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Wednesday, 21 December, 2005 12:35:24 PM
Clerk, U.S. District Court, ILCD

ratio and high mean effective cylinder pressure when operated in a manner just as described herein for the engine of FIG. **3**.

Alternatively, the engine of FIG. **33**, with one or more of its cylinders acting as compressor cylinders and having its camshaft arranged to rotate at crankshaft speed, operates in a 2-stroke cycle with the low compression ratio, high mean effective cylinder pressure and an extended expansion ratio when operated in the manner described herein for the engines of FIG. **8**, FIG. **9** and FIG. **11**.

Still referring to FIG. **33** of the drawings, additional fuel savings can be achieved in any of the engines of the present invention described hereinbefore by use of an economizer constructed as an air compressor retarder brake. For discussion of the disclosed retarder brake, this six-cylinder engine **100**[33] represents any of the engines of this invention which use externally compressed air (FIG. **1** through FIG. **33**) to either fully supply charge-air or which use it to enhance engine performance. The air retarder brake illustrated has a compressor **57A** operatively connected to the drive shaft of the vehicle (not shown) or geared to the engines crankshaft **20** and stores energy produced during braking or downhill travel which is utilized to supply compressed air to the engine power cylinders via the transfer manifold **58**. Such an economizer is coupled with an air reservoir **59** and during the time in which the economizer reservoir air pressure was sufficiently high for use in the power cylinders of the engine, the engine compressor can be clutchably disengaged or air pumped by the compressor(s) can be bypassed back to the inlet of the compressor(s) so that no compression work would be required of the compressor. A relief valve **60** prevents excess build up of pressure in the air reservoir. A valve **61** (being in this arrangement, a reversible one-way valve) allows air from the reservoir to be transferred to the manifold when the pressure in the reservoir **59** is higher than in the transfer manifold **58**, if the air is needed. In the case of engine constructions having compression cylinders, each compression cylinder of the engine can also be deactivated during this reserve air operation time by shutting off the admission valve so that no net work would be done by the compressor(s) until the manifold-reservoir pressure dropped below operating levels. Several systems of deactivating cylinder valves are described in the art and/or have been mentioned previously.

In an alternate arrangement, the compressor **57A** is eliminated and the air storage tank **59** is used to store excess air compressed by the compressor cylinders of the engine during braking and downhill travel. In this case, the valve **61** is a two-way valve and a blocking valve **70** is placed in the manifold **58** between the compressor cylinder(s) **66, 67** and the working cylinders **62–65**. During downhill travel or during braking, the blocking valve **70** between compressor and working cylinders is, preferably, closed, power cylinders **62–65** are deactivated, and the two-way valve at **61** is utilized in order to divert the air compressed by the compressor cylinder(s) into storage tank **59**.

When it is desired to operate the engine normally, the blocking valve **70** between the compressor and the expander cylinders is opened and the two-way valve **61** is closed. During reserve air operation, both the blocking valve **70** and the two-way valve **61** are opened. If desired, the compressor cylinder(s) **66, 67** are deactivated while in the reserve air operation mode, as described earlier. Also, a Jacob brake (a prior art retarder brake) could supply compressed air to the air reservoir tank.

Operating the engine on reserve air supply would improve the mean effective pressure (mep) of the engine for 20 percent improvement in power and efficiency, while reducing polluting emissions, during the time the engine was operating on the reserve air.

This feature would produce additional savings in energy especially in heavy traffic or in hilly country. For example, an engine producing 100 horsepower uses 12.7 pounds of air per minute. Therefore, if energy of braking were stored in the compressed air in the economizer reservoir **59**, a ten or fifteen minute supply of compressed air can be accumulated and stored during stops and down hill travel. When the reservoir pressure drops below the desired level for efficient operation, a solenoid (not shown) is used to reactivate the compression cylinder valves and they (with the supercharger, when needed) will begin to compress the air charge needed by the engine.

Using the air reservoir **59**, the engine needs no compression build-up for starting and as soon as the shaft was rotated far enough to open the intake valve, the compressed air and fuel would enter and be ignited for "instant" starting. Furthermore, the compressed air could be used to rotate the engine for this means of starting by opening intake valves earlier than usual to the expander cylinders to begin rotation and firing as is common in large diesel engines, thus eliminating the need for a starter motor. Alternatively, the compressed air could be used to charge a "hydrostarter" to crank the engine as is common on some heavy-duty diesel engines.

In an alternate, and still preferred embodiment, the reserve air in reservoir is additionally used to "motor" the engine to allow a vehicle such as a bus to pull away from a stop and operate fuelless for 30–60 seconds or more, which is the time that greatest pollution occurs in bus or stop-and-go delivery vehicle operation.

Remotely Compressed Air Embodiments

Referring now to FIG. **34**, there is seen a schematic representation of an engine **100** in accordance with an alternate embodiment of the present invention for externally providing charge-air for marine, locomotive, stationary, or electric power generating engines, or any engine applications of this invention, constant or variable load and speed, which have adequate electric power or waste or "bleed" air available. In FIG. **34**, a remote electric air compressor **35** preferably with one or more intercooled compression stages, preferably supplies temperature conditioned charge-air (both high and low pressure, if needed) for one or more engines of this invention. The charge-air, conditioned in temperature and pressure, is supplied directly to manifolds **13** and **14** by conduit **15AE** from compressor **35**. The engine intake conduit **9** of, for example, FIG. **4**, or low-pressure conduits **32** of other engines of this invention receive air from the atmosphere or alternatively receives low pressure air from a low pressure conduit **15BE** from compressor **35**. **25**

An alternate arrangement, also depicted in FIG. **34**, for providing combustion charge-air for any of the engines **100** of the present invention is to provide charge-air from conduit **15AR** which supplies waste or "bleed" air produced in industrial processes. The air is supplied either at 1 or 2 pressure levels. The lower pressure, if needed, preferably is supplied by dropping the pressure from the main incoming waste air conduit **15AR** with a pressure regulator valve (**25***a* leading to low-pressure conduit **15BR**). The arrangement is similar to the arrangement of conduits **15-A, 15-B** and valve **25** in, for example, FIG. **5**, with conduit **15-A** representing the supply conduit **15AR** from the waste air supply, and with conduit **15-B** representing conduit **15BR** in FIG. **34**.

The use of remotely compressed air, either waste air or from compressor **35**, eliminates the engines compressors **1**, **2** intercoolers **10**, **11**, **12**, certain conduits and valves **3**, **4**, **5**, **6** of the charge-air supply equipment, providing the air has been conditioned during or after the compression process (and prior to introduction to the manifolds **13**, **14**). Thus, the equipment of the engine **100** of the various embodiments shown throughout the various drawing figures of the engine **100** embodiments of this invention, is preferably eliminated up to those points designated by dashed lines A, B and C throughout the various drawings. The charge-air from either of the aforementioned remote sources is preferably introduced into the engines near the manifolds **13** and **14** and, in the appropriate embodiments, the low air pressure from the remote sources is introduced at conduit **32**, as shown in FIG. **34**.

In the remotely charged engines, the fuel can be carbureted prior to compression, can be throttle-body injected, port-injected, or directly cylinder injected.

Regarding Pollution Control

Referring now to FIG. **2** and FIG. **4**-C there is shown a method of further reducing polluting emissions in any of the engine embodiments of this invention which includes re-burning a portion of the exhausted gases when and if required. In the 4-stroke engines of FIGS. **1**–FIG. **3** and in the 2-stroke engines herein depicted having a single air intake, the exhaust outlet conduit(s) **18** have a shunt conduit **202** (refer to FIG. **2**) leading from a port **206** in the side of exhaust conduit **18** to a port **204** in the side of intake conduit **8**. A proportioning valve **201** is situated at the intake port **204** and is arranged to selectively restrict the flow of fresh air into conduit **8**, while at the same time opening the port **204** to the exhaust conduit to selectively allow entry of exhaust gases to the intake conduit **8**. This valve is variable and mechanically, electrically or vacuum solenoid operated and preferably controlled by an engine control module (ECM) or control **144** in FIG. **35** and FIG. **36**. This allows the re-burning of a portion of the exhausted gases, the amount of percentages thereof being adjusted by the engine control module in response to various sensors, such as an oxygen sensor, placed in strategic positions in the engine. Exhausted gases passing through conduit **202** can be cooled by either optional cooling fins **202***a* or by passing through an optional intercooler (not shown) before reaching the air intake conduit **8**.

With reference to FIG. **4**C, in engines having only one atmospheric intake conduit but having different air paths and conduits, such as conduits **15**-A and **15**-C of FIG. **4**B, a shunt conduit **202'** leading from the exhaust conduit **18** is divided into two shunt conduit portions **203***a*, **203***b*, each with a proportioning valve **209***a*, **209***b* operating so as to selectively admit exhausted gases to either or both of intake valve **16**-B (through conduit **9** and eventually conduit **15**-C) or to intake valve **16**-A (by way of conduit **8** and conduit **15**-A). Each proportioning valve **209**a, **209**b would allow either a portion or none of the exhausted gases to enter its respective port, meanwhile restricting entrance of fresh air if necessary. The exhausted gases can be cooled by optionally arranging fins **202***a* on conduit **202'** and/or **203***a*, **203***b* and **203***c* or by passing the exhaust through an optional intercooler (not shown) before the gases are introduced into the air intake(s) of the engine.

Alternatively, as shown in phantom on FIG. **4**C, one shunt portion **203***a* is diverted (shown as **203***c*) directly to conduit **15**-C and provided there with a proportioning valve **209***c*.

In the engines of FIG. **4** and FIG. **7** having dual atmospheric air intakes **8**, **9**, an arrangement similar to that shown in FIG. **4**C is utilized, it being understood, however, that conduit **8** is open to the atmosphere.

In any engines having dual air intake conduits or dual air paths a portion of exhausted gases can be introduced in any amount necessary, in from one to three points and controlled preferably by an engine control module (ECM) for better management of combustion and emissions characteristics.

This re-burn feature is of particular importance with diesel fuel operation.

Constant Load and Speed Engines

Whereas the preponderance of the foregoing specification describes embodiments and representative engines of the present invention which are optimized for vehicular (marine, truck, bus, automobile, tank, train and plane) duty cycles and describe systems and methods for varying power, torque and speed, the present invention finds useful application for obtaining high power and torque while maintaining optimum fuel economy and low polluting emissions in less complex engines, such as, for example, constant load and speed engines. FIG. **35** and FIG. **36** depict alternate embodiments of the present invention which embodiments are representative of constant load and speed engines (e.g., for electric power generation and in other stationary or industrial engine applications, e.g., for pumps and compressors) outfitted in accordance with the principles of the present invention.

The Engine of **100** System of FIG. **35**

Referring now to FIG. **35** there is shown is a schematic presentation of an engine which represents any of the 4-stroke or 2-stroke engines of the present invention outfitted for constant load and speed operation. The basic components of the engine **100**, such as compressors **1**, **2** and optional intercoolers **10**, **11**, **12** (shown in phantom) and their necessary associated conduits are, preferably, designed for optimum operating parameters having only the basic components. The various controls, shutter valves, air bypass valves and their associated bypass conduits such as those in previously described embodiments, are preferably eliminated in order to reduce weight, cost and complexity of operation. In FIG. **35**, the engine **100** is shown as outfitted with a first ancillary compressor **1** and a second ancillary compressor **2**, optional intercoolers **10**, **11**, **12** (shown in phantom) and interconnecting conduits, all operating as would be understood with reference to the previous detailed descriptions and operating with two stages of precompression of the charge-air, intercooled or adiabatically compressed.

FIG. **35** shows a preferred setup for power generation with any of the engines of this invention. The power output shaft **20** of the engine **100** is coupled schematically by line **140** to power input shaft **20"** of generator **141** which has electric power output lines **142**. As the shaft **20** of the engine **100** rotates the shaft **20"** of generator **141**, the amount of electric power produced by generator **141** is detected by sensor **143** and relayed to control unit and governor **144** which contains various relays and integrated circuits to quantify the power output and to send messages by line **145** to fuel/air control (not shown) on fuel line **148** and throttle **56**, and/or by line **149** to spark control to advance or retard the spark in spark-ignited engines and/or to send messages through lines **146** and **146***b* for engines having fuel injection systems, e.g. for natural gas, gasoline or diesel fuel, or to

fuel/air controls, all in order to control the fuel input, speed and output of engine **100** and hence the output of generator **141**. Control unit **144** also sends signals to control the proportioning valve **201**, shown in FIG. **4** and to proportioning valves **209***a*, **209***b*, **209***c* shown in FIG. **2** to control the amount, if any, of exhaust recirculated by these valves for re-burn in any engine of this invention utilizing this feature. Further explanation of the components and operation with the engine **100** of the present invention is deemed unnecessary as it would be understood by those skilled in the art having reference to the present disclosure.

The optional intercoolers **10**, **11**, **12** (shown in phantom) are preferably used for gaseous or gasoline fueled engines and are preferably eliminated or reduced in number or cooling capacity in the compression-ignited engine, this being made possible by low peak pressures and temperatures in the engines of this invention.

Referring now to FIG. **36** there is shown an engine illustrated as a 2-stroke engine but representing any of the engines of the present invention, 2-stroke or 4-stroke, which is coupled schematically by line **140** with an electric generator **141**. The engine and arrangements are similar in structure and operation as that shown and described for the engine of FIG. **35** with the exception that engine of FIG. **36**, operating as either 2-stroke or 4-stroke cycle engine **100**, has only a single stage of pre-compression, optionally intercooled by intercoolers **11**, **12** (shown in phantom), of the charge air. As with the engine of FIG. **35**, intercoolers **11**, **12** are preferably eliminated or reduced in cooling capacity in compression-ignited versions of the engine **100** of this invention. Also, as with the engine **100** of FIG. **35**, the governor, and other controls and the operation of the engine and generator would be understood by those skilled in the art having reference to the present disclosure.

It will be seen by the foregoing description of a plurality of embodiments of the present invention, that the advantages sought from the present invention are common to all embodiments.

While there have been herein described approved embodiments of this invention, it will be understood that many and various changes and modifications in form, arrangement of parts and details of construction thereof may be made without departing from the spirit of the invention and that all such changes and modifications as fall within the scope of the appended claims are contemplated as a part of this invention.

While the embodiments of the present invention which have been disclosed herein are the preferred forms, other embodiments of the present invention will suggest themselves to persons skilled in the art in view of this disclosure. Therefore, it will be understood that variations and modifications can be effected within the spirit and scope of the invention and that the scope of the present invention should only be limited by the claims below. Furthermore, the equivalents of all means-or-step-plus-function elements in the claims below are intended to include any structure, material, or acts for performing the function as specifically claimed and as would be understood by persons skilled in the art of this disclosure, without suggesting that any of the structure, material, or acts are more obvious by virtue of their association with other elements.

What is claimed is:

1. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, two cylinder inlet ports communicating between said cylinder and a source of air, and an exhaust port through which exhausted gases are expelled from said cylinder;

a piston movably mounted within said cylinder;

an intake valve selectively occluding each inlet port;

an exhaust valve selectively occluding said exhaust port;

at least one compressor in fluid communication via a conduit between said source of air and at least one cylinder inlet port;

at least one air cooler interconnected between said compressor and said inlet port; and

means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston, wherein one of said intake valves occupies an open position only while the other of said intake valves occupies a closed position.

2. The engine of claim **1**, wherein said at least one compressor includes a first compressor, and further comprising:

a second compressor in fluid communication between said first compressor and said inlet port with which said compressor is in communication,

whereby at least part of the intake air is selectively compressed a second time prior to entering the cylinder;

wherein said means for controlling includes means for controlling the operation of said second compressor.

3. The engine of claim **1**, wherein means are provided to minimize backflow of the charge during the closure of the higher pressure intake valve.

4. The engine of claim **3** wherein the means to minimize backflow is a one-way valve located between the intake valve and the cylinder.

5. The engine of claim **1**, wherein the compression stroke results in compressing of air within the cylinder, with means for managing air charge volumes to provide a compression ratio lower than the expansion ratio of the engine.

6. The engine of claim **1**, further comprising means for controlling operation of said compressor and said intake valves and for controlling one or more air charge characteristics selected from the group consisting of turbulence, density, pressure, temperature, and the mean and peak pressure.

7. The internal combustion engine of claim **1**, further comprising a means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston.

8. The internal combustion engine of claim **1**, further comprising a means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston and after compression has begun.

9. In an internal combustion engine having a crankshaft driven by at least one piston moving through at least a compression stroke and an intake stroke aided by combustion taking place within a cylinder, wherein the compression stroke results in the compressing of air within the cylinder, the improvement thereto comprising:

an external compression stage in which a second air charge is compressed outside the cylinder;

a delivery conduit linking said external compression stage to the cylinders, with an intercooler through which said secondary air charge is selectively directed from said external compression stage;

two cylinder intake ports with an intake valve in each port; and

means for directing low pressure air to one of said intake ports during the intake stroke of the piston and for directing highly compressed air to the other of said intake ports during the compression stroke of the piston, wherein one of said intake valves occupies an open position only during a compression stroke of said piston.

10. The engine of claim **9**, wherein the compression stroke results in compressing of air within the cylinder, with means for managing air charge volumes to provide a compression ratio lower than the expansion ratio of the engine.

11. In an internal combustion engine having a crankshaft driven by at least one piston moving through at least a compression stroke and an intake stroke aided by combustion taking place within a cylinder, wherein the compression stroke results in the compressing of air within the cylinder, the improvement thereto comprising:

an external compression stage in which a secondary air charge is compressed outside the cylinder;

delivery conduit linking said external compression stage to the cylinder, with an intercooler through which said secondary air charge is selectively directed from said external compression stage;

two cylinder intake ports with an intake valve in each port;

means for directing low pressure air to one of said intake ports during the intake stroke of the piston and for directing highly compressed air to the other of said intake ports during the compression stroke of the piston; and

a second external compressor in which said low pressure air charge is lightly compressed outside the cylinder and conduit directing said air charge from said second external compressor through an air cooler to a low pressure port of the cylinder during the intake stroke.

12. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, first and second inlet ports communicating between said cylinder and a source of air, and an exhaust port through which air is exhausted from said cylinder;

a piston movably mounted within said cylinder;

an intake valve selectively occluding each said intake port;

an exhaust valve selectively occluding said exhaust port;

means for directing air at a first pressure to said first inlet port and for directing air at a second pressure, different from said first pressure, to said second inlet port during a compression stroke of the piston, wherein one of said intake valves occupies an open position only while the other of said intake valves occupies a closed position.

13. The engine of claim **12**, wherein the compression stroke results in compressing of air within the cylinder, with means for managing air charge volumes to provide a compression ratio lower than the expansion ratio of the engine.

14. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, first and second inlet ports communicating between said cylinder and a source of air, and an exhaust port through which air is exhausted from said cylinder;

a piston movably mounted within said cylinder;

an intake valve selectively occluding each said intake port;

an exhaust valve selectively occluding said exhaust port; and

a first compressor directing air at a first pressure to said first inlet port and a second compressor directing air at a second pressure, different from said first pressure, to said second inlet port during a compression stroke of said piston.

15. The engine of claim **14**, wherein the compression stroke results in compressing of air within the cylinder, with means for managing air charge volumes to provide a compression ratio lower than the expansion ratio of the engine.

16. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, two cylinder inlet ports communicating between said cylinder and a source of air, and an exhaust port through which exhausted gases are expelled through said cylinder;

a piston movably mounted within said cylinder;

an intake valve selectively occluding each inlet port;

an exhaust valve selectively occluding said exhaust port;

at least one compressor in fluid communication via a conduit between said source of air and at least one cylinder inlet port;

at least one air cooler interconnected between said compressor and said inlet port;

means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston; and

a second external compressor in which said low pressure air charge is lightly compressed outside the cylinder and conduit directing said air charge from said second external compressor through an air cooler to a low pressure port of the cylinder during the intake stroke.

17. An internal combustion engine, comprising:

an engine block defining a least one cylinder therein, a first inlet port through which air is introduced to said cylinder, a second inlet port through which air is introduced to said cylinder, and an exhaust port through which exhausted gases are expelled from said cylinder;

a piston movably mounted within said cylinder, said piston moving through at least one intake stroke and one compression stroke;

a first intake valve selectively opening and closing said first inlet port, said first intake valve opening said first inlet port during at least a portion of said intake stroke;

a second intake valve selectively opening and closing said second inlet port, said second intake valve opening said second inlet port during at least a portion of said compression stroke;

an exhaust valve selectively opening and closing said exhaust port;

first conduit communicating said first inlet port to air at a first pressure; and

at least one compressor in fluid communication via a second conduit with said second inlet port, said compressor generating compressed air at least while said second intake valve is open, said second pressure being greater than said first pressure,

whereby air at at least the first pressure is introduced to the cylinder during the intake stroke and air at at least the second pressure is introduced into the cylinder during the compression stroke.

18. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, two cylinder inlet ports communicating between said cyl-

inder and a source of air, and an exhaust port through which exhausted gases are expelled through said cylinder;

a piston movably mounted within said cylinder;

a first intake salve cooperating with a first of said inlet ports and selectively movable between a closed position and an open position;

a second intake valve cooperating with a second of said inlet ports and selectively movable between a closed position and an open position;

an exhaust valve cooperating with said exhaust port;

at least one compressor in fluid communication via a conduit between said source of air and at least said first of said inlet ports; and

wherein said first intake valve occupies its said open position only while said second intake valve occupies its closed position.

19. The internal combustion engine of claim **18**, further comprising means for directing low pressure air to said second of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to said first of said inlet ports during a compression stroke of said piston.

20. The internal combustion engine of claim **18**, further comprising means for directing low pressure air to one of said inlet ports daring an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston and after compression has began.

21. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, two cylinder inlet ports communicating between said cylinder and a source of air, and an exhaust port through which exhausted gases are expelled through said cylinder;

a piston movably mounted within said cylinder;

a first intake valve cooperating with a first of said inlet ports and selectively movable between a closed position and an open position;

a second intake valve cooperating with a second of said inlet ports and selectively movable between a closed position and an open position;

an exhaust valve cooperating with said exhaust port;

at least one compressor in fluid communication via a conduit between said source of air and at least said first of said inlet ports; and

wherein said first intake valve occupies its said open position only during a compression stroke of said piston.

22. The internal combustion engine of claim **21**, further comprising a means for directing low pressure air to said second of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to said first of said inlet ports during a compression stroke of said piston.

23. The internal combustion engine of claim **21**, further comprising a means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston and after compression has begun.

24. An internal combustion engine, comprising:

an engine block defining at least one cylinder therein, two cylinder inlet ports communicating between said cylinder and a source of air, and an exhaust port through which exhausted gases are expelled through said cylinder;

a piston movably mounted within said cylinder;

a first intake salve cooperating with a first of said inlet ports and selectively movable between a closed position and an open position;

a second intake valve cooperating with a second of said inlet ports and selectively movable between a closed position and an open position;

an exhaust valve cooperating with said exhaust port;

at least one compressor in fluid communication via a conduit between said source of air and at least said first of said inlet ports; and

wherein said first intake valve occupies its said open position only after compression has begun during a compression stroke of said piston.

25. The internal combustion engine of claim **24**, further comprising a means for directing low pressure air to said second of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to said first of said inlet ports during a compression stroke of said piston.

26. The internal combustion engine of claim **24**, further comprising a means for directing low pressure air to one of said inlet ports during an intake stroke of the piston and for directing air highly compressed by said compressor to the other of said inlet ports during a compression stroke of said piston and after compression has begun.

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