United States Patent [19]

Gano

[11] **3,783,610**

[45] **Jan. 8, 1974**

[54] **ANTI-POLLUTION INTERNAL COMBUSTION ENGINE**

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[21] Appl. No.: **224,423**

[52] **U.S. Cl.** **60/16,** 192/3

[51] **Int. Cl.** **F01b 29/04**

[58] **Field of Search** 60/14, 16

[56] **References Cited**

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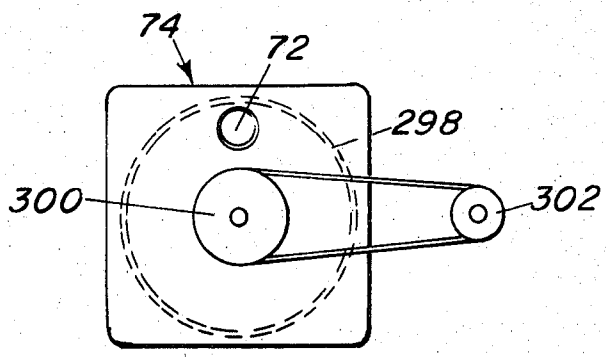
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Assistant Examiner—Allen M. Ostrager
Attorney—Harris C. Lockwood

[57] **ABSTRACT**

This disclosure relates to an anti-pollution internal combustion and compressed air operated engine. The engine includes a group of firing cylinders and a group of compression cylinders. A storage reservoir is filled with compressed air during the engine firing and braking modes of operation. After stopping, the stored air motors the engine until it begins firing. The engine is provided with a pressurized fuel system which is regulated by the pressure in the storage reservoir. A selector valve is used to select the proper modes of operation for the compression cylinders; namely, the braking mode for storing compressed air, the motoring mode for driving the engine on the compressed air stored during the braking mode or the normal compression mode when the engine is firing.

33 Claims, 13 Drawing Figures



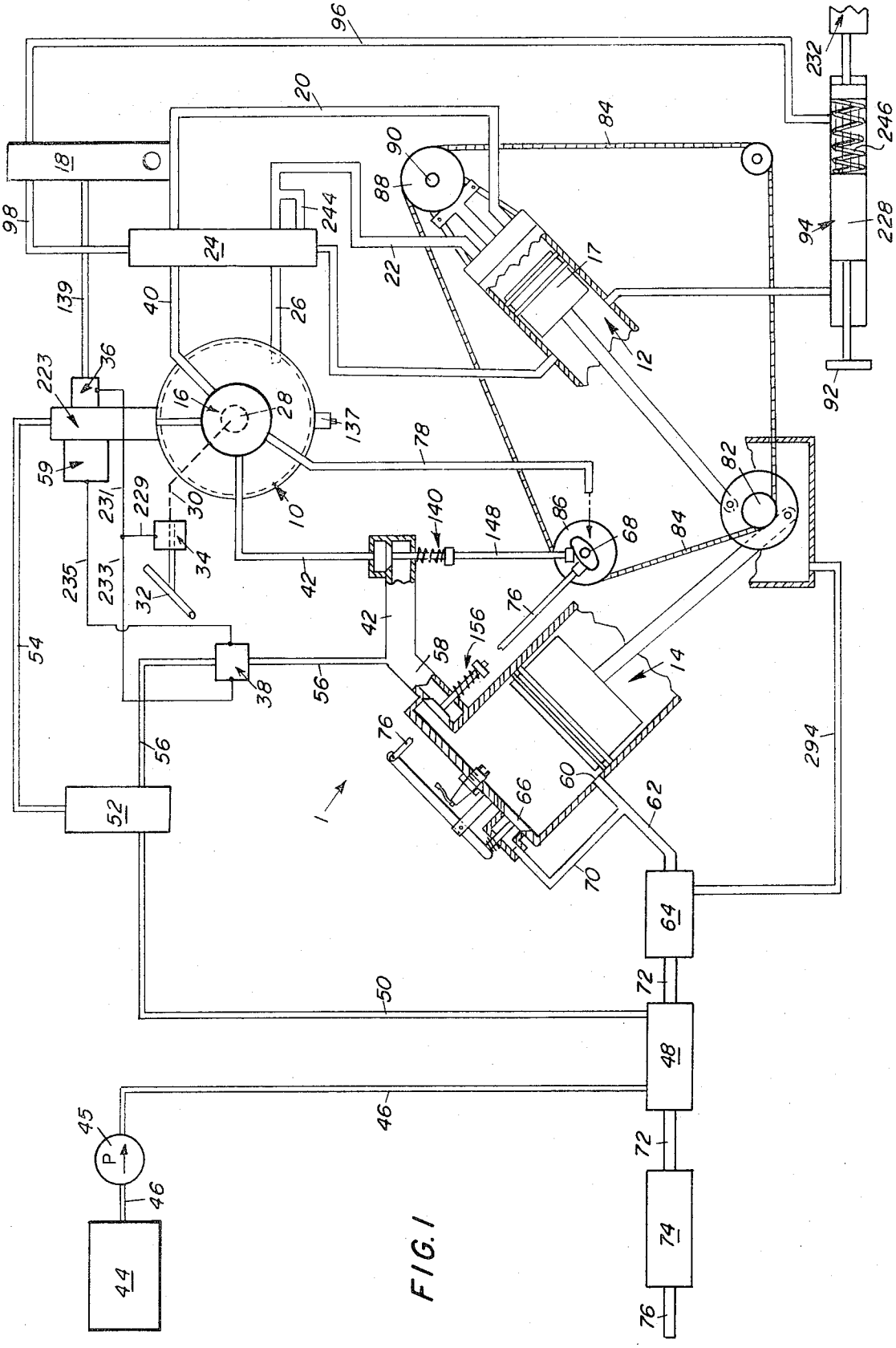

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FIG. 1

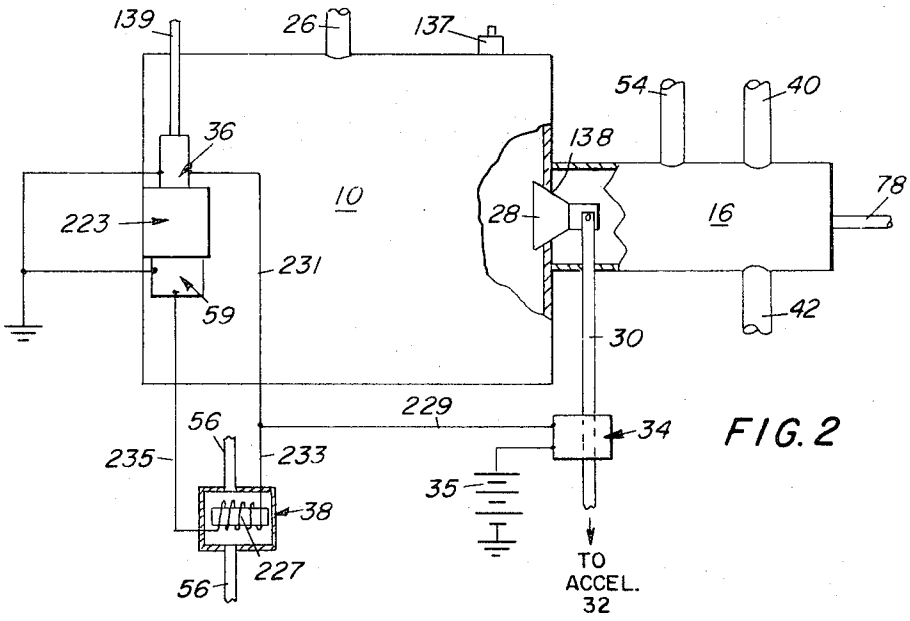


FIG. 2

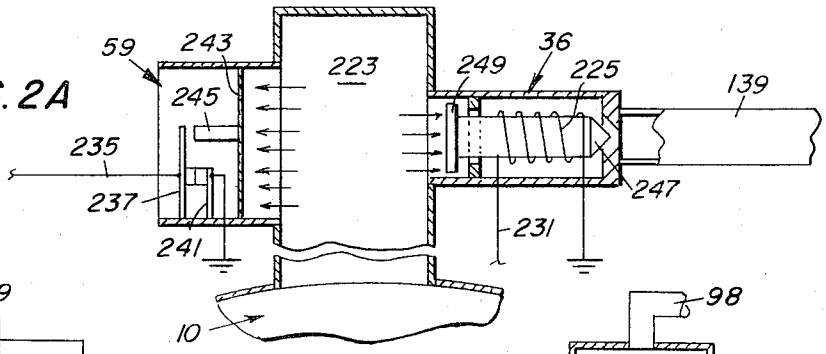


FIG. 2A

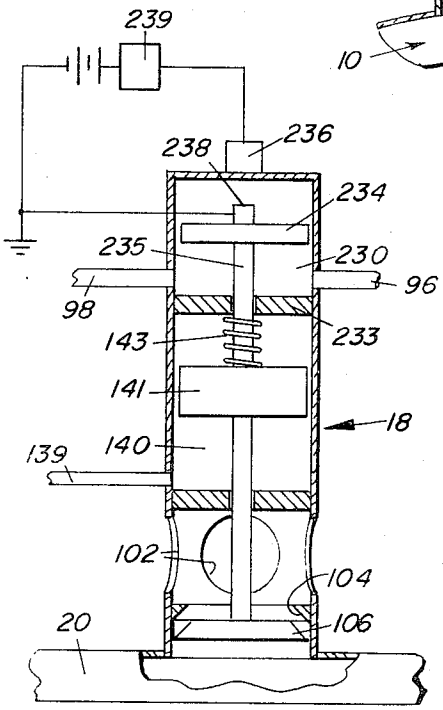


FIG. 3

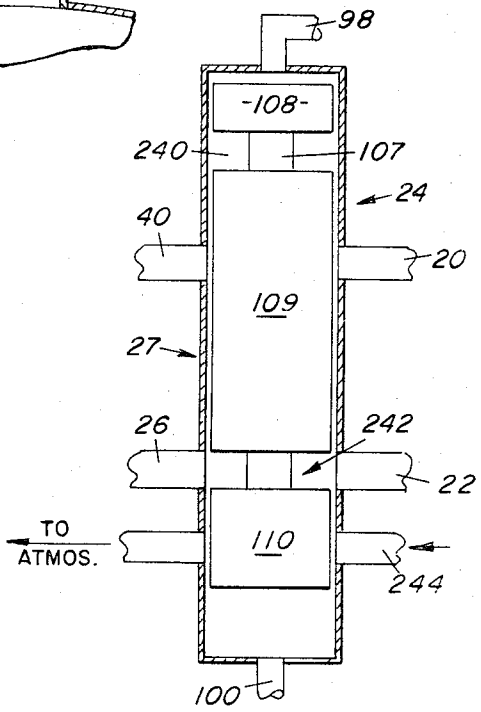


FIG. 4

FIG. 6

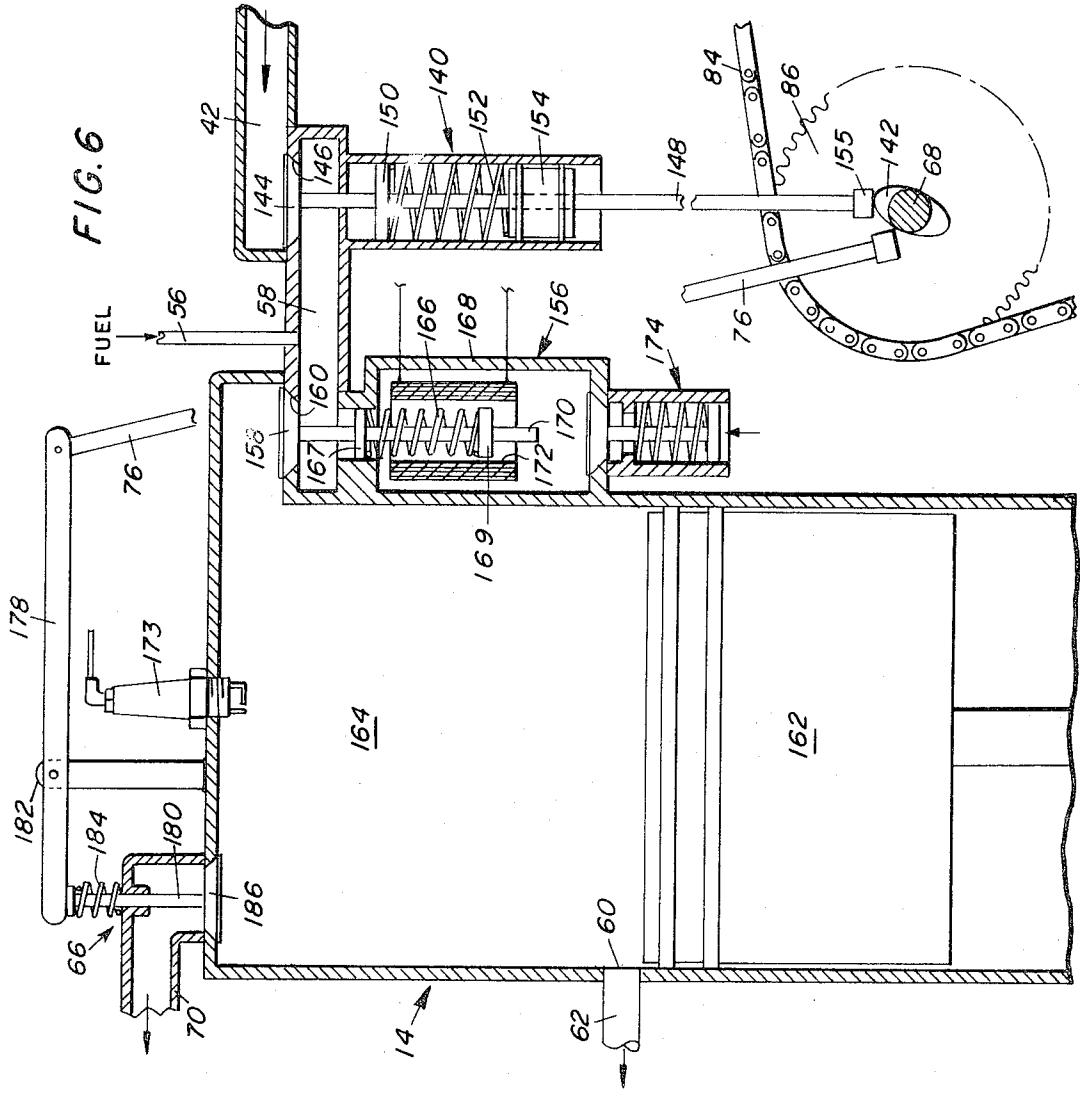

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FUEL
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FIG. 5

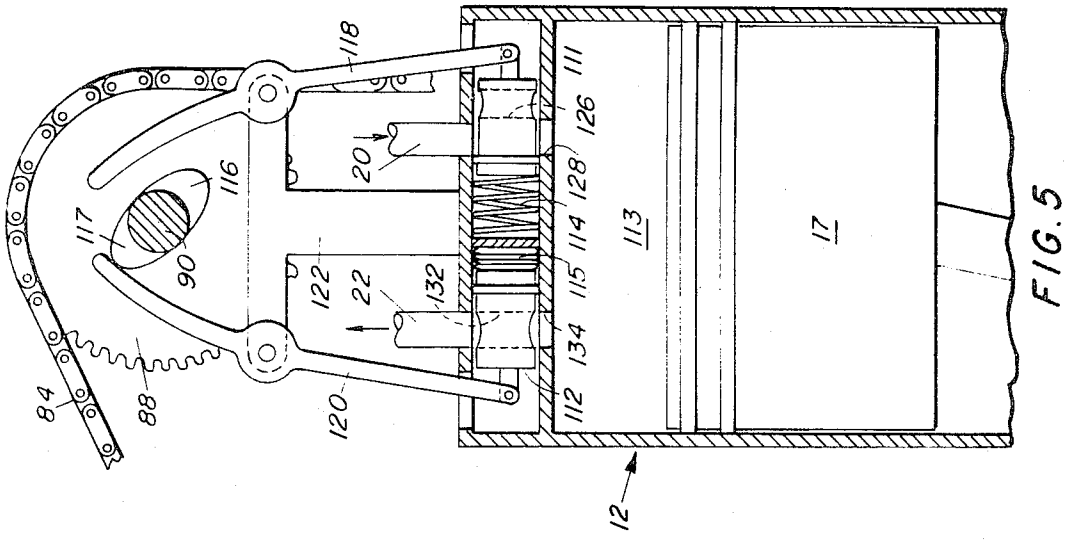
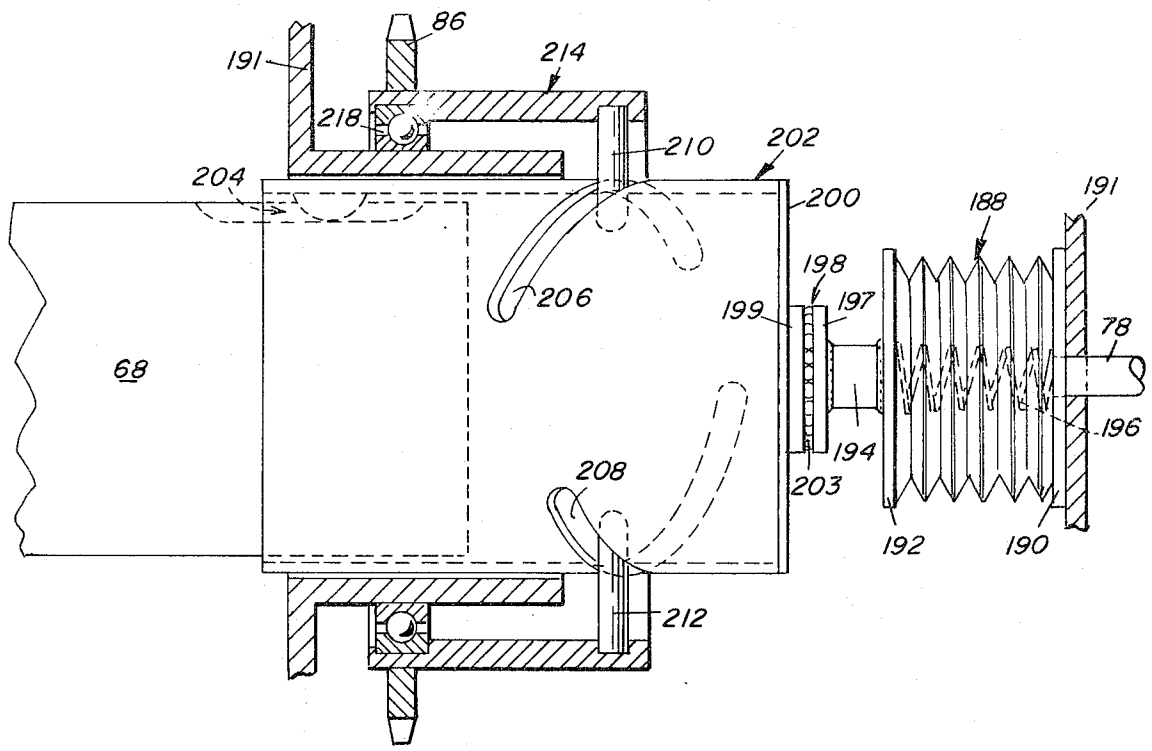

118
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FIG. 7


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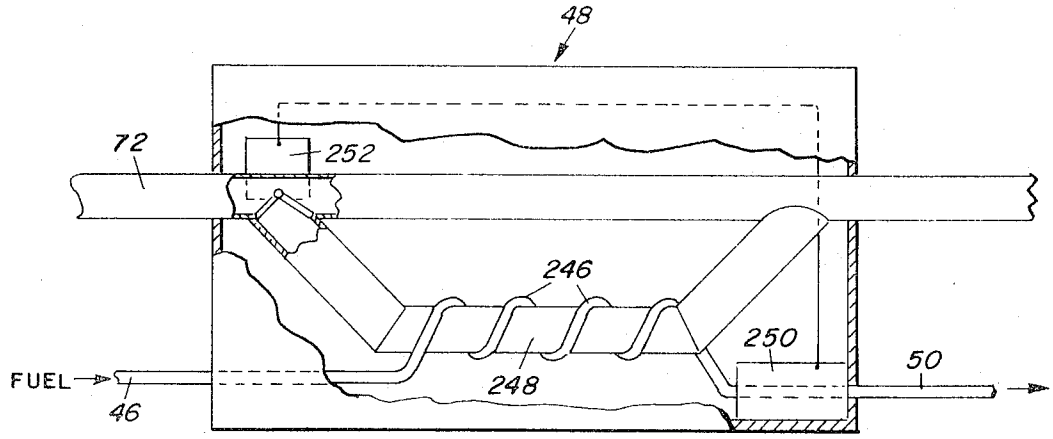

48
72
252
246
250
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FUEL
248
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FIG. 8

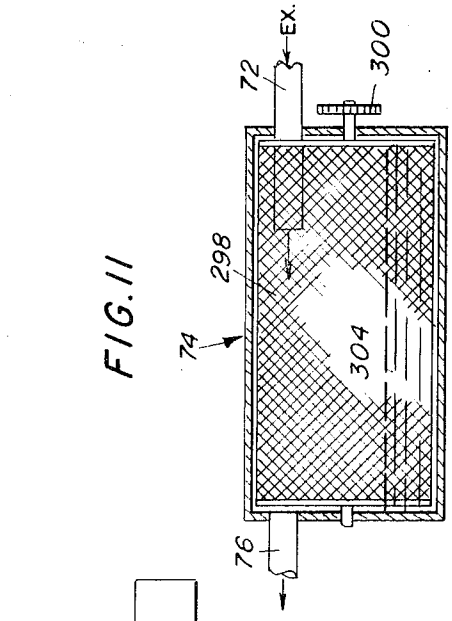


FIG. 11

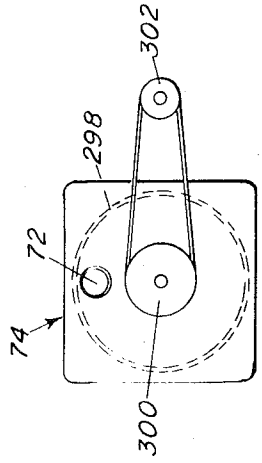


FIG. 12

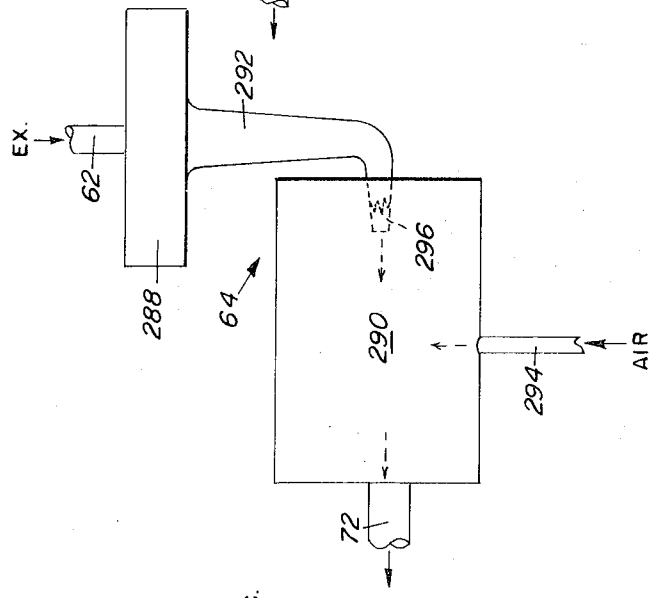


FIG. 10

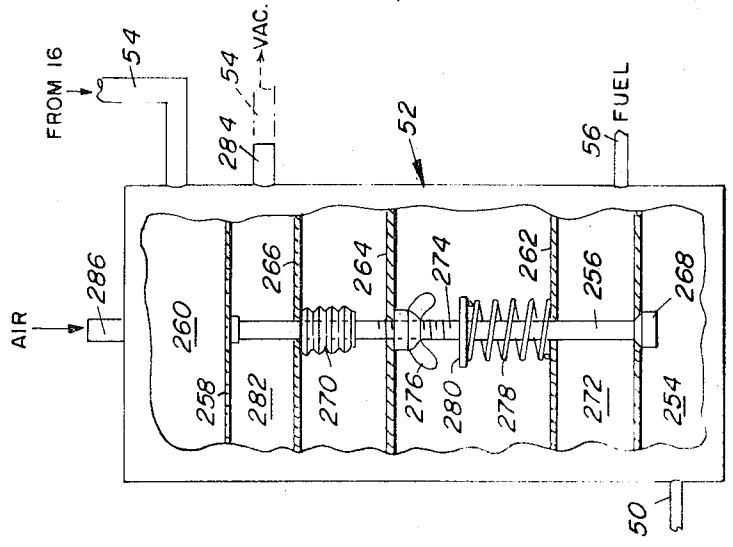


FIG. 9

ANTI-POLLUTION INTERNAL COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

This invention relates to an anti-pollution internal combustion and compressed air operated engine, and more particularly to an engine which can be started and motored for a period of time on compressed air which is stored during the firing and braking modes of operation of the engine.

Air pollution caused by the presently used internal combustion engine has become acute in recent years, and the resulting ecological problem has only recently been fully appreciated. Many new approaches have been examined in an effort to combat the pollution problems. For example, numerous mass transit systems are being developed to transport large groups of people and some efforts have been directed to developing non-gasoline burning vehicles such as the electric car since these types of cars will not emit carbon monoxide, nitrogen oxide, and other combustion products which are photosynthesized by the sun to produce smog. However, such a radical change in the system of powering motor vehicles would result in severe economic problems since the oil industry is one of the world's largest developers and employers. Therefore, it would appear that a logical alternative to completely replacing the internal combustion engine would be to develop a more pollution-free internal combustion engine. Some efforts by the oil industry have been directed to this area.

Although it is possible to produce a relatively efficient non-polluting engine by improving the engine and the fuel used, there will always be some pollution caused by the elements exhausted from the combustion of fuel in an internal combustion engine. The only effective method of eliminating this pollution is to eliminate its source altogether; however, as mentioned above, the economic problems that would be created for braking the world community are unacceptable. The best alternative to completely eliminating the internal combustion engine is to limit in some way the amount of time the engine will run without adversely affecting the vehicle's operation. This can be accomplished by eliminating the idling time of the internal combustion engine, for in the "stop and go" commuter traffic so prevelant in the world's urban communities, the idling engine causes a great portion of the pollution problem. The present invention is directed to an engine which is capable of eliminating this idling time, and thus takes a major step toward reduction of air pollution. The present invention accomplishes this through the use of compression cylinders which store air under pressure for subsequent use in motoring the engine when it is to be restarted.

There are several types of engines known in the prior art which utilize compression cylinders for compressing air, or an air and fuel mixture, to be used in a separate firing cylinder. In most of these dual cylinder engines, the operation of the valves of the compressor cylinders are correlated with the operation of the valves of the firing cylinders so that the compressed air is directed into the firing cylinder at or slightly after top dead center since the firing cylinder is not used for compressing the firing mixture. The explosion in the firing cylinder of these dual cylinder engines occurs at the same time as a standard internal combustion to drive the piston downwardly, thus turning the drive shaft.

Other engines have been developed which utilize a separate cylinder to compress air for the firing cylinder and to further store a portion of the compressed air in a reservoir for later restarting the engine. Generally, this type of stored air engine uses the stored air to initially drive the pistons and thus motor the engine until fuel is fed into the firing cylinders, thereby permitting combustion.

These presently known stored air engines utilize only one compression cylinder to compress the air for all the firing cylinders. One of the problems with this type of one cylinder arrangement is that it requires a manual adjustment of the piston position prior to restarting the engine. The present invention is designed to overcome this problem by providing several compressor cylinders which are arranged out of phase so that one or more cylinders will be over top dead center when restarting is attempted. Furthermore, these presently known stored air engines were developed relatively early and were not designed to be used to drive a motor vehicle, but were primarily designed to drive machinery. Although there is a possibility that these earlier engines might possibly be used on a vehicle, the subsequent prior art indicates that the advances in the internal combustion engine field have steered away from this type of approach.

The more recent prior art discloses that the industry has tried to develop the dual cylinder engines mentioned above which use a separate compression cylinder to compress air or an air and fuel mixture to be fed into the firing cylinder.

One of the basic reasons for the industry directing its efforts in this direction rather than developing a stored air engine would appear to be due to the operational problems which occur when using such an engine for a motor vehicle. One example of such a problem is the inability of such engines to store a sufficient amount of air to later be utilized in motoring the engine in today's stop and go traffic. The present invention is intended to overcome the operational problems of the stored air engines and to utilize such engines to drive a motor vehicle.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide an internal combustion engine for use in a vehicle that will reduce the amount of polluting elements that are emitted into the atmosphere.

Another object of this invention is to provide an internal combustion engine which will store compressed air during the firing and braking modes of operation to be later reused in restarting the engine and in the initial movement of the vehicle prior to a reactivation of the engine's firing mode of operation.

Another object of this invention is to provide an engine which will be capable of utilizing any one of several types of hydrocarbon combustible fuels such as pressurized butane, propane, natural gas or gasoline.

Another object of this invention is to provide an automatic cam advance and retard mechanism for an internal combustion engine which will vary the opening and closing of the inlet and exhaust valves to the firing and compression cylinders in response to the amount of pressure in the air storage reservoir.

Another object of the present invention is to provide an internal combustion engine having an after burner to eliminate the unburned hydrocarbons produced dur-

ing the firing stage and a muffler which removes the nitrogen oxide pollutants from the exhaust emissions as well as reduces noise.

Still another object of this invention is to provide a unique valving system operated from the throttle and brake pedal of a motor vehicle which will select the mode of operation of the internal combustion engine.

Still another object of this invention is to provide an internal combustion engine which will restart without the use of a starter motor.

These and other objects are accomplished by the present invention through the use of an internal combustion engine for a motor vehicle which will store compressed air while the vehicle is braking and thereafter use the stored compressed air to restart and motor the engine. The stored air drives the firing and compression cylinders, causing the engine to run on the air supply until the fuel-air ratio reaches the point that the engine will begin firing again. The engine utilizes a fuel system having a pressurized fuel tank containing any desired combustible fuel, such as liquid butane, propane, natural gas, gasoline, or the like. The fuel is fed into the firing cylinders of the engine with a quantity of the compressed air, and thus the firing cylinders are not required to compress the fuel-air mixture during the engine's firing mode of operation.

Fresh air enters the engine through an inlet valve and passes to a compression cylinder where the air is compressed and then directed to a storage tank. The storage tank is connected to a manifold through a throttle valve; upon opening of the throttle valve, compressed air in the tank is directed into the manifold. Fuel flow into the firing cylinders is regulated by a diaphragm valve which is responsive to pressure in the manifold. The air from the manifold is directed through a venturi line into which the fuel is directed. When the intake valves for the firing cylinder are opened, the fuel-air mixture from the venturi line is directed into the firing cylinder where it is burned in the normal manner to drive the firing piston downwardly, thus turning the engine crank shaft. The exhaust gases are drawn out through exhaust ports into an after burner and then through a muffler which extracts some of the polluting elements from the exhaust gases. The crankshaft drives the compression cylinders which feed compressed air to a storage tank, where it is held under pressure for use in feeding the firing cylinders during the firing mode.

During the braking mode of operation of the engine, air is compressed by the compression cylinders and stored in the storage tank. The compression of the air helps retard the operation of the engine, thus slowing the vehicle down. During this mode, no air is directed into the firing cylinders. Thereafter, operation of the brake pedal positions a selector valve so that in the motoring mode the engine is restarted on the compressed air which has been stored in the storage reservoir. The compressed air is directed into both the firing and compression cylinders to drive the pistons, thereby turning the vehicle drive shaft. When the air drops, fuel is supplied to the firing cylinders, the engine begins to fire and the selector valve is then returned to its normal position so that compressed air is again stored in the storage reservoir for use in the firing cylinders during the firing mode of operation. An automatic advance and retard device controlled by the amount of pressure in the manifold operates to selectively advance or retard the opening and closing of the inlet and outlet valves of the firing cylinder to insure that the engine will operate efficiently with variable amounts of pressure in the storage tank.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and additional objects, features and advantages of the present invention will be apparent to those skilled in the art from the following detailed description of a preferred embodiment taken with the accompanying drawings, in which:

FIG. **1** is a diagrammatic illustration of an internal combustion engine according to the present invention, and shows a single set of the firing and compression cylinder pairs which make up the engine;

FIG. **2** is a diagrammatic illustration of a suitable storage tank and manifold which can be used in the internal combustion engine shown in FIG. **1**;

FIG. **2A** is a diagrammatic illustration of a suitable inlet control valve and pressure switch which can be used in the internal combustion engine shown in FIG. **1**;

FIG. **3** is a diagrammatic illustration of a suitable air inlet valve which can be used in the internal combustion engine shown in FIG. **1**;

FIG. **4** is a diagrammatic illustration of a suitable selector valve for use in the internal combustion engine of FIG. **1**;

FIG. **5** is a diagrammatic illustration of a compression cylinder arrangement suitable for use in the internal combustion engine of FIG. **1**;

FIG. **6** is a diagrammatic illustration of the firing cylinder and the intake valve mechanisms suitable for use in the internal combustion engine shown in FIG. **1**;

FIG. **7** is a diagrammatic illustration of the automatic cam advance and retard mechanism utilized in the internal combustion engine illustrated in FIG. **1**;

FIG. **8** is a diagrammatic illustration of a heat exchanger system suitable for use in the internal combustion engine disclosed in FIG. **1**;

FIG. **9** is a diagrammatic illustration of a fuel regulator suitable for use in the internal combustion engine disclosed in FIG. **1**;

FIG. **10** is a diagrammatic illustration of a suitable afterburner assembly used in the internal combustion engine disclosed in FIG. **1**; and

FIGS. **11** and **12** are diagrammatic illustrations of a side view and a front view, respectively, of a suitable anti-pollution muffler which can be utilized in the internal combustion engine of FIG. **1**.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring more particularly to the drawings, in FIG. **1**, the numeral **1** indicates a stored air internal combustion engine for use in a vehicle, the engine having a compressed air storage reservoir or tank **10** (see also FIG. **2**) which receives air that is compressed by one or more compression cylinders **12**.

The compressed air is directed to a plurality of firing cylinders **14** and compression cylinders **12** through a suitable manifold **16**, and through various conduits connecting the compression and firing cylinders to the manifold. The sequences and purposes for directing the compressed air to the various cylinders will be explained hereinafter. For clarity and ease of illustration, only one set of cylinders is illustrated in the drawings and described herein; however, it should be understood that a plurality of firing and compression cylinders will

normally be used in the internal combustion engine of the subject invention and the present invention is not limited to the single set of two cylinders disclosed in the drawings. The storage tank can be of any shape desired and located in any desired position on the internal combustion engine or the vehicle. In the preferred embodiment disclosed herein, the storage tank **10** is cylindrical in shape having one end closed and the other end partially closed but carrying and communicating with a cylindrical manifold.

Fresh air is drawn into compression cylinder **12** by means of reciprocating piston **17** through an inlet valve **18** and conduit **20** as the piston moves downwardly. Upon compression, the air is directed through conduit **22,** selector valve **24,** and conduit **26** into storage tank **10.** The compressed air within tank **10** can escape into the manifold **16** through an aperture in the end of the tank which is opened and closed by a throttle valve **28** (FIG. **2**).

The throttle valve **28** is connected by a suitable mechanical linkage **30** to an accelerator pedal **32** for operation thereby. The mechanical linkage **30** passes through and operates a mechanical switch **34** to make or break a set of contacts so that circuits between a standard power source **35,** such as a battery, an inlet control solenoid valve **36,** and a fuel control solenoid valve **38** will be energized or de-energized. When the inlet control valve **36** is energized, tank pressure is applied to inlet valve **18,** as will be explained hereinafter.

The manifold **16** has outlet conduits **40** and **42** which are directed to the compression cylinders **12** and firing cylinders **14,** respectively. The outlet conduit **40** communicates with the compression cylinder **12** by way of the selector valve **24** and the inlet conduit **20,** while the outlet conduit **42** communicates directly with the firing cylinders **14** through appropriate intake valves at the cylinders, to be described. Compressed air from the tank **10** is supplied to each of the cylinders through their respective outlet conduits at preselected times in accordance with the mode of operation of the engine.

A pressurized fuel tank **44** (FIG. **1**) containing natural gas, propane, butane or other suitable fuel is connected through conduit **46** and a pump **45** to a heat exchanger **48.** The heat exchanger vaporizes the fuel before it is directed through a conduit **50** to a fuel regulator **52.** In a preferred embodiment of the invention, the heat exchanger is associated with the engine exhaust manifold, obtaining heat therefrom for use in vaporizing the fuel. The fuel regulator is controlled by the pressure in manifold **16** through a conduit **54** which extends between the manifold and the regulator. The fuel regulator permits a suitable amount of fuel to pass into conduit **56** and thence into the inlet of Venturi line or passage **58** of each of the firing cylinders **14.** The fuel control solenoid valve **38** is located in line **56** between the fuel regulator **52** and Venturi line **58** and is controled by switch **34** and thus by the accelerator pedal **32.** A second control for the fuel control valve **38** is provided by a pressure switch **59** which is sensitive to the pressure in tank **10.** The pressure switch **59** will prevent the fuel valve **38** from opening when excessive pressure is in tank **10.** These two controls cause fuel valve **38** to be closed to prevent the flow of fuel to the firing cylinder under two conditions: first, when the engine is in a BRAKING mode of operation, since the accelerator will be released and the fuel control circuit will be de-energized by switch **34,** and second, when the engine is in the motoring mode of operation, since the pressure in tank **10** will be high enough to operate pressure switch **59,** as will be explained hereinafter.

When the engine operates in the firing mode, the firing cylinders **14** produce exhaust gases which are initially exhausted through port **60** in the cylinder wall and carried by conduit **62** into an afterburner **64.** Port **60** is located slightly above the level of the top surface of the piston head when the piston is at its lowest position in the cylinder, and is closed by the piston during its upward stroke. During the exhaust stroke of the piston, an exhaust valve **66** is opened by a cam lobe carried on a cam shaft **68** so that any remaining exhaust gases flow through valve **66,** conduit **70,** conduit **62** and into the afterburner **64.** The action of the afterburner **64** will be explained hereinafter. Upon leaving the afterburner **64,** the gases pass through conduit **72** into muffler **74** where they are reacted with a chemical solution and then passed to the atmosphere through exhaust pipe **76.**

The rotation of cam shaft **68,** mentioned above, controls the opening and closing of the intake and exhaust valves of the firing cylinders **14,** as will be explained hereinafter. The rotation of the cam shaft is automatically advanced or retarded, thus varying the timing of the opening and closing of the valves, by an automatic cam shaft positioning mechanism which is controlled by the amount of pressure in manifold **16.** The cam automatic advance and retard mechanism communicates with the manifold **16** through conduit **78.** The operation of the automatic advance and retard mechanism will be discussed hereinafter. Crank shaft or drive shaft **80** is connected to the piston arms of each of the compression and firing cylinders in the conventional manner. The drive shaft also carries a timing sprocket **82** which is interconnected by way of a timing chain **84** to a pulley **86** on cam shaft **60** and a pulley **88** on compressor cam shaft **90,** whereby shafts **60** and **90** are driven by the crankshaft **80.**

The various modes of operation of the present internal combustion engine are controlled by the selector valve **24** which is positioned between the storage tank manifold assembly and the compression cylinders. The selector valve is, in turn, controlled by a closed loop hydraulic brake system so that depression or release of a brake pedal **92** causes hydraulic fluid in brake reservoir **94** to be directed through conduit **96,** valve **18** and conduit **98** to one side of the selector valve **24** or through conduit **100** to the opposite end of selector valve **24.**

FIRING MODE OF OPERATION

Although FIG. **1** provides an overall illustration of the present invention, many of the details have been shown only diagrammatically for clarity. These details together with an explanation of the various modes of operation of the present invention will be set forth in the following description.

As has been indicated, the present invention has three basic modes of operation: a firing mode, where the device operates as an internal combustion engine; a braking mode, where the engine is shut down, and its compression cylinders feed air under pressure to the storage tank; and a motoring mode, where the compressed air is fed to the firing cylinder without fuel, to drive the engine. Following through with a complete operation cycle of the internal combustion engine, the explanation will begin with the engine running nor-

mally in the firing mode. As mentioned above, air is drawn into the engine from the atmosphere through apertures **102** (see FIG. 3) in air inlet valve **18,** due to the partial vacuum formed by the downstroke of the piston in compression cylinder **12.** The air drawn through the aperture **102** will flow between the inlet valve seta **104** and the inlet valve heat **106,** which is in the open position illustrated, into conduit **20.** In the firing mode of operation the selector valve **24** is positioned as illustrated in FIG. **4** with its cylindrical valve stem **107** in its uppermost position. This valve stem is formed with upper, middle and lower sections **108, 109** and **110,** respectively, which are enlarged to engage the cylindrical walls of valve **24** in the manner of a conventional sliding valve. As shown, section **109** blocks the path between lines **20** and **40** so that there is no communication between inlet valve **18** and the manifold **16.** Any air drawn in through the inlet valve **18** is therefore directed through the conduit **20** into the compression cylinder **12.**

As shown in FIG. **5,** the compression cylinder of this preferred embodiment has two slide valves **111** and **112** which are used to open and close passageways between the cylinder chamber **113** and inlet conduit **20** and outlet conduit **22,** respectively. The slide valves are biased to close the passageways by means of bias springs **114** and **115,** and are moved to open the passages by cam lobes **116** and **117** on shaft **90,** which shaft is driven by the drive shaft or crankshaft **80** (see FIG. **1**) through the timing chain **84** and pulley **88.** The cams **116** and **117** engage cam followers **118** and **120,** respectively, which are in contact with slide valves **111** and **112,** respectively, rotation of the cam shaft causing the valve to be opened at preselected times. The cam follwers **118** and **120** are pivotally secured to the cylinder by a bracket **122.**

In operation, the cam **116** engages the upper end of cam follower **118,** thereby causing the lower end of cam follower **118** to force slide valve **111** toward the center of the cylinder, as can be seen in FIG. **5.** The timing is such that the slide valve **111** is forced toward the center of the cylinder at the beginning of the downward movement of piston **17** of compression cylinder **12.** Valve **111** is fully open when a bore **126** in the valve body is aligned with inlet conduit **20,** approximately at mid stroke of the piston. Air is drawn through the inlet valve **18,** conduit **20,** bore **126,** and inlet opening **128** leading into compression chamber **113.** As the cam **116** is rotated, it disengages the upper end of cam follower **118,** and a spring **114** or other suitable biasing means forces valve **111** away from the center of the cylinder. When bore **126** in valve **110** is no longer in registration with conduit **20** and inlet port **128,** the air flow into chamber **113** is shut off, and this occurs at approximately the bottom of the piston intake stroke.

When the piston **17** is driven upwardly by the rotation of crankshaft **80** in the compression stroke, slide valve **111** is in the closed position; slide valve **112** begins to open at the beginning of the upward stroke. The cam **117** on shaft **90** engages the upper end of cam follower **120,** thus causing the lower end of the cam follower to move slide valve **112** towards the center of the compression cylinder, as illustrated. Valve **112** is fully opened when a bore **132** in the valve body is aligned with outlet conduit **22,** at approximately the midpoint of the upward stroke of the piston. The compression chamber **113** communicates with the outlet conduit **22** upon registration of bore **136** in slide valve **112** with outlet port **134** and outlet conduit **22.** The air in the chamber will flow through inlet port **134,** bore **132,** conduit **22,** selector valve **24** and line **26** into storage tank **10** when the pressure generated exceeds the pressure in tank **10.** A double check valve arrangement (not shown) is utilized to prevent backflow from tank **10** to the cylinders. The check valves will normally be positioned in line **22** next to outlet slide valve **112** and in line **26** between selector valve **24** and tank **10.** Therefore, the air compressed by cylinder **12** is stored in the tank **10** until it is to be used. A biasing arrangement similar to that for the inlet slide valve **111** is utilized with outlet slide valve **112,** whereby spring **115** closes the slide valve when the cam **117** disengages the upper end of cam follower **120.**

By the above described sequence of valve operation, the compression cylinder is not required to compress the air in the compression cylinder, but only has to overcome the pressure in tank **10** in order to store air. A relief valve **137** is provided in tank **10** to prevent over-pressurization. If desired, however, the timing of the inlet and outlet valves in the compression cylinder can be modified to permit the air to be compressed in the cylinder **12** before the outlet slide valve **112** is opened.

Continuing with the firing mode of operation of the internal combustion engine, as the air is being drawn in through the inlet valve **118,** compressed by cylinder **12,** and directed into tank **10,** the compressed air in the storage tank is released to the manifold **16** (see FIG. **2**) through throttle port **138** when valve **28** is open. As mentioned above, throttle **28** is connected to mechanical linkage **30** and will be unseated when the vehicle operator manipulates the accelerator pedal **32.** It should be understood that any type of foot pedal, hand lever or the like can be used to open the throttle. Pressurized air that is released into the manifold **16** flows into several conduits—namely, conduit **42** which communicates with the firing cylinders **14;** conduit **78** which communicates with the automatic cam shaft advance and retard mechanism, the operation of which will be explained hereinafter; conduit **54** which communicates with fuel regulator **52;** and conduit **40** which is connected to selector valve **24.** During the firing mode of operation, the compressed air will not pass through selector valve **24** (see FIG. **4**) and thus will not be directed into inlet conduit **20.**

The operation of the throttle linkage **30** to open throttle valve **28** also operates switch **34** to energize the control valve circuits so that the solenoids in the control valve **36** and fuel control valve **38** are operated. The inlet control valve **36** regulates the flow of air between storage tank **10** and the inlet valve **18** through a conduit **139** (see FIGS. **1** and **2A**). This in turn controls the position of valve **106** to regulate the flow of air into conduit **20** from openings **102** in inlet valve **18.** The air flow from tank **10** is to an air chamber **140** defined in valve **18** by a piston **141** and a wall **142.** The pressurized air forces air piston **141** upwardly against the bias of spring **143** and thus will vary the opening between valve seat **104** and valve head **106** in accordance with the pressure in tank **10.** The fuel flow control valve is energized to permit fuel to be supplied to the engine.

As can be seen in FIGS. **1** and **6,** compressed air from manifold **16** passes through conduit **42** to a first inlet valve **140** on the firing cylinder **14.** The inlet valve **140**

is mechanically operated by cam **142** carried on cam shaft **68** to lift valve head **144** from its valve seat **146,** thereby permitting compressed air to flow into the Venturi line **58.** The opening and closing of the valve is controlled in the standard manner by rotation of the cam shaft **68.** Valve stem **148** extends through an aperture in the engine casing and has a guide washer **150** or other suitable means fixed within the valve casing, or cylinder, to maintain the stem in a proper position. A spring **152** is positioned between the washer **150** and a suitable blocking member **154** which is fixed to the valve stem **148.** The blocking member seals the valve cylinder and prevents compressed air from escaping through the valve cylinder. Any suitable sealing member may be utilized. The spring **152** returns the valve to the closed position after the lower end **155** of the valve stem is disengaged from the cam **142.**

The compressed air passing through Venturi **58** picks up vaporized fuel which is entering the Venturi through conduit **56.** The pressure of the compressed air and fuel mixture in the Venturi **58** causes a second inlet valve **156** to operate, the pressure causing valve head **158** to be lifted from seat **160** shortly after valve **140** opens. The opening of valve **158** is timed to occur when the piston head **162** of firing cylinder **14** reaches top dead center. After the compressed air and fuel mixture is released into the firing chamber **164,** the second valve **156** is returned to its closed position by a spring **166** which is secured between a fixed guide washer **167** at the upper end of the valve casing **168** and a shoulder **169** fixedly secured to valve stem **170.** Any suitable means may be used to maintain the valve stem in proper alignment within its casing and which will permit its operation as explained above.

As mentioned above, the opening and closing of valve **140** is controlled by the rotation of cam shaft **68.** The cam shaft **68** has an automatic advance and retard mechanism which will vary the timing of the opening and closing of the firing cylinder valves in response to the amount of pressure which is in the manifold **16** upon opening throttle valve **28.** Therefore, when the pressure in the manifold varies, the inlet valve **140** will open and close at different times with respect to the motion of piston **162** within the firing cylinder. For example, if the pressure in the manifold is relatively low, the inlet valve **140** will be opened early in the upward stroke of the piston so that the air which is fed into the firing cylinder chamber **164** can be further compressed by the piston prior to firing. If the pressure in the manifold **16** is high, the opening of valve **140** will be retarded because the piston **162** will not be needed to compress the fuel-air mixture prior to firing; in this case, the valve will be opened when the piston is near or at top dead center. In order to prevent any time lag which may occur in the opening of the valve **156,** a solenoid coil **172** is positioned around the stem **170** of the valve so that the valve stem **170** acts as a solenoid core. The winding of coil **172** is connected to a circuit breaker which is operated by the rotation of cam shaft **68** so that it will be energized periodically to aid in the opening of the valve head **158.** By placing the breaker contacts on the camshaft, the time at which the solenoid is energized and de-energized will be varied by the camshaft advance and retard mechanism, and thus with the pressure in the storage tank.

Continuing with the firing mode of operation of the engine, the compressed air and fuel mixture is directed into chamber **164** and, at a preselected time, is ignited by a standard spark plug **173.** The ignition system in this preferred embodiment includes a rotor driven from the compression cam shaft **90,** a standard coil, and breaker points with condenser. Only four contacts are required for this engine, one for each firing cylinder. The spark plug **173** for each cylinder will always fire when the corresponding firing piston **162** is at or near top dead center. Since the camshaft **90** is not controlled by the automatic advance and retard mechanism, the timing relationship between the firing cylinder piston movement and the camshaft **90** will remain constant, and the firing will occur at precisely the same time no matter when the fuel and air mixture enters the firing cylinder.

Upon firing of the fuel and air mixture by the sprak plug, the gas begins to expand, thus forcing the piston **162** downwardly. In order to reduce any vacuum effect that might occur during the last part of the downward movement of piston **162** after the explosive force has ended, or that might occur during the breaking mode of operation, a vacuum vent valve **174** is provided at the lower end of the casing **168** of valve **156.** As the piston **162** is driven downwardly by the explosion in the cylinder, the vacuum vent valve **174** is allowed to unseat, permitting air from the atmosphere to pass through the casing of valve **156** to unseat valve head **158.** This allows the air from the atmosphere to pass into firing chamber **164.** Any suitable vent valve may be provided; however, it should be biased against opening while the compression gas is being directed into the firing cylinder.

When the piston **162** approaches the lower limits of its stroke, exhaust port **60** is exposed to permit most of the combustion product gases to be exhausted from the cylinder. This feature is particularly important when the "no lead" gasolines are used because they have a tendency to burn and pit conventional exhaust valves. The gases ae exhausted through conduit **62** into the afterburner **64,** as can be seen in FIG. **1.** During the subsequent upward stroke of piston **162,** the exhaust valve **66** is opened by a mechanical linkage between the valve stem **180** and the camshaft **68** to permit the remaining gases to escape. As shown in this preferred embodiment, a cam follower **176** is positioned near cam shaft **68** and extends upwardly to a rocker arm or other suitable linkage **178** which is in engagement with the upper end of the stem **180.** The rocker arm is pviotally mounted at support **182.** A biasing spring **184** is provided on the valve stem **180** to maintain the exhaust valve normally in the closed position. As the firing piston **162** is moved upwardly and at a preselected time which is determined by the rotation of camshaft **68,** exhaust valve **66** is forced downwardly to unseat valve head **186,** thus allowing the remaining exhaust gas to pass through conduit **70** into conduit **62** and then into the afterburner **64,** and preventing the buildup of pressure in the cylinder. The exhaust valve is closed just prior to the opening of inlet valve **140.** The opening and closing of the exhaust valve is controlled and varied by the cam shaft advance and retard mechanism associated with cam shaft **68.**

AUTOMATIC CAM SHAFT ADVANCE AND RETARD MECHANISM

As discussed above, the automatic advance and retard mechanism is controlled by the pressure in the

manifold **16.** Compressed air from the manifold flows through conduit **78** which is connected to bellows assembly **188** (see FIG. **6**) associated with the automatic advance and retard mechanism. The bellows assembly has two end plates **190** and **192,** end plate **190** being fixed to a portion **191** of the engine block and having conduit **78** extending therethrough, and end plate **192** being secured to a movable stud shaft **194.** A spring **196** carried with the bellows assembly tends to collapse the bellows assembly, thus causing end plate **192** to move towards end plate **190,** as can be seen by the above description. The linear position of the end plate **192** will be determined by the amount of pressure in the bellows assembly which is the same as the pressure in the manifold **16.**

The stud shaft **194** is fixedly secured to one side **197** of a thrust bearing **198** so that the bellows assembly **188** will not rotate with the camshaft **68.** The other side **199** of thrust bearing **198** is fixedly secured to the end plate **200** of a cylindrical sleeve **202,** ball bearings **203** permitting the opposite sides of the thrust bearing to rotate with respect to each other. Sleeve **202** is slidably mounted on cam shaft **68** through the use of a key and slot arrangement **204,** whereby sleeve **202** is permitted to reciprocate axially with respect to the cam shaft **68** but rotates with the camshaft. As shown in FIG. **7,** the sleeve has two helical slots **206** and **208** spaced at diametrically opposed locations around the sleeve. Trunnions **210** and **212** carried on a cylindrical support member **214** engage slots **206** and **208,** respectively. The trunnions are secured against axial motion along the length of the cam shaft, so that when sleeve **202** is moved axially along the shaft by bellows **188** the trunnions carried on support member **214** cause the cam shaft **68** to be rotated. Any suitable means can be used to mount the cylindrical support member **214** so that it will be axially fixed; in this preferred embodiment, the cylindrical support fits over a portion of the engine block **191** and rests on a bearing **218,** thus permitting the support member **214** to rotate with the cam shaft.

The cylindrical support member **214** also carries timing sprocket **86,** so that any angular variation in the position of sleeve **202** will cause the angular relationship between the shaft **68** and the timing sprocket **86** to be varied. This changes the time relationship between the opening and closing of compression cylinder slide valves **111** and **112,** which operate from sprocket **86,** and the opening and closing of the inlet valve **140** and exhaust valve **66** of the firing cylinder, which operate from the cam shaft. Furthermore, since the circuit breaker for solenoid coil **172** is also carried on shaft **68,** the timing of the energizing and de-energizing of the coil **172** is varied by the advance and retard mechanism. Any desirable type of contact points or distributor meachanism which will make and break the circuit to the solenoid coil may be used on the cam shaft **68.** Thus, it can be seen that the automatic advance and retard mechanism operates the opening and closing of the firing cylinder valve at the proper time in accordance with the pressure in the manifold **16,** which in turn depends on the pressure in tank **10.**

BRAKING MODE OF OPERATION

The next mode of operation which will be described is the braking mode, wherein the engine and the vehicle which it drives are to be decelerated. When the vehicle operator removes his foot from the accelerator pedal **32,** the throttle port **138** in the air storage tank **10** is closed by throttle valve **28,** cutting off the flow of compressed air through manifold **16** to the firing cylinder. The closing of the throttle will also cause the mechanical linkage **30** to open switch **34** de-energizing the circuit to inlet control valve **36** and fuel control valve **38.** This causes the two solenoid valves to close, thus shutting off air flow to inlet valve **18** and the fuel flow to Venturi line **58.** Therefore, by simply releasing the accelerator pedal and closing the throttle, the operator prevents the engine from firing and sets the compression side of the engine up for storage of compressed air in the storage tank **10.**

When inlet control valve **36** is closed, the flow of pressurized air from the tank **10** to the air chamber **140** in inlet valve **18** (FIG. **3**) is shut off, and the air piston **141** is forced downwardly by spring **143.** The inlet valve **106** moves downwardly and opens the path from the inlet air passages **102** to the compression cylinder **12,** so that air is drawn into the compression cylinder **12** through inlet conduit **20** in exactly the same manner as it does during the firing mode of operation. The air is compressed by the compression cylinder **12** and flows through outlet line **22,** through selector valve **24,** into conduit **26** and then into the storage tank **10.** Since the compression cylinders are working to compress air for the storage tank, this produces the braking effect of the engine. The firing cylinders also assist the braking operation, for the spring-loaded vacuum vent valve **174** admits air to the firing cylinder chamber during the downstroke of the piston and the firing cylinder piston will tend to compress this air until vent valve **66** is opened during the upstroke.

If the operator correctly judges the distance required to stop, using only the retarding action of the compression and firing cylinders, the air intake path will remain open to feed pressurized air to the storage tank. Any excess pressure in tank **10** will vent through valve **137.** The compression cylinder continues to brake the vehicle until it comes to a rest. If the operator does not judge the distance properly and an emergency stop is required, conventional brakes actuated by brake pedal **92** can be utilized to stop the vehicle. The operation of the brakes, however, sets up the selector valve **24** for the motoring mode of operation and prevents air from flowing from the compression cylinders to the storage tank.

Upon depression of brake pedal **92** (see FIG. **1**), a piston **228** in the brake reservoir **94** is moved to the right, as viewed in FIG. **1,** thus forcing hydraulic fluid through conduit **96** to an oil chamber **230** in inlet valve **18.** Movement of piston **228** to the right may also operate a conventional hydraulic braking system **232.** As the oil from brake reservoir **94** flows into the oil chamber **230,** which is defined by a lower wall **233** and an oil piston **234** within the valve **18,** the inlet valve stem **235** to which piston **234** is attached, is forced upwardly, thus tending to move inlet valve head **106** against valve seat **104,** against the bias of spring **226.** A pair of contacts **236** and **238** carried in the upper wall of inlet valve housing and on the top of piston **234,** respectively, will close causing an indicator lamp **239** on vehicle dash to indicate to the operator when the inlet INLET valve **106** is closed.

The hydraulic fluid entering chamber **230** in valve **18** will exit the chamber and flow through conduit **98** to selector valve **24,** as can be seen in FIGS. **3** and **4.** As

the hydraulic oil passes into the upper portion of the selector valve casing defined by upper piston section **108,** the valve piston **107** is forced downwardly, thus causing the upper annular groove **240** to move into registration with inlet and outlet lines **24** and **40.** The lower annular groove **242** will also move into registration with exhaust line **244** which communicates with the atmosphere. The passage between the outlet conduit **22** from the compression cylinder and the storage tank conduit **26** is closed by the valve section **109.** Any type of selector valve which can accomplish the above operation can be used.

It should be understood that an emergency stop will not prevent the engine from assisting the hydraulic brake mechanism in stopping the vehicle, but there will be no storage of compressed air by the compression cylinder in this situation since inlet valve **106** will be closed when the hydraulic brake system is operated. In an emergency stop situation, the compression cylinders will tend to draw a vacuum and the firing cylinders will draw air from the atmosphere through vent valve **174** into the firing chamber where it will be compressed to assist in braking the vehicle.

MOTORING MODE OF OPERATION

After the engine has come to a stop in accordance with the preceding braking operation, it may be restarted through the use of the compressed air in the storage tank. This air is directed into the cylinders without fuel to drive the engine until the stored air supply has been depleted.

To initiate the motoring mode of operation, the brake pedal **92** is released partially to release the hydraulic braking mechanism **232** but not far enough to release selector valve **24.** This can be done in various ways, as by using a two position brake pedal or some other suitable mechanical means. After the brake pedal is partially released, the accelerator pedal **32** is depressed, thus opening the throttle valve **28** to allow the compressed air in tank **10** to flow into the manifold **16.** In the motoring mode of operation, both the firing and compression cylinders are used as driving cylinders to turn the crank shaft. The air flowing into the manifold **16** passes through conduit **40** and the selector valve **24** to conduit **20,** since annular groove **240** remains registered with conduits **40** and **20** because of the operation of the brake system. The air proceeds through conduit **20** and slide valve **111** which has been opened by the operation of cam **116** and follower **198** in the normal manner in at least one of the four compression cylinders. Upon entering the chamber **114,** the compressed air forces the piston **17** downwardly and thereby turns the crank shaft. When the compression cylinder is moving upwardly on the return stroke, the slide valve **112** is opened and the now-expanded air is forced out of the compression chamber **114** into conduit **22** which is now in communication with the atmosphere through exhaust line **244** and selector valve **24.**

The compressed air from the manifold is also directed into conduit **42** which communicates with one of the firing cylinders **14.** The air passes the intake valves **140** and **156** in the same manner as if the firing cylinder were in its firing sequence. The compressed air is forced into the firing chamber **164** just after top dead center and forces the piston **162** in the firing cylinder downwardly to rotate the crank shaft. The opening and closing of the inlet and exhaust valves on the firing cylinder is again varied and controlleed by the operation of the automatic advance and retard mechanism which adjusts the cam shaft **68** as the air pressure in the manifold drops.

When the accelerator pedal **32** is maipulated to open the throttle valve **28,** mechanical linkages **30** operate switch **34;** however, if a sufficient pressure has been built up in tank **10** during the braking mode of operation, inlet control valve **36** and fuel control valve **38** will be prevented from operating. The reason for this can be seen in FIGS. **2** and **2A** where the pressure switch **59** and inlet control valve **36** are shown as being carried on and communicating with a pressure chamber **223** which in turn is carried on and communicates with storage tank **10.** Solenoid valve **36** is shown in FIG. **2A** as being operated by a coil **225,** while valve **38** is operated by a coil **227,** as shown in FIG. **2.** One side of coil **225** is connected by way of lines **231** and **229** and switch **34** to power source **35,** while the other side of coil **225** is connected to ground. Similarly, coil **227** is connected to power source **35** through switch **34** and wires **229** and **233.** The other side of coil **227** is connected by wire **235** to a movable, pressure-sensitive contact **237** in pressure switch **39.** Contact **237** is movable with respect to a fixed contact **241** which is connected to ground.

The pressure switch **59** has a diaphragm **243** which carries a projection **245** adapted to engage the movable contact **237.** When the pressure in chamber **223** is at a sufficient level to cause the diaphragm **243** to deflect outwardly, projection **245** will engage the upper end of movable contact **237** and force it outwardly so that contacts **237** and **241** disengage, thereby opening the circuit to the coil of fuel control valve **38.** As the pressure in chamber **223** decreases, diaphragm **243** will return to its normal position and projection **245** will disengage contact **237,** allowing contacts **237** and **241** to close and energize the fuel control valve circuit. In this way, the opening and closing of fuel control valve can be regulated by the pressure in the storage tank **10.** This control for the fuel control valve **38** is provided to prevent the fuel from being fed into the firing cylinders during the motoring mode of operation of the engine and while the pressure in the storage tank **10** is high. This permits the firing cylinder to be driven on compressed air only, without fuel, when throttle valve **28** is open. Any suitable pressure control switch known in the art which will de-energize the fuel control valve circuit in response to an increased pressure in the storage tank can be used and it will be apparent that the illustrated circuit can be modified in accordance with standard practice.

Turning now to the operation of the inlet control valve **36** during the motoring mode of operation, when throttle valve **28** is opened by manipulating the mechanical linkage **30,** air flows into manifold **16** as explained hereinabove. Manipulation of the mechanical linkage **30** also operates switch **34** to energize the solenoid coil **225** which operates valve **36.** The solenoid core is a valve stem **247** which is movable to permit communication between pressure chamber **223** and inlet valve **18** by way of conduit **139.** In the motoring mode of operation, however, the air pressure in chamber **223** is initially high and will act on an enlarged portion or head **249** of valve stem **247** to maintain the valve in its closed position against the operation of coil **225,** thereby preventing communication between

chamber 233 and valve 18. As the pressure in tank 10 decreases, the force of the solenoid will overcome the pressure in chamber 223 so that the valve 247 is unseated, permitting air to flow through conduit 139 to chamber 140 of inlet valve 18. This is set to occur at approximately the same time that the pressure switch 59 closes its contacts 237, 241. It may be found desirable to produce smoother transition between the motoring and firing modes of operation in which case the inlet control valve 36 can be adjusted to open at a lower or higher pressure than is required to operate pressure switch 59.

Upon energization of fuel control valve 38, fuel will flow into Venturi line 58 where it will be mixed with air flowing in conduit 42 from the storage tank. The firing cylinders will then begin firing and the brake pedal 92 may be fully released either by the operator or by automatic sensing means responsive to the start of the firing mode. Upon complete release of the brake pedal 92, a bias spring 246 in the reservoir 94 forces the piston 228 to the left, as viewed in FIG. 1, forcing hydraulic fluid through conduit 100 into the bottom of selector valve 24. The lower portion 110 of the selector valve piston is forced upwardly to reset the selector valve for the normal firing mode of operation, with groove 242 registered with the outlet line 22 from compression cylinder 12 and the inlet line 26 to the storage tank 10. The outlet line 40 from manifold 16 is closed off from the inlet line 20 of compression cylinder 12, and exhaust line 244 is closed off from atmosphere. The oil pressure in chamber 230 of inlet valve 18 is decreased, thus permitting spring 143 to unseat valve 106 so that fresh air can be drawn into the compression cylinder from inlets 102. The inlet control valve 36, which is now open, permits air from storage tank 10 to pass into the air chamber 139 of the inlet control valve 18 and thereby regulate the amount valve 106 is open. The lamp 239 on the vehicle dash is extinguished as the valve 106 opens since contacts 236 and 238 disengage.

If the occasion should arise where there is insufficient pressure in the tank to motor the engine, such as after a long period of idleness, an electric starter motor (not shown) is provided to turn the engine over as in the standard internal combustion engine. With the throttle valve 28 closed, the engine is turned over for a few minutes to permit the compression cylinders to build up the pressure in the storage tank 10 to a predetermined level. A pressure readout gauge can be provided on the vehicle dash to monitor the pressure in the tank. The ignition system is then activated and the starter motor operates again to continue the build up pressure. Upon the opening of throttle valve, the engine should start in the manner described above and continue to build up pressure until it begins to run smoothly.

FUEL SYSTEM

As mentioned hereinabove, the fuel used in the internal combustion engine of the present invention can be natural gas, propane, butane, gasoline, or any other suitable hydrocarbon fuel. The fuel is stored in a pressurized storage tank 44 (see FIG. 1) and is normally maintained in a liquid state. Since it is desirous to have the fuel in a gaseous state when it is fed into the Venturi 58, the preferred embodiment of this invention provides a heat exchanging device 48 between the fuel tank 44 and the fuel regulator 52.

One type of heat exchanger device which can be used in the subject invention is illustrated in FIG. 8. The fuel is passed through line 46 from the fuel tank by pump 45. The line 46 is coiled at 246 around a branch or bypass 248 of the exhaust pipe 72 and then is directed through a thermostat 250 in line 50 to fuel regulator 52, which will be discussed hereinafter. The thermostat 250 controls the operation of a flip-flop valve 252 which when operated will divert a part or all of the hot exhaust gases flowing in exhaust pipe 72 through bypass 248, thereby heating the fuel in coil 246. The use of this particular type of heat exchanging device will also serve to cool the exhaust gases before directing them to the muffler 74.

The heated fuel passes through conduit 50 into the lower chamber 254 of fuel regulator 52, illustrated in detail in FIG. 9. The fuel regulator is generally cylindrical in shape and has a valve stem 256 extending from a lower fuel chamber 254 upwardly through the fuel regulator cylinder. The stem 256 is fixedly secured at its upper end to a diaphragm 258 which is attached to the outer wall of the regulator. Above diaphragm 258 is an upper pressure chamber 260 which communicates with manifold 16 through conduit 54, as can be seen in FIG. 1. The stem 256 extends through central apertures in regulator dividing walls 262, 264 and 266. A bellows seal 270 is provided between the stem 256 and wall 266 to prevent the gaseous fuel from passing into the upper compartments of the regulator when the valve head 268, which forms the lower end of stem 256, is unseated. The gaseous fuel flows from lower chamber 254 to an intermediate fuel chamber 272 and then into conduit 56 when the valve is open, the rate of flow depending on the amount which the valve is opened. The valve stem is threaded along its center portion at 274 and a wing nut 276 is carried on the stem. The wing nut can be used to position the valve stem and thus adjust the amount of increase or decrease in pressure in upper chamber 260 required to deflect diaphragm 258 and open the valve. The valve opens against the compressive strength of biasing spring 278 which is positioned between wall 262 and a fixed washer 280 which is carried on the valve stem 256. As the pressure in the manifold 16 builds up, pressure is applied to the upper surface of the diaphragm 258, thus forcing valve stem 256 downwardly and thereby unseating valve head 268 to permit fuel to flow into line 56. An alternative method of operating the fuel regulator is through a vacuum system wherein the line 54 is connected between a chamber 282 of fuel regulator 52, which is on the lower side of diaphragm 258, and a suitable vacuum source on the engine. Such a connection may be made by way of a suitable fitting 284. A vacuum vent 286 is provided on the top of the regulator 52 and communicates with upper chamber 260 to permit air to enter chamber 260 in the event a vacuum is drawn in that chamber. The wing nut 276 can be utilized to insure that some fuel flows through the system no matter how much pressure is in the manifold simply by varying the position of the valve stem.

EXHAUST SYSTEM

The exhaust gases passing from the firing cylinders are directed through port 60 into exhaust line 62 or through the exhaust valve 66 into line 70 which communicates with exhaust line 62. The exhaust line can be a manifold having any suitable arrangement, depending

upon how many dual cylinder (timing and compression) units are used in the engine. The exhaust gases pass through a manifold **288** (FIG. **10**) and into an after-burner or combustion chamber **290** through a single inlet nozzle **292.**

Air is drawn through line **294** from the engine crank case by the draft of the high velocity exhaust gases as they pass through the nozzle **292** into the afterburner chamber **290**; thus, any unburned fuel in the hot gases is supplied with oxygen and will be burned in the afterburner **64.** If the heat from the exhaust gases is insufficient to cause combustion, an ignitor **296,** such as a glow plug or sparking device may be located at the exit of nozzle **292** to ignite the unburned fuel as it is emitted from the nozzle. The hot gases pass from the afterburner chamber **290** through exhaust pipe **72** to muffler **74.** As described above, these exhaust gases can be used in the heat exchanger **48,** and by using them in this manner to heat the fuel, it will be understood that the temperature of the exhaust gases will be reduced prior to entering the muffler **47.**

One of the most damaging pollutants contained in the exhaust of an internal combustion engine is nitrogen oxide. Therefore, the present engine utilizes a muffler that is specifically designed to remove the nitrogen oxides from the exhaust gases, as illustrated in FIGS. **11** and **12.** The muffler **74** includes a rotating cylindrical screen **298** which is mounted within the muffler container **74.** The cylindrical screen is rotated by a sprocket **300** and suitable drive means **302,** which drive means can be a power takeoff from the engine, a separate electric motor, or the like. The screen rotates through a chemical bath **304** carried in the muffler casing **74.** A suitable chemical solution such as a soda ash solution which will react with and remove the pollutants in the exhaust gases can be used. The exhaust gases will enter the muffler **74** through exhaust line **72** which extends within the periphery of the cylindrical screen **298.** As the screen rotates, some of the solution **304** is carried by the screen over the end of the exhaust line **72** so that the gases will be required to pass through the solution and out the tail pipe **76.**

It has been found that if the incoming gases are too hot, the water in the solution will evaporate, and thus will be carried out the pipe as steam, causing the solution to eventually dry up so that the muffler becomes ineffective. Therefore, it is necessary to lower the temperature of the exhaust gases, and this can be accomplished by the use of the heat exchanger **48.** It should be understood, however, that other suitable means may be used to lower the temperature of the exhaust gases.

It can be seen from the above description and drawings that the apparatus described hereinabove provides an internal combustion engine which will reduce the amount of pollutants that are normally expelled into the air by reducing the running time or firing time of the engine while also providing other features such as the afterburner and chemical bath to remove a large portion of the pollutants which will occur during the firing of the engine. The device also provides an automatic advance and retard mechanism for use with an internal combustion engine to vary the timing of the opening and closing of the valves in the engine when the pressure of the compressed air supply for the engine has been reduced.

As will be apparent to those skilled in the art, there are many variations and changes which can be made to this internal combustion engine; for example, the methods of biasing the valves in their normal position, the use of different types of valves other than the slide valves on the compression cylinder, and other changes to the specific structural elements in this manner and other variations and changes of this nature can be made to the invention as above described and illustrated without departing from the true spirit and scope thereof as defined in the following claims.

What is claimed is:

1. An anti-pollution internal combustion engine for use in a vehicle comprising:

a. first cylinder means for compressing air during a firing and braking mode of operation of said engine, said first cylinder means being driven by said compressed air during a motoring mode of operation of said engine;

b. second cylinder means utilizing said compressed air for a fuel combustion reaction during said firing mode of operation, said second cylinder means being driven by said compressed air during said motoring mode of operation;

c. reservoir means for storing said compressed air from said first cylinder means during said firing and braking modes of operation;

d. air manifold means associated with said reservoir means for distributing the compressed air to said second cylinder means during said firing mode of operation and to said first and second cylinder means during said motoring mode of operation;

e. selector valve means for controlling the flow of said compressed air from said first cylinder means into said reservoir means during said firing and braking modes of operation and from said manifold means to said first cylinder means during said motoring mode of operation; and

f. throttle means for releasing said compressed air from said reservoir means to said manifold means during said firing and motoring modes of operation and for controlling the fuel flow into said second cylinder means.

2. The engine of claim **1,** further including means for operating said selective valve means at predetermined times to register said selective valve means in a proper position for a selected mode of operation.

3. The engine of claim **1,** further including a fuel supply means comprising:

a. a pressurized fuel tank for carrying the combustible fuel;

b. heat exchanger means for evaporating the fuel;

c. means for pumping the fuel from said pressurized fuel tank through said heat exchanger means; and

d. fuel regulator means for supplying the vaporized fuel to said throttle means, said fuel regulator means being controlled by the pressure in said manifold means.

4. The engine of claim **1,** further including an exhaust means comprising:

a. an exhaust manifold which communicates with said second cylinder means to receive exhaust gases produced by said second cylinder means during said firing mode of operation;

b. afterburner means connected to said exhaust manifold for burning the unburned fuel remaining in said exhaust gases produced during said firing mode of operation; and

c. muffler means connected to said afterburner means for eliminating undesired pollutants from said exhaust gases.

5. The engine of claim **3,** further including an exhaust gas means comprising:

a. an exhaust manifold which communicates with said second cylinder means to receive exhaust gases produced by said second cylinder means during said firing mode of operation;

b. afterburner means connected to said exhaust manifold for burning the unburned fuel remaining in the exhaust gases produced during said firing mode of operation; and

c. muffler means connected to said afterburner means for eliminating undesired pollutants from said exhaust gases.

6. The engine of claim **4,** wherein said afterburner means includes:

a. a casing forming a combustion chamber, said casing having an air inlet to introduce air into the combustion chamber;

b. a nozzle having one end connected to said exhaust manifold and the other end extending into said combustion chamber so that the unburned fuel in the exhaust gases is mixed with the air in the combustion chamber; and

c. igniter means for igniting the unburned fuel-air mixture within said combustion chamber.

7. The engine of claim **4,** wherein said muffler means includes:

a. a housing containing a bath of chemical solution that will react with and remove various pollutants in said exhaust gases;

b. a cylindrical screen rotatably mounted within said housing, a portion of said cylindrical screen being rotated through said bath, whereby some of the solution will adhere to the screen as it emerges from the bath, said solution being redeposited into said bath as said screen continues to rotate;

c. means for rotating said cylindrical screen; and

d. inlet conduit having one end connected to said afterburner to receive said exhaust gases and the other end extending within said housing to a position between the surface of said bath and the portion of said screen above said bath so that the exhaust gases from said engine will pass through said solution as it is being redeposited.

8. The engine of claim **6,** whrein said muffler means includes:

a. a housing containing a bath of chemical solution that will react with and remove various pollutants in said exhaust gases;

b. a cylindrical screen rotatably mounted within said housing, a portion of said cylindrical screen being rotated through said bath, whereby some of the solution will adhere to the screen as it emerges from the bath, said solution being redeposited into said bath as said screen continues to rotate;

c. means for rotating said cylindrical screen; and

d. inlet conduit having one end connected to said afterburner to receive said exhaust gases and the other end extending within said housing to a position between the surface of said bath and the portion of said screen above said bath so that the exhaust gases from said engine will pass through said solution as it is being redeposited.

9. The engine of claim **5,** wherein said heat exchanger includes:

a. an exhaust bypass conduit located between said afterburner means and said muffler means;

b. a fuel conduit connecting said pump means to said fuel regulator means, said fuel conduit being coiled around said exhaust bypass conduit;

c. valve means for diverting the exhaust gases through said exhaust bypass conduit; and

d. thermal means for controlling the operation of said valve means.

10. The engine of claim **3,** wherein said fuel regulator means includes:

a. a housing comprising an upper pressure chamber, a second vacuum chamber, an intermediate chamber, a lower fuel inlet having a valve seat opening through one wall, and an outlet fuel chamber;

b. a diaphragm located between said pressure chamber and said vacuum chamber which is moved by applying pressure to the pressure chamber and producing a partial vacuum in the vacuum chamber ;

c. valve means regulated by said diaphragm to control the flow of fuel between said inlet fuel chamber and said outlet fuel chamber; and

d. means for adjusting the position of said valve means.

11. The engine of claim **10,** wherein said throttle means includes:

a. a throttle valve located between said reservoir means and said manifold means for releasing compressed air into said manifold means;

b. linkage means for opening and closing said throttle valve;

c. inlet control valve associated with said reservoir means to supply pressure to said inlet valve to regulate the opening and closing of said inlet valve;

d. fuel control valve for permitting fuel to flow into said second cylinder means, said fuel control valve being regulated by said inlet control valve; and

e. switch means operated by said linkage means to energize and de-energize said inlet control valve.

12. The engine of claim **1,** wherein said first cylinder means includes:

a. an inlet valve;

b. at least one compression cylinder connected to said vehicle drive shaft for turning the drive shaft during the motoring mode of operation, said compression cylinder having an inlet and outlet, said inlet valve means communicating with said compression cylinder by a first inlet conduit, said inlet valve regulating the amount of air drawn into said compression cylinder during the firing and braking mode of operation of said engine, said compression cylinder having an outlet conduit connected to said reservoir means through said selector valve means, and a second inlet conduit connecting said manifold means to said first inlet conduit through said selector valve means for introducing compressed air from said reservoir into said compression cylinder during said motoring mode of operation of said engine;

c. compression cylinder valve means for opening and closing the inlet and outlet of said compression cylinder at preselected times;

d. first cam means for operating said compression cylinder valve means; and

e. means associated with said vehicle drive shaft for operating said first cam means.

13. The engine of claim **1**, wherein said second cylinder means includes:

a. at least one firing cylinder asscoiated with the vehicle drive shaft for turning the drive shaft during the firing and motoring mode of operation;

b. firing cylinder inlet valve means connecting said manifold means and said throttle means to said firing cylinder for introducing a compressed air and fuel mixture into said firing cylinder during the firing mode of operation and for introducing compressed air into said firing cylinder during the motoring mode of operation;

c. exhaust valve means for permitting said exhaust gases to flow from said firing cylinder after the combustion in said firing cylinder;

d. second cam means associated with said vehicle drive shaft for operating said firing cylinder inlet valve means and said exhaust valve means at preselected times;

e. means for advancing and retarding the operation of said second cam means; and

f. means associated with said vehicle drive shaft for operating said second cam means.

14. The engine of claim **13**, wherein said firing cylinder inlet valve means includes:

a. a first valve operated by said second cam means;

b. a second valve operated by the compressed air and fuel mixture being directed into said firing cylinder; and

c. a venturi connecting said first and second valves, said venturi being connected to said throttle means.

15. The engine of claim **14**, wherein said second valve means further includes:

a. a vacuum valve for preventing the firing cylinder from drawing a vacuum during the exhaust phase of the firing cylinder operation and for permitting air to flow into said firing cylinder during said braking mode of operation; and

b. means for operating said second valve to eliminate the time lag between the opening and closing of said first valve and said second valve.

16. The engine of claim **13**, wherein said second cam means includes a second shaft carrying a plurality of cam lobes for operating said firing cylinder inlet valve means and said exhaust valve means.

17. The engine of claim **16**, wherein said means for advancing and retarding the operation of said second cam means includes:

a. a bellows assembly contiguous to said second shaft and communicating with said manifold means, said bellows assembly being reciprocable in a linear direction, the linear position of said bellows assembly being controlled by the pressure in said manifold means;

b. a sleeve carried on said second shaft;

c. means for permitting said sleeve to reciprocate on said second shaft while permitting said sleeve to rotate with said second shaft;

d. bearing means connecting said bellows assembly and said sleeve, said bearing means transmitting the linear movement of said bellows assembly to said sleeve while preventing the rotational movement of said sleeve to be transmitted to said bellows assembly;

e. a support member associated with said second shaft and sleeve, said support member being mounted for rotation on said engine; and

f. means for transmitting the rotational motion of said second shaft and sleeve to said support member.

18. The engine of claim **17**, wherein said means for operating said second cam means includes:

a. a first timing sprocket carried on said support member;

b. drive shaft sprocket carried on said drive shaft; and

c. timing chain encircling said first timing sprocket and said drive shaft sprocket.

19. The engine of claim **1**, further including means for operating said selective valve means.

20. The engine of claim **19**, wherein said means for operating said selector valve means includes:

a. a closed loop fluid brake means for shifting said selector valve means between a first and second position, said selector valve means being in said first position during the firing and braking modes of operation and in said second position during the motoring mode of operation; and

b. means for selectively operating the fluid brake means between a first position wherein the selector valve means is in its first position for the firing and braking mode of operation, a second position wherein the selector valve means is moved to its second position and a mechanical braking mechanism for the vehicle is actuated and a third position wherein the mechanical braking system of the vehicle is released and the selector valve means is maintained in its second position.

21. The engine of claim **20**, wherein the fluid brake means includes:

a. a fluid cylinder means containing a fluid and having a reciprocating piston, said piston being connected to said means for selectively operating the fluid brake means; and

b. first and second conduits connecting said fluid cylinder means to said selector valve means so that when said piston is reciprocated in said fluid cylinder said fluid is selectively forced through said first and second conduits to said selector valve means to set the selector valve means in its first and second positions.

22. The engine of claim **12**, wherein said compression cylinder valve means includes first and second slide valves associated with said compression cylinder to open and close the inlet and outlet to said compression cylinder, and wherein said first cam means includes:

a. a first shaft carrying cam lobe means and mounted for rotation on said engine;

b. first and second cam follwers associated with said first shaft for actuating said first and second slide valves to an open position upon engagement of cam follower by said cam lobe means carried on said first shaft; and

c. first biasing means for returning said first and second slide valves to a closed position when said cam followers are disengaged from said cam on said first shaft.

23. The engine of claim **22**, wherein said means for operating said first cam means includes:

a. a second timing sprocket carried on said first cam shaft;

b. a drive shaft sprocket carried on said vehicle drive shaft; and

c. timing chain encircling said second timing sprocket and said drive shaft sprocket.

24. The engine of claim **12,** wherein said second cylinder means includes:

a. at least one firing cylinder associated with the vehicle drive shaft for turning the drive shaft during the firing and motoring mode of operation;

b. firing cylinder inlet valve means connecting said manifold means and said throttle means to said firing cylinder for introducing a compressed air and fuel mixture into said firing cylinder during the firing mode of operation and for introducing compressed air into the firing cylinder during the motoring mode of operation;

c. exhaust valve means for permitting exhaust gases to flow from said firing cylinder after the combustion in said firing cylinder;

d. second cam means associated with said vehicle drive shaft for operating said firing cylinder inlet valve means and said exhaust valve means at preselected times;

e. means for advancing and retarding the operation of said second cam means; and

f. means associated with said vehicle drive shaft for operating said second cam means.

25. The engine of claim **24,** wherein said firing cylinder inlet valve means includes:

a. a first valve means operated by said second cam means;

b. a second valve operated by the compressed air and fuel mixture during the firing mode of operation, said second valve means communicating with said firing cylinder; and

c. a venturi connecting said first and second valves, said venturi being connected to said throttle means.

26. The engine of claim **25,** further including means for operating said selector valve means.

27. The engine of claim **26,** wherein said means for operating said selector valve means includes:

a. closed loop fluid brake means for shifting said selector valve means between a first and second position, said selector valve means being in said first position during the firing and braking modes of operation and in the second position during the motoring mode of operation; and

b. means for selectively operating said brake means between a first position wherein said selector valve means is in its first position for the firing and braking modes of operation, a second position wherein a mechanical braking system on said vehicle is actuated and said selector valve means is moved to said second position and a third position wherein said selector valve remains in said second position and said mechanical braking system is released.

28. The engine of claim **24,** wherein said second cam means includes a second shaft carrying a plurality of cam lobes for operating said firing cylinder inlet valve means and said exhaust valve means.

29. The engine of claim **28,** wherein said means advancing and retarding the operation of said cam means includes:

a. a bellows assembly contiguous to said second shaft and communicating with said manifold means, said bellows assembly being reciprocal in a linear direction, the linear position of said bellows assembly being controlled by the pressure in said manifold means;

b. sleeve carried on said second shaft;

c. means for permitting said sleeve to reciprocate on said second shaft while permitting said sleeve to rotate with said second shaft;

d. bearing means connecting said bellows assembly and said sleeve, said bearing means transmitting the linear movement of said bellows assembly to said sleeve while preventing the rotational movement of said sleeve to be transmitted to said bellows assembly;

e. support member associated with said second shaft and said sleeve, said support member being mounted for rotation on said engine; and

f. means for transmitting the rotary movement of said second shaft and said sleeve to said support member.

30. The engine of claim **24,** wherein said compression cylinder valve means includes first and second slide valves associated with said compression cylinder to open and close the inlet and outlet to said compression cylinder; and wherein said first cam means includes:

a. a first shaft carrying cam lobe means and mounted for rotation on said engine;

b. first and second cam followers associated with said first shaft for actuating said first and second slide valves to an open position upon engagement of said cam follower by said cam lobe means on said first shaft; and

c. first biasing means for returning said first and second side valves to a closed position wherein said cam follower disengages from said cam on said first shaft.

31. The engine of claim **30,** wherein said means for operating said first cam means includes:

a. a second timing sprocket carried on said first shaft;

b. a drive shaft sprocket carried on the vehicle drive shaft; and

c. timing chains encircling said second timing sprocket and said drive shaft sprocket.

32. The engine of claim **24,** further including a fuel supply means comprising:

a. a pressurized fuel tank for carrying a combustible fuel;

b. heat exchanger means for vaporizing said fuel;

c. means for pumping said fuel from said pressurized fuel tank through said heat exchanger means; and

d. fuel regulator means for supplying the vaporized fuel to said throttle means, said fuel regulator means being controlled by the pressure in said manifold means.

33. The engine of claim **32,** further including an exhaust means comprising:

a. an exhaust manifold which communicates which said second cylinder means to receive exhaust gases produced by said second cylinder means during the firing mode of operation;

b. afterburner means connected to said exhaust manifold for burning the unburned fuel remaining in the exhaust gas produced during the firing mode of operation; and

c. muffler means connected to said afterburner means for eliminating undesired pollutatns from said exhaust gases.

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