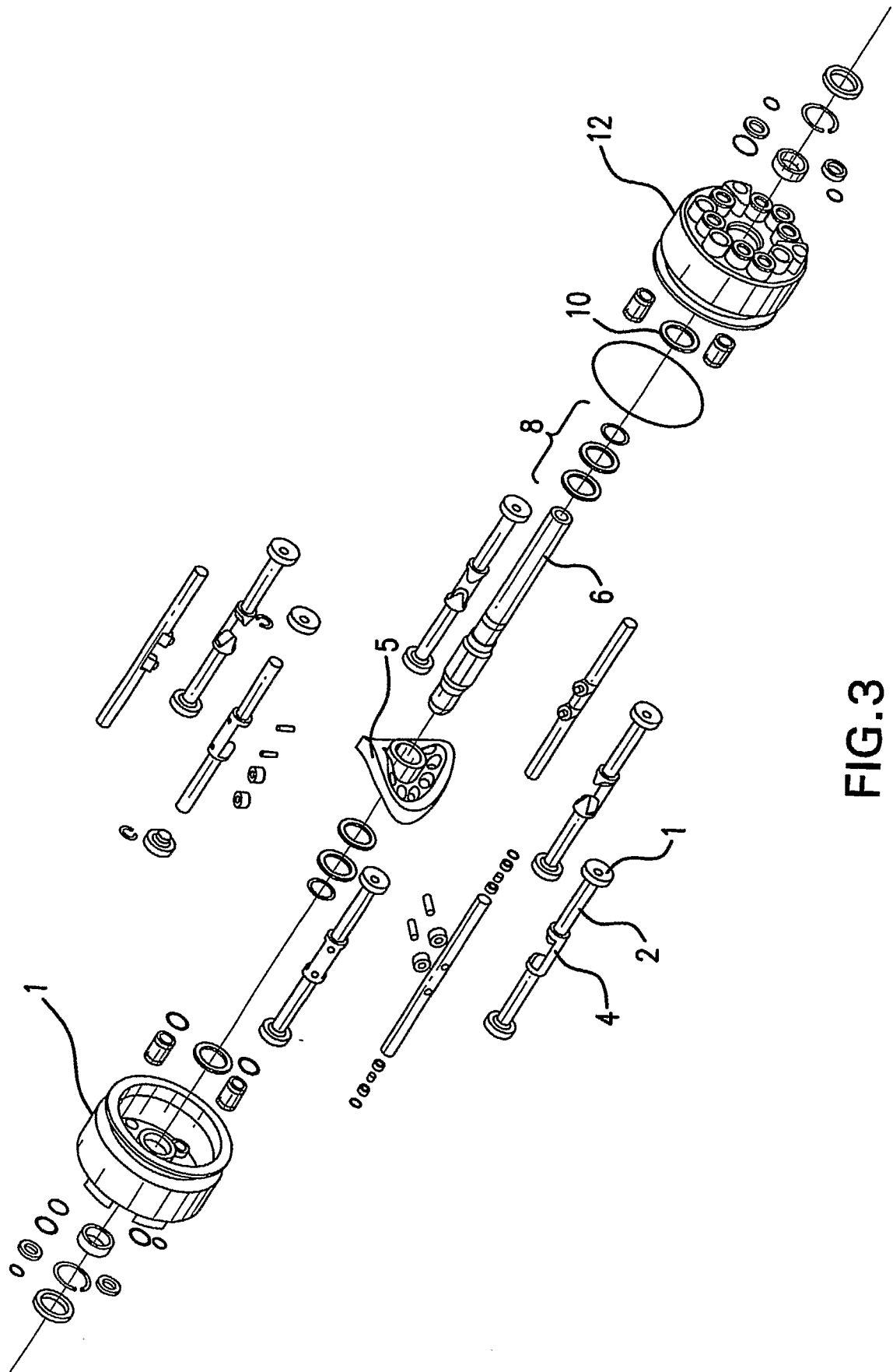
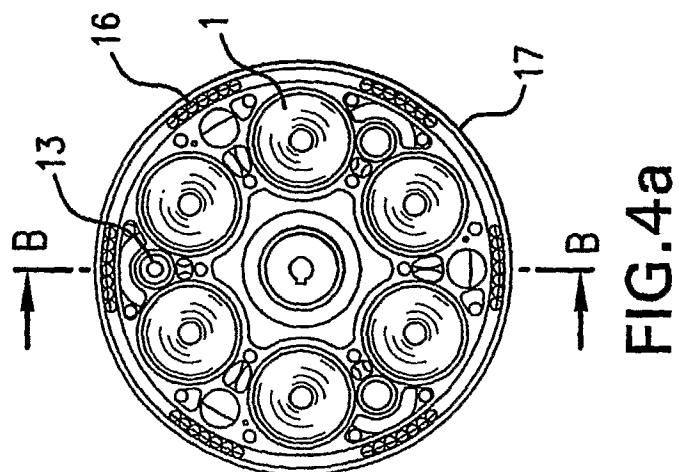
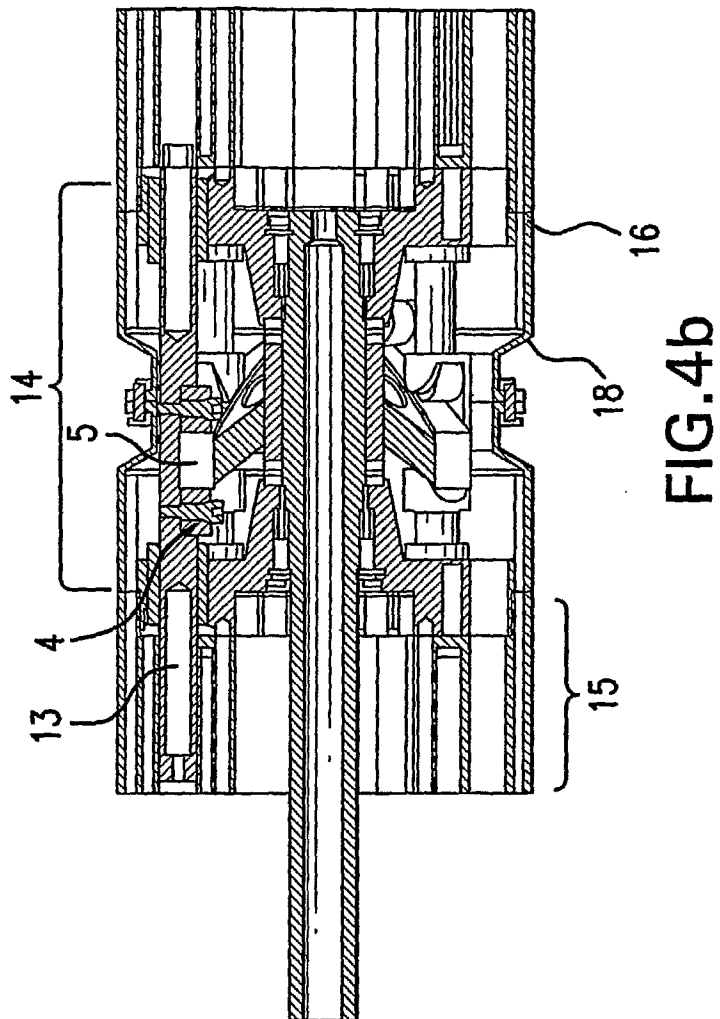
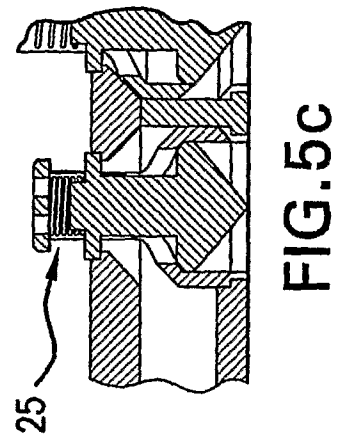
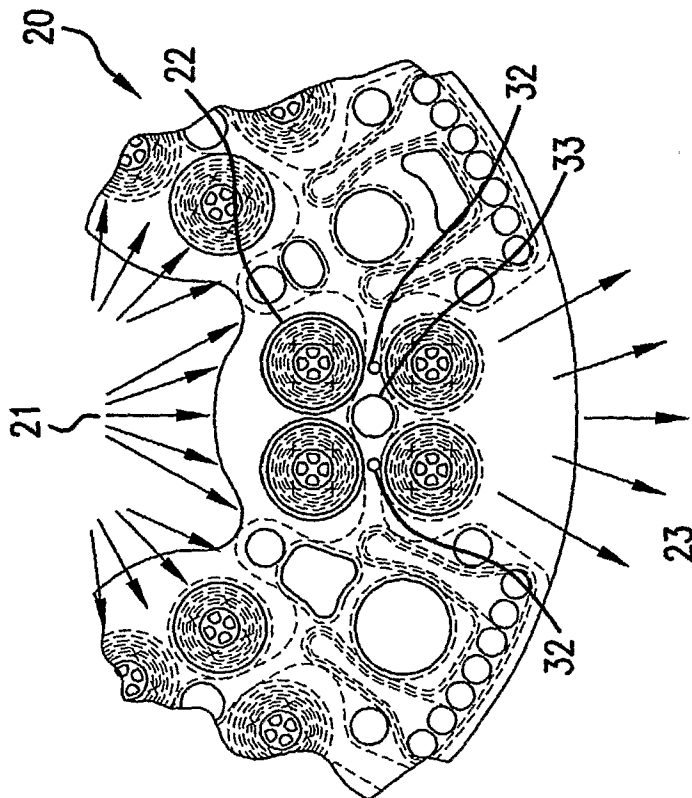
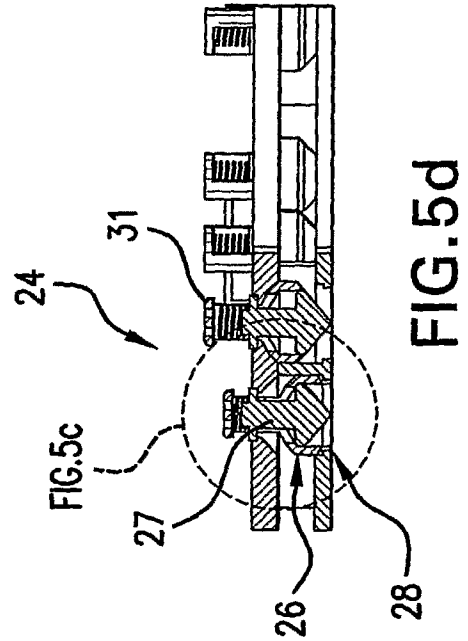
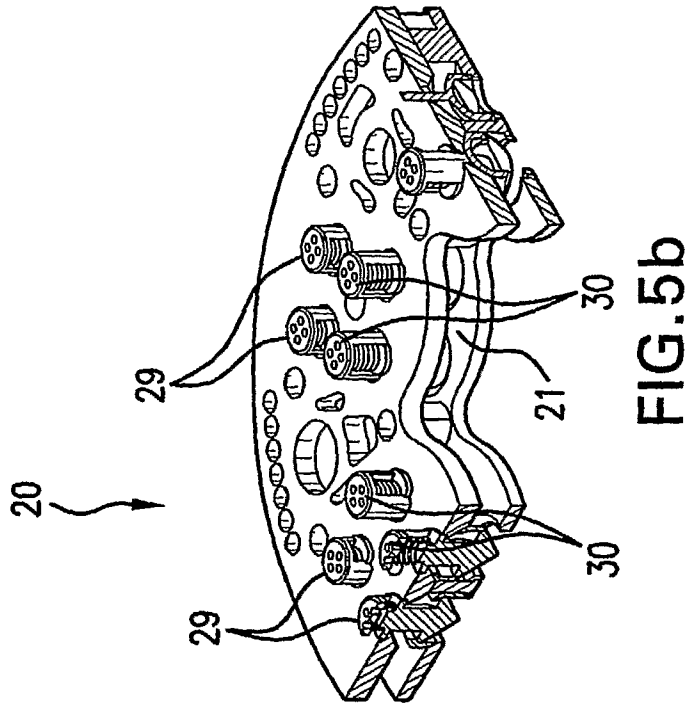


FIG.3





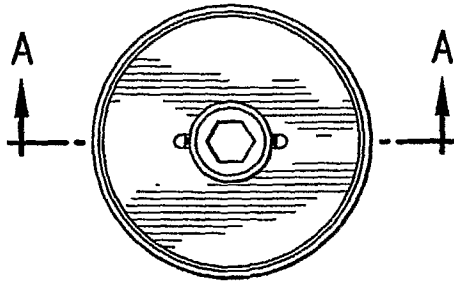
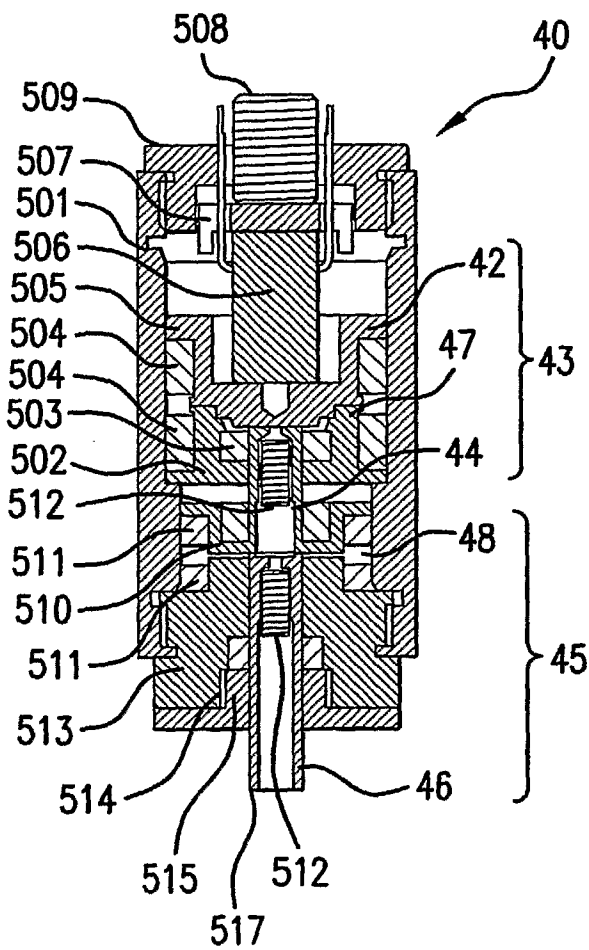


FIG. 6



SECTION A-A

FIG. 6a

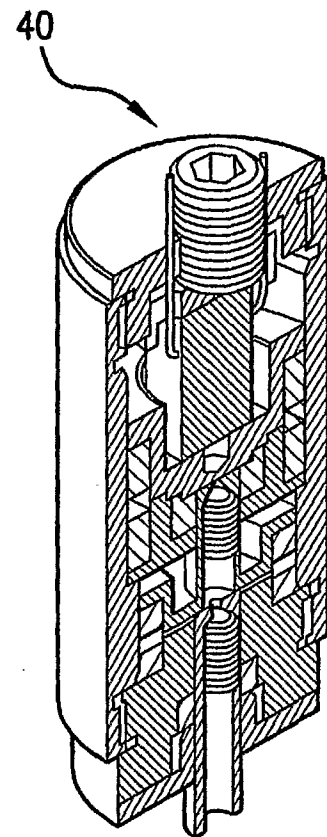


FIG. 6b

ENGINE TIMING FOR FUEL  
INJECTION AND IGNITION  
AT 2000 RPM

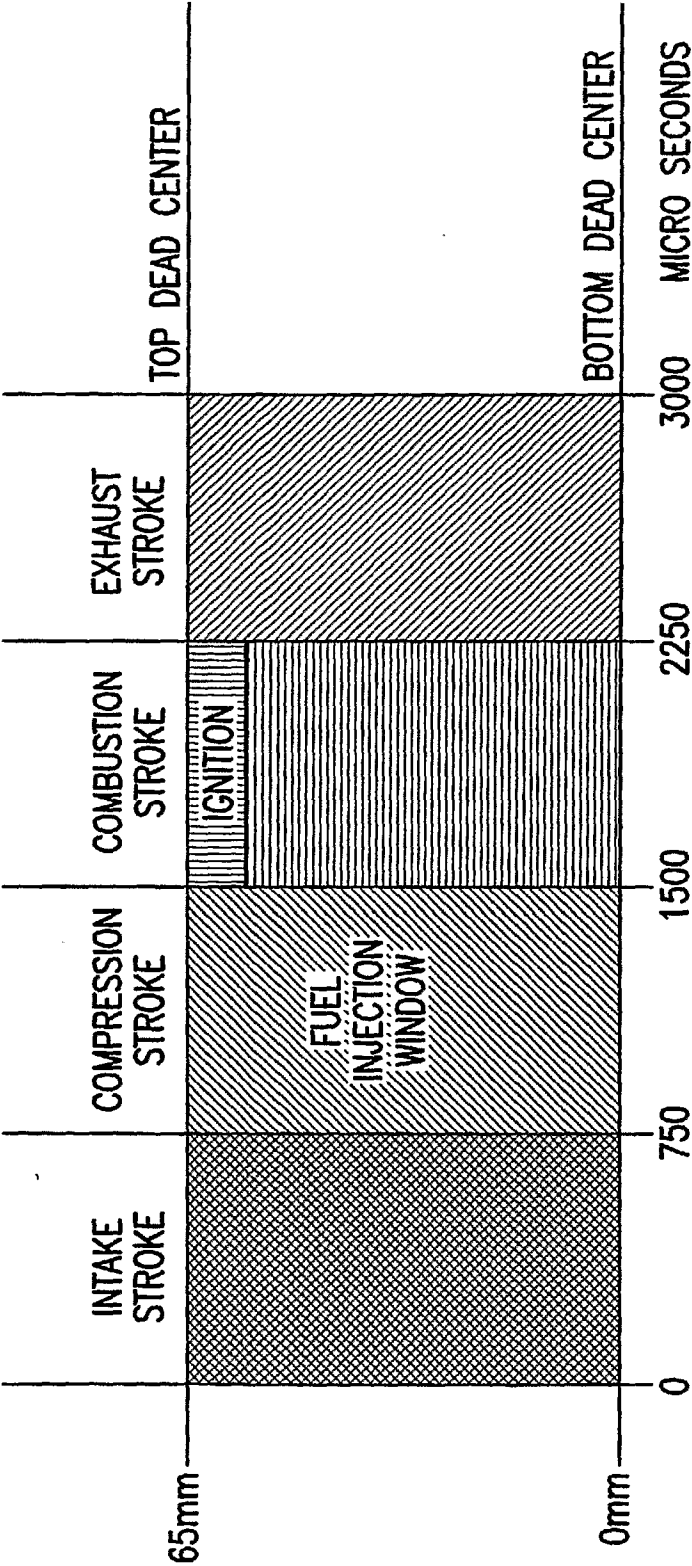


FIG.7

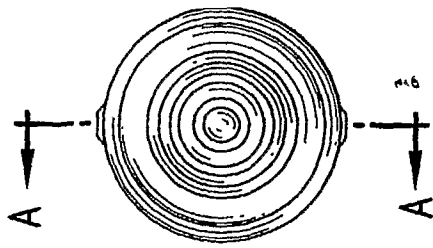


FIG. 8e

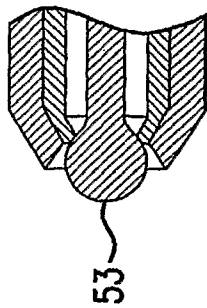


FIG. 8d

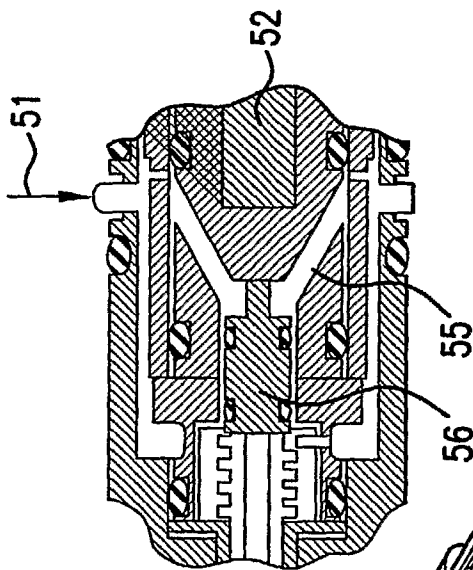


FIG. 8c

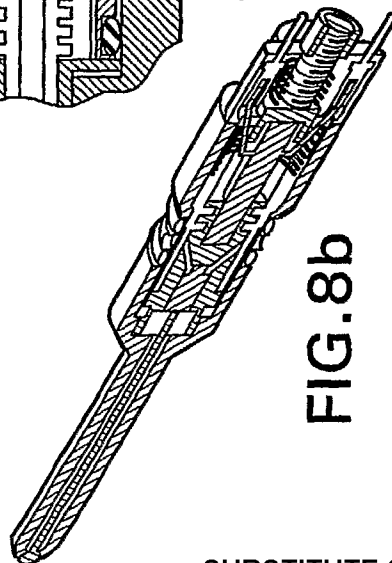


FIG. 8b

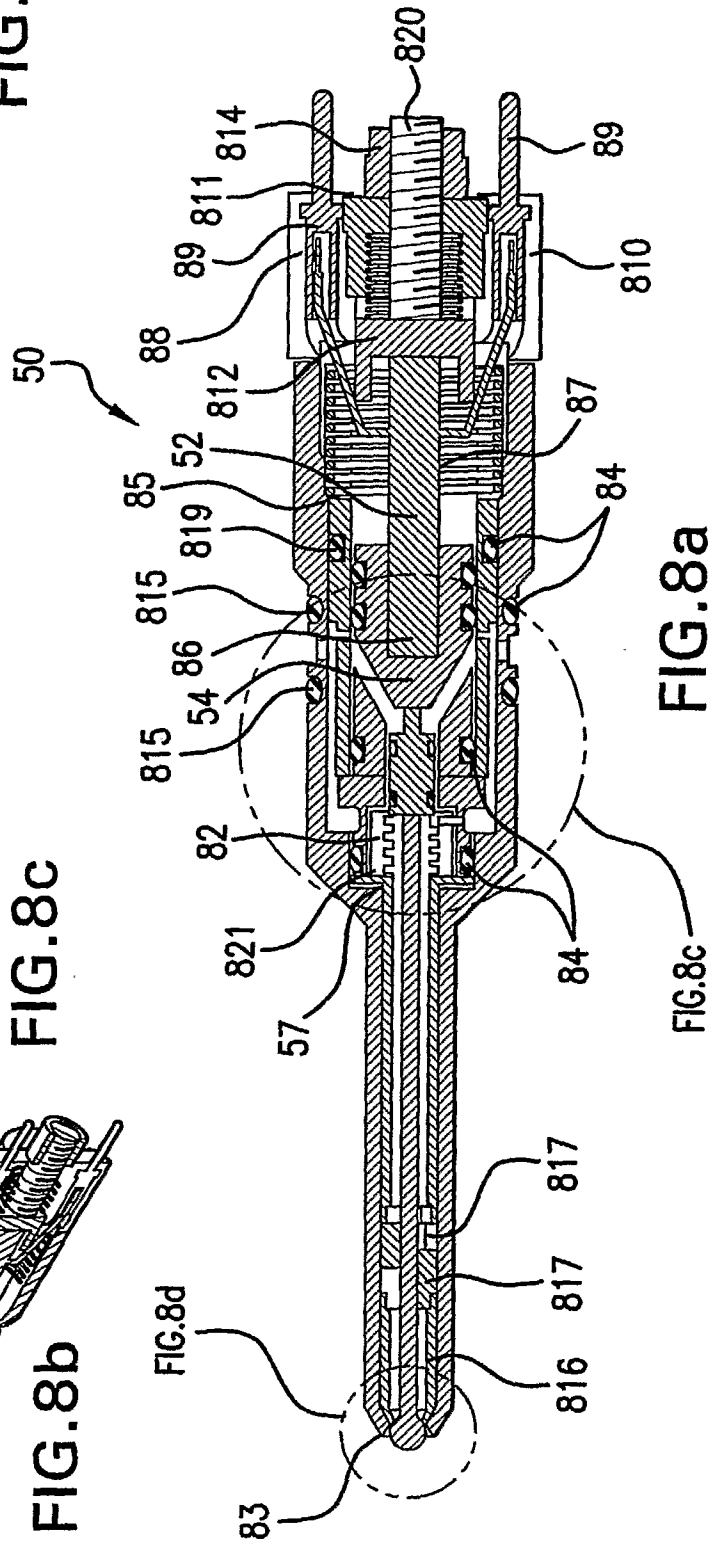


FIG. 8a

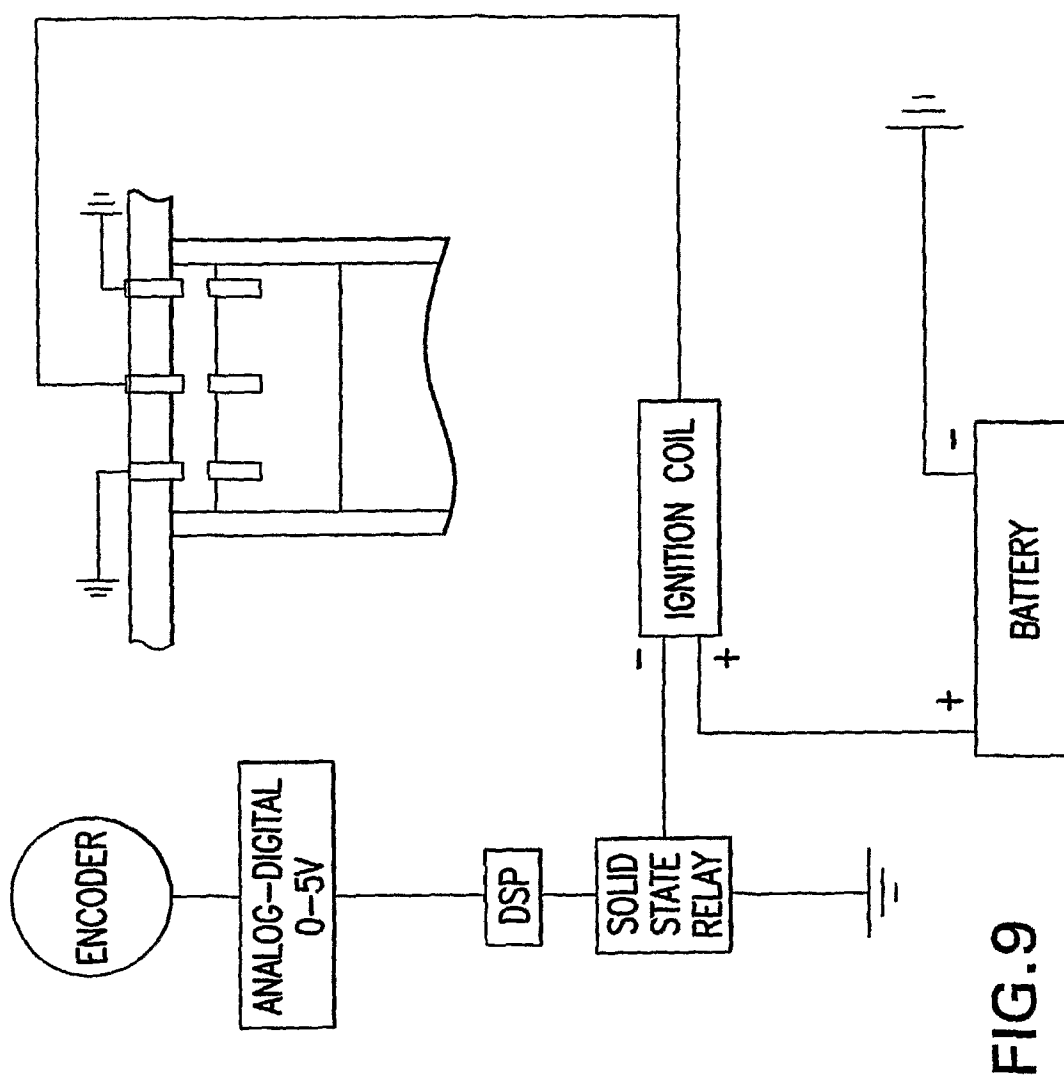


FIG.9

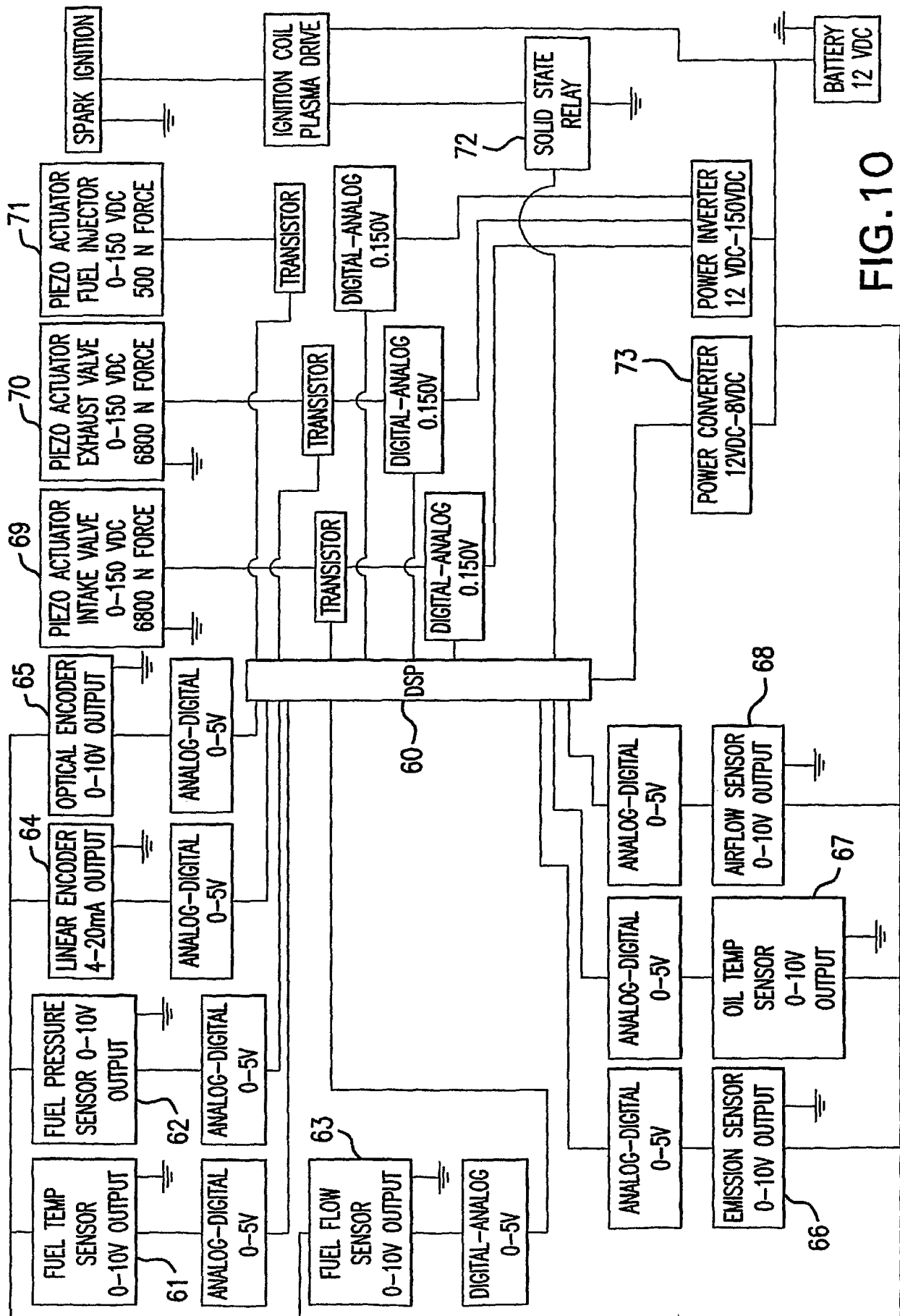


FIG. 10

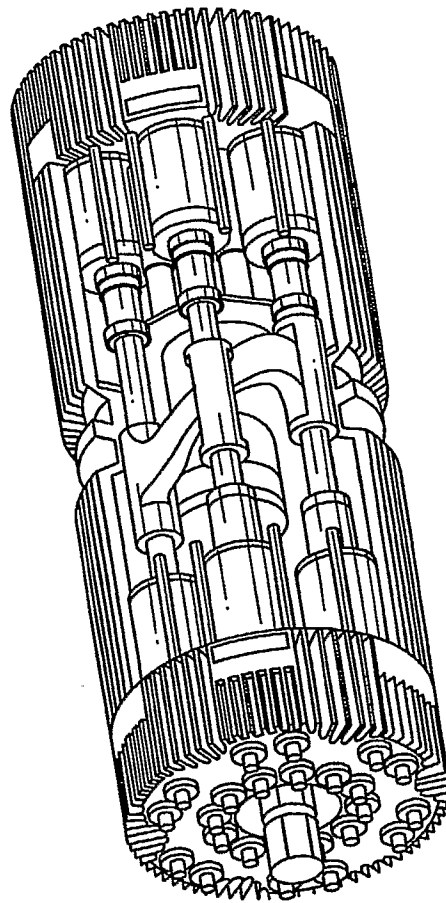


FIG. 11