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Caterpillar Inc. v. Entec Engine Corporation and Clyde C. Bryant

CATERPILLAR INC.'S COMPLAINT FOR DECLARATORY RELIEF

EXHIBIT "A"
Part II

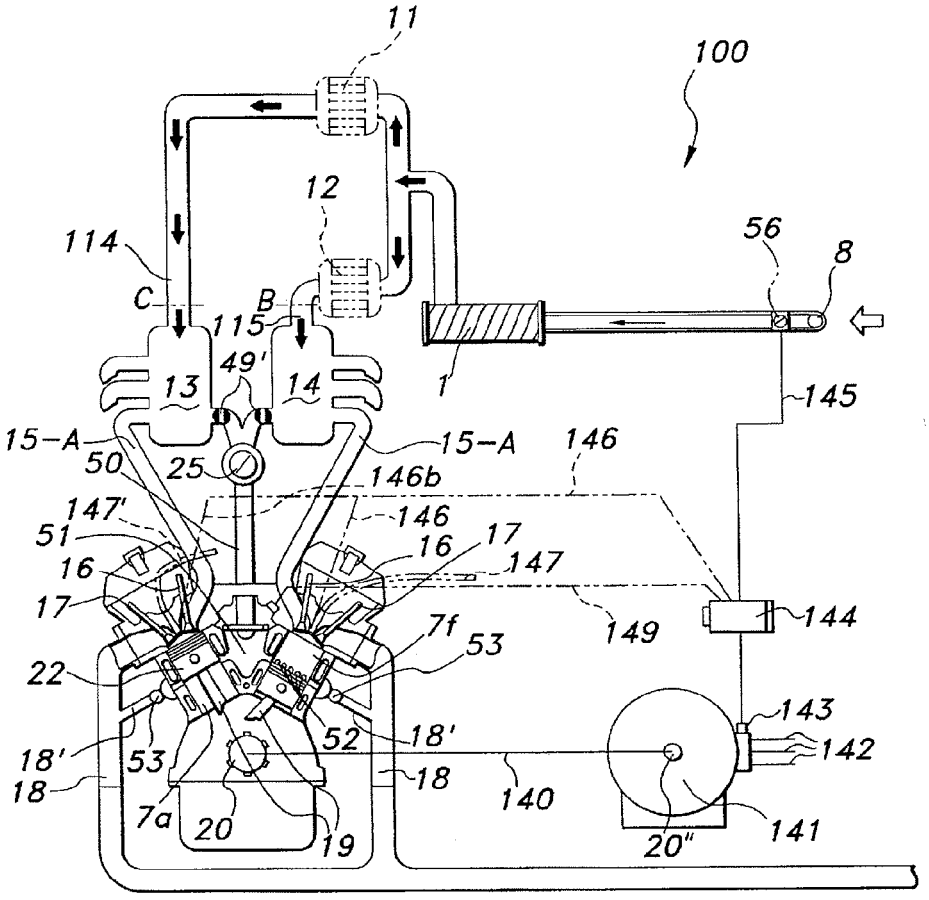

11
100
12
114
56
8
C
B
115
49'
13
14
1'
145
15-A
50
25
15-A
146
146b
147'
146
51
16
17
147
16
17
149
144
7f
53
22
143
52
18'
18'
53
142
18
18
140
7a
20
19
20"
141

FIG 36

INTERNAL COMBUSTION ENGINE

RELATED APPLICATIONS

This application claims the priority of U.S. Provisional Application 60/022,102, filed Jul. 17, 1996; 60/023,460, filed Aug. 6, 1996; 60/029,260, filed Oct. 25, 1996; and 60/040,630, filed Mar. 7, 1997. Furthermore, this application is a continuation-in-part of U.S. application Ser. No. 08/841,488, filed Apr. 23, 1997, abandoned.

This invention relates to a method of deriving mechanical work from combusting gas in an internal combustion engine by means of a new thermodynamic working cycle and to reciprocating internal combustion engines for carrying out the method.

BACKGROUND OF INVENTION

It is well known that as the expansion ratio of an internal combustion engine is increased, more energy is extracted from the combustion gases and converted to kinetic energy and the thermodynamic efficiency of the engine increases. It is further understood that increasing air charge density increases both power and fuel economy due to further thermodynamic improvements. The objectives for an efficient engine are to provide a high-density charge, begin combustion at maximum density and then expand the gases as far as possible against a piston.

Conventional engines have the same compression and expansion ratios, the former being limited in spark-ignited engines by the octane rating of the fuel used. Furthermore, since in these engines the exploded gases can be expanded only to the extent of the compression ratio of the engine, there is generally substantial heat and pressure in the exploding cylinder which is dumped into the atmosphere at the time the exhaust valve opens resulting in a waste of energy and producing unnecessarily high polluting emissions.

Many attempts have been made to reduce the compression ratio and to extend the expansion process in internal combustion engines to increase their thermodynamic efficiency, the most notable one being the "Miller" Cycle engine, developed in 1947.

Unlike a conventional 4-stroke cycle engine, where the compression ratio equals the expansion ratio in any given combustion cycle, the Miller Cycle engine is a variant, in that the parity is altered intentionally. The Miller Cycle uses an ancillary compressor to supply an air charge, introducing the charge on the intake stroke of the piston and then closing the intake valve before the piston reaches the end of the inlet stroke. From this point the gases in the cylinder are expanded to the maximum cylinder volume and then compressed from that point as in the normal cycle. The compression ratio is then established by the volume of the cylinder at the point that the inlet valve closed, being divided by the volume of the combustion chamber. On the compression stroke, no actual compression starts until the piston reaches the point the intake valve closed during the intake stroke, thus producing a lower-than-normal compression ratio. The expansion ratio is calculated by dividing the swept volume of the cylinder by the volume of the combustion chamber, resulting in a more-complete-expansion, since the expansion ratio is greater than the compression ratio of the engine.

In the 2-stroke engine the Miller Cycle holds the exhaust valve open through the first 20% or so of the compression stroke in order to reduce the compression ratio of the engine. In this case the expansion ratio is probably still lower than

the compression ratio since the expansion ratio is never as large as the compression ratio in conventional 2-stroke engines.

The advantage of this cycle is the possibility of obtaining an efficiency higher than could be obtained with an expansion ratio equal to the compression ratio. The disadvantage is that the Miller Cycle has a mean effective pressure lower than the conventional arrangement with the same maximum pressure, but with no appreciable improvements in emissions characteristics.

The Miller Cycle is practical for engines that are not frequently operated at light-loads, because at light-load operation the mean cylinder pressure during the expansion stroke tends to be near to, or even lower than, the friction mean pressure. Under such circumstances the more-complete-expansion portion of the cycle may involve a net loss rather than a gain in efficiency.

This type of engine may be used to advantage where maximum cylinder pressure is limited by detonation or stress considerations and where a sacrifice of specific output is permissible in order to achieve the best possible fuel economy. The cycle is suitable only for engines that operate most of the time under conditions of high mechanical efficiency, that is, at relatively low piston speeds and near full load.

SUMMARY OF THE INVENTION

Briefly described, the present invention comprises an internal combustion engine system (including methods and apparatuses) for managing combustion charge densities, temperatures, pressures and turbulence in order to produce a true mastery within the power cylinder in order to increase fuel economy, power, and torque while minimizing polluting emissions. In its preferred embodiments, the method includes the steps of (i) producing an air charge, (ii) controlling the temperature, density and pressure of the air charge, (iii) transferring the air charge to a power cylinder of the engine such that an air charge having a weight and density selected from a range of weight and density levels ranging from atmospheric weight and density to a heavier-than-atmospheric weight and density is introduced into the power cylinder, and (iv) then compressing the air charge at a lower-than-normal compression ratio, (v) causing a predetermined quantity of charge-air and fuel to produce a combustible mixture, (vi) causing the mixture to be ignited within the power cylinder, and (vii) allowing the combustion gas to expand against a piston operable in the power cylinder with the expansion ratio of the power cylinder being substantially greater than the compression ratio of the power cylinders of the engine. In addition to other advantages, the invented method is capable of producing mean effective [cylinder] pressures ("mep") in a range ranging from lower-than-normal to higher-than-normal. In the preferred embodiments, the mean effective cylinder pressure is selectively variable (and selectively varied) throughout the mentioned range during the operation of the engine. In an alternate embodiment related to constant speed-constant load operation, the mean effective cylinder pressure is selected from the range and the engine is configured, in accordance with the present invention, such that the mean effective cylinder pressure range is limited, being varied only in the amount required for producing the power, torque and speed of the duty cycle for which the engine is designed.

In its preferred embodiments, the apparatus of the present invention provides a reciprocating internal combustion engine with at least one ancillary compressor for compress-

ing an air charge, an intercooler through which the compressed air can be directed for cooling, power cylinders in which the combustion gas is ignited and expanded, a piston operable in each power cylinder and connected to a crankshaft by a connecting link for rotating the crankshaft in response to reciprocation of each piston, a transfer conduit communicating the compressor outlet to a control valve and to the intercooler, a transfer manifold communicating the intercooler with the power cylinders through which manifold the compressed charge is transferred to enter the power cylinders, an intake valve controlling admission of the compressed charge from the transfer manifold to said power cylinders, and an exhaust valve controlling discharge of the exhaust gases from said power cylinders. For the 4-stroke engine of this invention, the intake valves of the power cylinders are timed to operate such that charge air which is equal to or heavier than normal can be maintained within the transfer manifold when required and introduced into the power cylinder during the intake stroke with the intake valve closing at a point substantially before piston bottom dead center position or, alternatively, with the intake valve closing at some point during the compression stroke, to provide a low compression ratio. In some designs another intake valve can open and close quickly after the piston has reached the point the first intake valve closed in order to inject a temperature adjusted high pressure secondary air charge still at such a time that the compression ratio of the engine will be less than the expansion ratio, and so that ignition can commence at substantially maximum charge density. The 2-stroke engine of this invention differs in that the intake valves of the power cylinders are timed to operate such that an air charge is maintained within the transfer manifold and introduced into the power cylinder during the scavenging-compression (the 2nd) stroke at such a time that the power cylinder has been scavenged by low pressure air and the exhaust valve has closed, establishing that the compression ratio of the engine will be less than the expansion ratio of the power cylinders. Means are provided for causing fuel to be mixed with the air charge to produce a combustible gas, the combustion chambers of the power cylinders are sized with respect to the displaced volume of the power cylinder such that the exploded combustion gas can be expanded to a volume substantially greater than the compression ratio of the power cylinder of the engine.

The chief advantages of the present invention over existing internal combustion engines are that it provides a compression ratio lower than the expansion ratio of the engine, and provides, selectively, a mean effective cylinder pressure higher than the conventional engine arrangement with the same or lower maximum cylinder pressure than that of prior art engines.

This allows greater fuel economy, and production of greater power and torque at all RPM, with low polluting emissions. Because charge densities, temperatures and pressures are managed, light-load operation is practical even for extended periods, with no sacrifice of fuel economy. The new working cycle is applicable to 2-stroke or 4-stroke engines, both spark-ignited and compression-ignited. For spark-ignited engines the weight of the charge can be greatly increased without the usual problems of high peak temperatures and pressures with the usual attendant problem of combustion detonation and pre-ignition. For compression-ignited engines, the heavier, cooler, more turbulent charge provides low peak cylinder pressure for a given expansion ratio and allows richer, smoke-limited air-fuel ratio giving increased power with lower particulate and NO_x emissions. Compression work is reduced due to reduced heat transfer during the compression process. Engine durability is improved because of an overall cooler working cycle and a cooler than normal exhaust. It also provides a means of regenerative braking for storing energy for subsequent positive power cycles without compression work and for transient or "burst" power which further increases the overall efficiency of the engine.

All of the objects, features and advantages of the present invention cannot be briefly stated in this summary, but will be understood by reference to the following specifications and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of internal combustion engines according to the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. **1** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine operating in a 4-stroke cycle, and representing a first embodiment of the apparatus of the present invention from which a first method of operation can be performed and will be described. Among its other components, this embodiment is seen as having one ancillary compressor, a cooling system and valves to control charge pressures, density and temperature.

FIG. **2** is a schematic drawing of a six cylinder internal combustion engine, similar to the engine of FIG. **1**, operating in a 4-stroke cycle, and representing a second embodiment of the apparatus of the present invention from which a second method of operation can be performed and will be described. Among its other components, this embodiment is seen as having two compressors, three intercoolers, four control valves, dual air paths for both the primary and the ancillary compressors, dual manifolds and showing a means of controlling charge-air pressures, density and temperatures.

FIG. **3** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine operating in a 4-stroke cycle, and representing a third embodiment of the apparatus of the present invention from which a third method of operation can be performed and will be described.

FIG. **4** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine operating in a 4-stroke cycle, and representing a fourth embodiment of the apparatus of the present invention from which a fourth method of operation can be performed and will be described. Among its other components, this embodiment is seen as having an ancillary compressor, with two charge-air intake ducts and dual intake air routes, one of which is low pressure and one which is high pressure, and both leading to the same power cylinder, a cooling system and valves for controlling charge-air pressures, density and temperature and an ancillary atmospheric air intake system.

FIG. **4**-B is a perspective view (with portions in cross-section) of an engine similar to the engine of FIG. **4** with the exception that there is only one atmospheric air intake which supplies charge-air to the power cylinders at two different pressure levels.

FIG. **4**-C is a schematic view of an exhaust and an air intake system of an engine showing a means of re-burning exhaust gases in order to reduce polluting emissions.

FIG. **5** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder

internal combustion engine operating in a 4-stroke cycle, and representing a fifth embodiment of the apparatus of the present invention from which a fifth method of operation can be performed and will be described. Among its other components, this embodiment is seen as having one atmospheric air intake, an ancillary compressor with two charge-air routes, one of which is low pressure and which has two optional routes, and one which is high pressure, both leading to the same power cylinder, and control valving means and air coolers for varying charge densities, pressures and temperatures in the combustion chamber of the engine.

FIG. **6** is a part sectional view through one power cylinder of the 4-stroke engine of FIG. **4**, FIG. **4**-B, FIG. **5**, FIG. **7** or FIG. **33** at the intake valves showing an alternative method (adaptable to other embodiments of the present invention) of preventing charge-air back flow and of automatically adjusting the charge pressure-ratio of the cylinder during the air charging process.

FIG. **7** is a schematic drawing of a six cylinder, 4-stroke engine representing yet another embodiment of the apparatus of the present invention, from which yet another method of operation can be performed and will be described, and depicting three alternative systems (two in phantom lines) of inducting a low pressure primary air charge. Among its other components, this embodiment is seen as having three air coolers and dual manifolds and the means of controlling the temperature, density and pressure of the charge by an engine control module and by valving variations.

FIG. **8** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine, operating in a 2-stroke cycle, and representing a first 2-stroke embodiment of the apparatus of the present invention from which still another method of operation can be performed and will be described. Among its other components, this embodiment is seen as having a primary and an ancillary compressor, a cooling system and conduits and valves to adjust charge density, temperature and pressure according to the invention.

FIG. **9** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine operating in a 2-stroke cycle, and representing a second 2-stroke embodiment of the apparatus of the present invention from which still another method of operation of can be performed and will be described. Among its other components, this embodiment is seen as having one atmospheric air intake, a primary and an ancillary compressor, with two charge-air routes, one of which is low pressure which has alternate routes, and one of which is high pressure, and both leading to the same power cylinder, and control valving means and air coolers for varying charge densities, pressures and temperatures in the combustion chamber of the engine.

FIG. **9**-B is a schematic drawing of a six cylinder, 2-stroke engine representing yet another embodiment of the apparatus of the present invention, from which yet another method of operation can be performed and will be described, and depicting two alternative systems (one in phantom lines) of inducting a low pressure primary air charge. Among its other components, this embodiment is seen as having three air coolers and dual manifolds and the means of controlling the temperature, density and pressure of the charge by an engine control module and by valving variations.

FIG. **10** is a part sectional view through one power cylinder of the 2-stroke engine of FIG. **9**, at the intake valves, showing an alternative method (adaptable to other embodiments of the present invention) of preventing charge-air back flow during high pressure air charging and showing a pressure balanced valve having a pumped oil/air cooling system.

FIG. **11** is a perspective view (with portions in cross-section) of the cylinder block and head of a six cylinder internal combustion engine operating in a 2-stroke cycle, and representing a third 2-stroke embodiment of the apparatus of the present invention from which still another method of operation of can be performed and will be described. Among its other components, this embodiment is seen as having a primary and an ancillary compressor, a cooling system and conduits and valves to adjust charge density, temperature and pressure and having a single air intake runner for each power cylinder with at least two intake valves arranged in such a manner that one intake valve can operate with timing independent of the other intake valve.

FIG. **12** is a pressure-volume diagram comparing the cycle of the engine of this invention with that of a high-speed diesel engine.

FIG. **13** is a chart showing improvements possible in the engine of this invention in effective compression ratios, peak temperatures and pressures, charge densities and expansion ratios, in comparison with a popular heavy-duty 2-stroke diesel engine.

FIG. **14** is a chart showing improvements possible in the engine of this invention in effective compression ratios, peak temperatures and pressures, charge densities and expansion ratios, in comparison with a popular heavy-duty, 4-stroke diesel engine.

FIG. **15** is a schematic drawing of suggested operating parameters for operation of the engines, both 2-stroke and 4-stroke, of FIGS. **5**–**7** and FIGS. **9**–**10** showing dual intercoolers for the main compressor, a single intercooler for a secondary compressor and a control system and valves for selecting different charge-air paths for light-load operations, and depicting (one in phantom lines) two alternative systems of inducting a low pressure primary air charge.

FIG. **16** shows suggested valve positions for supplying manifolds **13** and **14** with an air charge optimum for medium-load operation for the engines of FIGS. **5**–**7** and FIGS. **9**–**10**. For medium-load operation the shutter valve **5** of compressor **2** would be closed and the air bypass valve **6** would be open to pass the air charge uncooled without compression to the intake of compressor **1** where closed shutter valve **3** and closed air bypass valve **4** directs the air charge now compressed by compressor **1** past the intercoolers to manifolds **13** and **14** with the air compressed and heated by compressor **1**, for medium-load operation.

FIG. **17** shows a suggested scenario for providing the engines of FIGS. **5**–**7** and FIGS. **9**–**10** with a high density air charge for heavy duty, high power output operation. FIG. **17** shows all shutter valves **5** and **3** and all air bypass valves **6** and **4** closed completely so that the primary stage of compression is operative and a second stage of compression is operative and the entire air charge, with the exception of any going through conduit **32** to intake valve **16**-B, is being passed through the intercoolers **10**, **11** and **12** to produce a very high density air charge to manifolds **13** and **14** and to the engines power cylinders for heavy-load operation.

FIG. **18** shows a schematic drawing representing any of the engines of FIG. **3**–FIG. **11**, depicting an alternative type of auxiliary compressor **2'** and a system of providing a means for disabling or cutting out the auxiliary compressor when high charge pressure and density is not needed. For relieving compressor **2'** of work, shutter valve **5** is closed

and air bypass valve is opened so that air pumped through compressor **2'** can re-circulate through compressor **2'** without requiring compression work.

FIG. **19** is a schematic drawing representing the engines shown in FIGS. **5–7** and FIGS. **9–10** and having two compressors, and one intercooler for one stage of compression, dual intercoolers for a second stage of compression, dual manifolds, four valves and an engine control module (ECM) and illustrating means of controlling charge-air density, pressure and temperature by varying directions and amounts of air flow through the various electronic or vacuum operated valves and their conduits.

FIG. **20** is a schematic drawing showing optional electric motor drive of the air compressors of the engines of FIG. **1** through FIG. **11**.

FIG. **21** is a schematic transverse sectional view of a pre-combustion chamber, a combustion chamber and associated fuel inlet ducts and valving suggested for gaseous or liquid fuel operation for the engines of this invention or for any other internal combustion engine.

FIG. **22** is a part sectional view through one cylinder of an engine showing an alternate construction whereby there is supplied two firing strokes each revolution of the shaft for a 2-stroke engine and one firing stroke each revolution of the shaft for a 4-stroke engine, having a beam which pivots on its lower extremity, a connecting rod which is joined midpoint of the beam and is fitted to the crankshaft of the engine, and whereby a means is provided for varying the compression ratio of the engine at will.

FIG. **23** is a part sectional view through one cylinder of an engine showing an alternate construction whereby there is supplied two firing strokes each crankshaft revolution for a 2-stroke engine and one firing stroke each revolution of the shaft for a 4-stroke engine, and whereby the beam connecting the connecting rod and the piston pivots at a point between the piston and the piston connecting rod, which connecting rod is attached to the crankshaft of the engine, and an alternate preferred means of power take-off from the piston by a conventional piston rod, cross-head and connecting rod arrangement.

FIG. **24** is a part sectional view through one cylinder of an engine showing a means of providing extra burn-time each firing stroke in a 2-stroke or 4-stroke engine.

FIG. **25** is a perspective view of the cylinder block and head of a six cylinder internal combustion engine operating in a 2-stroke cycle and representing a yet another embodiment of the apparatus of the present invention from which still another method of operation of can be performed and will be described. Among its other components, this embodiment is seen as having scavenging ports in the bottom of the piston sleeves and having a primary and an ancillary compressor, a cooling system, valves and conduits to control the pressure, density and temperature of the charge-air, and valves and conduits to supply scavenging air to the cylinders.

FIG. **26** is a schematic drawing of an engine similar to the engine of FIG. **25** showing one intercooler for one optional stage of compression, dual intercoolers for a primary compression stage and showing a control system (including engine control module (ECM) and valving) for controlling charge-air density, weight, temperature and pressure by controlling directions and amounts of air flow through the various valves, conduits and an optional throttle valve, and showing two optional routes for supplying scavenging air to the scavenging ports in the bottom of the cylinders, and alternative routes for the exhausted gases to exit the engine.

FIG. **27** through FIG. **30** are schematic drawings of the engine of FIG. **25** and FIG. **26** showing four alternate methods suggested for efficient scavenging of the engines, FIG. **27** and FIG. **28** also show a schematic drawing for an engine control module (ECM) and valving to control charge-air and scavenging air at a pressure, density and temperature deemed appropriate for each.

FIG. **31** is a schematic drawing showing suggested optional electric motor drive for the engine's air compressors.

FIG. **32** is a schematic drawing of the 2-stroke engine of FIG. **25** and FIG. **26**, having only one compressor for supplying both charge-air and scavenging air, and showing a control system and means of controlling charge and scavenging air at a pressure, density and temperature deemed appropriate for each, and showing means of channeling the air through different paths for the same purpose;

FIG. **33** is a schematic transverse sectional view through a six cylinder engine having two compressor cylinders, four power cylinders, one supercharger, five regulatory valves, and showing an engine control module (ECM) for controlling charge temperatures, density and weight, and adopted for storage of compressed air compressed by regenerative braking, or for storage of bleed-air produced in some industrial processes, in any of the engines of this invention.

FIG. **34** is a schematic drawing representing any of the engines of the present invention and showing an alternate embodiment which includes a separate, electric-powered air compressor and, alternatively, an entrance conduit leading from a supply of waste or "bleed" compressed air for supplying charge-air to the engine (or to a plurality of engines), whereby the need for engine-powered compressors is eliminated.

FIG. **35** is a schematic drawing representing any of the engines of the present invention depicted in an alternate embodiment which is configured to operate as a constant load and constant speed engine. This constant load and constant speed engine embodiment of the present invention is shown as including both a primary and an ancillary compressor with optional intercoolers for providing two stages of pre-compressed charge-air, either optionally intercooled or adiabatically compressed.

FIG. **36** is a schematic drawing representing any of the engines of the present invention, and depicting a constant load and constant speed engine in accordance with an alternate embodiment of the present invention in which there is provided a single compressor with optional intercoolers for providing a single stage of pre-compressed charge-air, either optionally intercooled or adiabatically compressed.

DETAILED DESCRIPTION OF THE DRAWINGS

With reference now in greater detail to the drawings, a plurality of alternate, preferred embodiments of the apparatus of the Improved Internal Combustion Engine **100** of the present invention are depicted. Like components will be represented by like numerals throughout the several views; and, in some but not all circumstances, as the writer might deem necessary (due to the large number of embodiments), similar but alternate components will be represented by superscripted numerals (e.g., **100'**). When there are a plurality of similar components, the plurality is often times referenced herein (e.g., six cylinders **7***a*–**7***f*), even though fewer than all components are visible in the drawing. Also, components which are common among multiple cylinders are sometimes written with reference solely to the common numeral, for ease of drafting—e.g. piston **22***a*–**22***f*=> piston

22. In an effort to facilitate the understanding of the plurality of embodiments, (but not to limit the disclosure) some, but not all, sections of this Detailed Description are sub-titled to reference the system or sub-system detailed in the subject section.

The invented system of the present invention is, perhaps, best presented by reference to the method(s) of managing combustion charge densities, temperatures, pressures and turbulence; and the following description attempts to describe the preferred methods of the present invention by association with and in conjunction with apparatuses configured for and operated in accordance with the alternate, preferred methods.

Some, but not necessarily all, of the system components that are common to two or more of the herein depicted embodiments include a crankshaft **20**, to which are mounted connecting rods **19***a*–**1** **9***f*, to each of which is mounted a piston **22***a*–**22***f*; each piston traveling within a power cylinder **7***a*–**7***f*; air being introduced into the cylinders through inlet ports controlled by intake valves **16**, and air being exhausted from the cylinders through exhaust ports controlled by exhaust valves **17**. The interaction, modification and operation of these and such other components as are deemed necessary to an understanding of the various embodiments of the present invention are expressed below.

The Engine **100**[1] of FIG. **1**

Referring now to FIG. **1**, there is shown a six cylinder reciprocating internal combustion engine **100**[1] in which all of the cylinders **7***a*–**7***f* (only one of which is shown in a sectional view) and associated pistons **22***a*–**22***f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. An ancillary compressor **2** (herein depicted as a Lysholm rotary compressor) selectably supplies air which has been compressed, or allows delivery of air therethrough at atmospheric pressure, to manifolds **13** and **14** and to cylinders **7***a*–**7***f*, which cylinders operate in a 4-stroke cycle. Valves **3**, **5** and **6** and intercoolers **10**, **11** and **12** are used, in the preferred embodiments, to control air charge density, weight, temperature and pressure. The intake valves **16***a*–**16***f*, **16***a*'–**16***f* are timed to control the compression ratio of the engine **100**'. The combustion chambers are sized to establish the expansion ratio of the engine.

The engines **100**[1]–**100**[5], **100**[7] of FIG. **1**, FIG. **2**, FIG. **3**, FIG. **4**, FIG. **5**, and FIG. **7**, respectively, have camshafts **21** fitted with cams and are arranged to be driven at one-half the speed of the crankshaft in order to supply one power stroke for every two revolutions of the crankshaft, for each power piston. The rotary compressors **2** of FIG. **1**, FIG. **2**, FIG. **3**, FIG. **4**, FIG. **4**-B, FIG. **5**, FIG. **7** and FIG. **33** can be driven by a ribbed V-belt and would have a step-up gear between the V pulley and the compressor drive shaft, the rotary compressors could also be fitted with a variable-speed step-up gear as in some aircraft engines. The reciprocating compressor **1** of FIG. **3** is shown as having double-acting cylinders linked to the crankshaft **20** by a connecting rod **19***g*; and the crankshaft **20** to which it is linked by connecting rod **19***g* would supply two working strokes for each revolution of the crankshaft **20**. In one alternate approach, the reciprocating compressor **1** is driven by the connecting rod **19***g* being connected to a short crankshaft above the main crankshaft **20** to which the ancillary crankshaft (not shown) would be geared by a step-up gear in order to provide more than two working strokes per revolution of the main crankshaft **20**. Alternatively, the compressor system can have multiple stages of compression for either rotary or reciprocating compressors. Whereas, the ancillary compressor **1** and second ancillary compressor **2** of the various embodiments are depicted throughout as a reciprocating compressor or a rotary compressor, it is noted that the invention is not limited by the type of compressor utilized for each; and the depicted compressors may be interchanged, or may be the same, or may be other types of compressors performing the functions described herein.

The engine **100**[1] shown in FIG. **1** is characterized by a more extensive expansion process, a low compression ratio and the capability of producing a combustion charge varying in weight from lighter-than-normal to heavier-than-normal, and capable of providing, selectively, a mean effective cylinder pressure higher than can the conventional arrangement of normal engines but capable of having a lower maximum cylinder pressure in comparison to conventional engines. An engine control module (ECM) (not shown in FIG. **1**) and variable valves **3**, **5** and **6** on conduits, as shown, provide a system for controlling the charge density, pressure, temperature, and the mean and peak pressure within the cylinder which allows greater fuel economy, production of greater torque and power at low RPM, with low polluting emissions for both spark and compression-ignited engines. In alternate embodiments, a variable valve timing system can be used and, with a control system such as an ECM, can control the time of opening and the time of closing of the intake valves **16** and **16**' to further provide an improved management of conditions in the combustion chambers of cylinders **7***a*–**7***f* of the engine **100**[1] to allow for a flatter torque curve and higher power, when needed, and with low levels of both fuel consumption and polluting emissions.

Brief Description of Operation of the Engine **100**[1] shown in FIG. **1**

The engine **100**[1] of this invention shown in FIG. **1** is a high efficiency engine that attains both high power and torque with low fuel consumption and low polluting emissions. The new working cycle is an external compression type combustion cycle. In this cycle, part of the intake air (all of which is compressed in the power cylinders in conventional engines) is, selectively, compressed by at least one ancillary compressor **2**. The temperature rise during compression can be suppressed by use of air coolers **10**, **11**, **12** which cool the intake air, and by a shorter compression stroke.

One suggested, preferred method of operation of the new-cycle engine **100**[1] is thus:

1. Depending upon the power requirements of the engine (e.g., differing load requirements), either intake air at atmospheric pressure or intake air that has been compressed by at least one ancillary compressor **2** and has had its temperature and pressure controlled by bypass systems and charge-air coolers, is drawn into the power cylinder **7** by the intake stroke of piston **22**.
2. (a) After the intake stroke is complete, the intake valve **16** (which can be single or multiple, **16**, **16**') is left open for a period of time after the piston **22** has passed bottom dead center, which pumps part of the fresh air charge back into the intake manifold **13**, **14**. The intake valve **16**, **16**' is then closed at a point which action seals the cylinder **7**, thus establishing the compression ratio of the engine.

   (b) Alternatively, the intake valve **16**, **16**' is closed early, during the intake stroke, before the piston **22** has reached bottom dead center. The trapped air charge is then expanded to the full volume of the cylinder **7** and

compression of the charge starts when the piston **22** returns to the point in the compression stroke at which the intake valve **16**, **16'** closed.

3. (a) During the compression stroke of piston **22**, at the point the intake valve **16** closed, either in **2**(*a*) or **2**(*b*) operation, compression begins, producing a small compression ratio. This makes it possible to restrain the temperature rise during the compression stroke.

   (b) During light-load operation, such as in vehicle cruising or light-load power generation, the shutter valve **5** is closed and the air bypass valve (ABV) **6** on the compressor is, preferably opened so that the intake air is returned to the intake conduit **8** of the compressor **2** without being compressed. Shutter valve **3** can then direct the air charge around or through intercoolers **11** and **12**. During this time, the engine pistons **22***a*–**22***f* are drawing in naturally aspirated air through the compressor **2**. This reduces compressor drive work and improves fuel economy.

   (c) When more power is required, the charge density and pressure can be increased by closing air bypass valve (ABV) **6** causing compressor **2** to raise the air pressure and, alternatively, this can be accomplished by either cutting in a second stage of compression by compressor **1**, as shown in FIG. **2**, or by increasing the speed of compressor **2**. At the same time, control valves **5** and **3** preferably, direct some or all of the air charge through one or more of intercoolers **10**, **11**, and **12** in order to increase charge-air density.

4. Compression continues, fuel is added, if not already present, the charge is ignited and combustion produces a large expansion of the gases against the piston **22** producing great energy in either mode **3**(*a*), (*b*) or (*c*). This energy produces a high mean effective cylinder pressure and is converted into high torque and power, especially in mode (c).

Detailed Description of Operation of the Engine **100**[1] of FIG. **1**

During the intake (1st) stroke of the piston **22** air flows through air conduits **15** from a manifold of air **13** or **14**, which air (depending on power requirements) is either at atmospheric pressure or has been compressed to a higher pressure by compressor **2**, through the intake valve **16** into the cylinder **7**. During the intake stroke of piston **22** the intake valve **16** closes early (at point x). From this point, the cylinder **7** contents are expanded to the maximum volume of the cylinder. Then, during the compression (2nd) stroke, no compression takes place until the piston **22** has returned to the point x where the intake valve **16** was closed during the intake stroke. (At point x, the remaining displaced volume of the cylinder is divided by the volume of the combustion chamber, to establish the compression ratio of the engine.) Alternatively, during the intake (1st) stroke of piston **22**, the intake valve **16** is held open through the intake stroke and past bottom dead center piston position, and through part of the compression (2nd) stroke for a significant distance, 10% or, to perhaps 50% or more of the compression stroke, thus pumping some of the charge-air back into intake manifold **13** or **14**, and the intake valve **16** then closes to establish a low compression ratio in the cylinders of the engine. At the time of closure of intake valve **16**, the density, temperature and pressure of the cylinder will be at approximate parity with the manifold **13** or **14** contents.

During light-load operation, such as in vehicle cruising or light-load power generation, the shutter valves **5** and **3** are closed and the air bypass valve (ABV) **6** on the compressor is, preferably, opened so that the intake air is returned to the intake conduit **8** of the compressor **2** without being compressed. During this time the engine pistons **22***a*–**22***f* are drawing in naturally aspirated air through the compressor **2**. This reduces compressor drive work and improves fuel economy.

When medium torque and power is needed, such as highway driving or medium electric power generation, preferably the shutter valve **5** to compressor **2** is closed and the air bypass valve (ABV) **6** is closed also. This causes the atmospheric pressure intake air to cease re-circulating through the compressor **2** and the compressor **2** begins to compress the charge-air to a higher-than-atmospheric pressure, while the closed shutter valves **5** and **3** direct the charge-air through conduits **104**, **110**, **111**, and **121/122** bypassing the air coolers **10**, **11** and **12**, with the charge-air going directly to the manifolds **13** and **14** to power cylinders **7***a*–**7***f* where the denser, but hot, charge increases the mean effective cylinder pressure of the engine to create greater torque.

When more power is needed, such as when rapid acceleration is needed or for heavy-load electric power generation, preferably the air bypass valve (ABV) **6** is closed and the shutter valves **3** or **5** or both are opened. This causes the compressor **2** to compress all of the air charge. Shutter valves **3** or **5** or both then supply (depending on the respective opened/closed conditions of valves **3** and **5**), the conditioned air charge through conduits **105** or **104**, to conduit **1** **10**, and then through conduits **111** or **112** to the manifolds, **13**, **14** and to the cylinders **7***a*–**7***f* via one, two, or all three of the charge coolers **10**, **11** and **12**. The very dense cooled air charge when mixed with fuel and ignited and expanded beyond the compression ratio of the engine produces great torque and power.

When greater power is needed the charge-air density and weight can be increased by increasing the speed of the compressor **2** or by cutting in a second compressor as in FIG. **2**, for a second stage of pre-compression. The latter can be done by the engine control module **27** signaling air bypass valve (ABV) **6**, FIG. **2**, to close to prevent re-circulation of part of the intake air into conduit **103** which negates, selectively, any second compression stage during light-load operation. At the time air density and pressure is increased, shutter valves **3** and **5** can direct part of all of the air charge through intercoolers **10**, **11** and **12** in order to condense the charge and lessen the increase in the charge temperature and pressure, both accomplished by the cooling of the charge. This increases the mean effective cylinder pressure during combustion for high torque and power.

The heavier the weight of the air charge and the denser the charge, the earlier in the intake stroke (or the later in the compression stroke) the intake valve can be closed to establish a low compression ratio and retain power, and the less heat and pressure is developed during compression in the cylinder. In this 4-stroke engine the intake charge can be boosted in pressure by as much as 4–5 atmospheres and if the compression ratio is low enough, say 4:1 to 8:1 (higher for diesel fuel), even spark-ignited there would be no problem with detonation. The expansion ratio should still be large, 14:1 would be a preferred expansion ratio for spark ignition, perhaps 19:1 for diesel operation.

The compression ratio is established by the displaced volume of the cylinder **7** remaining after point x has been reached in the compression stroke (and intake valve **16** is closed) being divided by the volume of the combustion

chamber. The expansion ratio in all cases is greater than the compression ratio. The expansion ratio is established by dividing the total displaced volume of the cylinder by the volume of the combustion chamber.

Fuel can be carbureted, or it can be injected in a throttle-body **56** (seen in FIG. **16**), or the fuel can be injected into the inlet stream of air, injected into a pre-combustion chamber (FIG. **21**) or, injected through the intake valve **16**, or it may be injected directly into the combustion chamber. If injected, it should be at or after the piston **22** has reached point x and the intake valve is closed. The fuel can also be injected later, similar to diesel operation, and can be injected at the usual point for diesel oil injection, perhaps into a pre-combustion chamber or directly into the combustion chamber or directly onto a glow plug. Some fuel can be injected after top dead center even continuously during the first part of the expansion stroke for a mostly constant pressure combustion process.

Ignition can be by compression (which may be assisted by a glow plug), or by electric spark. Spark ignition can take place before top dead center, as normally done, at top dead center or after top dead center.

At an opportune time the air-fuel charge is ignited and the gases expand against the piston for the power (3rd) stroke. Near bottom dead center at the opportune time exhaust valve(s) **17** open and piston **22** rises in the scavenging (4th) stroke, efficiently scavenging the cylinder by positive displacement, after which exhaust valve(s) **17** closes.

This completes one cycle of the 4-stroke engine.

The Engine **100²** of FIG. **2**

Referring now to FIG. **2**, there is shown a six cylinder reciprocating internal combustion engine **1002** in which all of the cylinders **7***a*–**7***f* (only two **7***a*, **7***f* of which are shown in a schematic drawing) and associated pistons **22***a*–**22***f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. An ancillary compressor **2** (herein depicted as a rotary compressor) supplies air which has been compressed, or allows delivery of air therethrough at atmospheric pressure, to manifolds **13** and **14** and to cylinders **7***a*–**7***f* which cylinders operate in a 4-stroke cycle. A second ancillary compressor **1** is used, selectively, to boost the air pressure to compressor **2**. Valves **3**, **4**, **5** and **6** and intercoolers **10**, **11** and **12** are used, in the preferred embodiments, to control air charge density, weight, temperature and pressure. The intake valves **16***a*–**16***f* are timed to control the compression ratio of the engine **100²**. The combustion chambers are sized to establish the expansion ratio of the engine.

The engine **100²** shown in FIG. **2** is characterized by a more extensive expansion process, a low compression ratio and the capability of producing a combustion charge varying in weight from lighter-than-normal to heavier-than-normal, and capable of selectively providing a mean effective cylinder pressure higher than can the conventional arrangement of normal engines but having similar or lower maximum cylinder pressure in comparison to conventional engines. An engine control module (ECM) **27** and variable valves **3**, **4**, **5** and **6** on conduits, as shown, provide a system for controlling the charge density, pressure, temperature, and the mean and peak pressure within the cylinder which allows greater fuel economy, production of greater torque and power at low RPM, with low polluting emissions for both spark and compression-ignited engines. In alternate embodiments, a variable valve timing system can be used and, with a control system such as an engine control module (ECM) **27**, can control the time of opening, and the time of closing of the intake valves **16** to further provide an improved management of conditions in the combustion chambers of cylinders **7***a*–**7***f* of the engine **100²** to allow for a flatter torque curve and higher power, and with low levels of both fuel consumption and polluting emissions.

Brief Description of Operation of the Engine **100²** of FIG. **2**

The engine **100²** of this invention shown in FIG. **2** is a high efficiency engine that attains both high power and torque with low fuel consumption and low polluting emissions. The new working cycle is an external compression type combustion cycle. In this cycle, part of the intake air (all of which is compressed in the power cylinders in conventional engines) is compressed, selectively, by at least one ancillary compressor **1**, **2**. The temperature rise during compression can be suppressed by use of air coolers **10**, **11**, **12**, which cool the intake air, and by a shorter compression stroke.

One suggested, preferred method of operation of the new-cycle engine **100²** is thus:

1. Depending upon the power requirements of the engine (e.g., differing load requirements), either intake air at atmospheric pressure or intake air that has been compressed by at least one ancillary compressor and has had its temperature and pressure adjusted by bypass systems and charge-air coolers, is drawn into the power cylinder **7** by the intake stroke of piston **22**.
2. (a) After the intake stroke is complete, the intake valve **16** (which can be single or multiple) is left open for a period of time after the piston **22** has passed bottom dead center which pumps part of the fresh air charge back into the intake manifold **13**, **14**. The intake valve **16** is then closed at a point which action seals cylinder **7**, thus establising the compression ratio of the engine.
   (b) Alternatively, the intake valve **16** is closed early, during the intake stroke, before the piston **22** has reached bottom dead center. The trapped air charge is then expanded to the full volume of the cylinder **7** and compression of the charge starts when the piston **22** reaches the point in the compression stroke at which the intake valve **16** closed.
3. (a) During the compression stroke of piston **22**, at the point the intake valve **16** closed, either in 2(a) or 2(b) operation, compression begins, producing a small compression ratio. This makes it possible to lessen the temperature rise during the compression stroke.
   (b) During light-load operation, such as in vehicle cruising or light-load power generation, the shutter valves **3** and **5** are closed and the air bypass valves (ABV) **4** and **6** to both compressors **1** and **2** are, preferably, opened so that the intake air is returned to the intake conduits **110** and **103** of the compressors **2** and **1** without being compressed. During this time, the engine pistons **22***a*–**22***f* are drawing in naturally aspirated air past the compressor(s). This reduces compressor drive work and further improves fuel economy.
   (c) When greater power is required, the charge density and pressure can be increased by closing air bypass valve (ABV) **4** causing compressor **2** to raise the charge-air pressure and, in addition, by either cutting in the second stage of compression by compressor **1** in the same manner, that of closing air bypass valve ABV **6**, or by increasing the speed of compressor **2** or of both com-

pressors. At the same time, shutter valves **3** and **5** would be opened to direct some or all of the air charge through intercoolers **10**, 11 and **12** in order to increase charge-air density.

4. Compression continues, fuel is added if not already present, the charge is ignited and combustion produces a large expansion of the gases against piston **22** producing great energy in either mode 3(a), (b) or (c). This energy produces a high mean effective cylinder pressure and is converted into high torque and power, especially in mode (c).

Detailed Description of Operation of the Engine **100**[2] of FIG. **2**

During the intake (1st) stroke of the piston **22** air flows through air conduits **15** from the manifold **13** or **14** of air which air (depending on power requirements) is either at atmospheric pressure or has been compressed to a higher pressure by compressor **2** and/or compressor **1**, through the intake valve **16** into the cylinder **7**. During the intake stroke of piston **22** the intake valve **16** closes at point x sealing cylinder **7**. From this point the air charge is expanded to the maximum volume of the cylinder. Then during the compression (2nd) stroke, no compression takes place until the piston **22** has returned to the point x where the intake valve **16** was closed during the intake stroke. (At point x, the remaining displaced volume of the cylinder is divided by the volume of the combustion chamber, to establish the compression ratio of the engine.) Alternatively, during the intake (1st) stroke of piston **22**, the intake valve **16** is held open through the intake stroke and passed bottom dead center, and through part of the compression (2nd) stroke for a significant distance, 10% or, to perhaps 50% or more of the compression stroke, thus pumping some of the charge-air back into intake manifold **13** or **14**, and the intake valve **16** then closes, sealing cylinder **7**, to establish a low compression ratio in the cylinders of the engine. At the time of closure of intake valve **16**, the density, temperature and pressure of the cylinder **7** contents will be approximately the same as that of the air charge in the intake manifolds **13** and **14**.

During light-load operation, such as in vehicle cruising or light-load power generation, the shutter valves **3** and **5** are closed and the air bypass valves (ABV) **4** and **6** to both compressors **1** and **2** are, preferably opened so that the intake air is returned to the intake conduits **110** and **103** of the compressors **2** and **1** without being compressed. During this time the engine pistons **22***a*–**22***f* are drawing in naturally aspirated air past the compressor(s). This reduces compressor drive work and further improves fuel economy.

When medium torque and power is needed, such as highway driving or medium electric power generation, preferably the shutter valves **3** and **5** are closed and the air bypass valves (ABV) **4** and **6** are closed. This causes the atmospheric pressure intake air to cease re-circulating through the compressor **2** and **1** and both compressors begin to compress the charge-air to a higher-than-atmospheric pressure, while the closed shutter valves **3** and **5** direct the charge-air through conduits **104**, **110**, 111, and **121**/**122** bypassing the air coolers **10**, **11** and **12**, in FIG. **2**, with the charge-air going directly to the manifold **13** and **14** and to power cylinders *7a–7f* where the denser, but hot, charge increases the mean effective cylinder pressure of the engine to create greater torque and power.

When more power is needed, such as when rapid acceleration is needed or for heavy-load electric power generation, preferably the air bypass valve (ABV) **4** is closed and the shutter valve **3** is opened. This causes the compressor **2** to compress all of the air charge and shutter valve **3** directs the air charge through conduits **112** and **113** and the compressed charge-air is supplied to the manifolds **13** and **14** and to the cylinders *7a–7f* via the charge coolers **11** and **12**. For even greater power the shutter valve **5** is opened and the air bypass valve **6** is closed and compressor **1** begins a second stage of compression, and all of the air charge is now directed through intercoolers **10**, **11** and **12** for high charge density. The very dense cooled air charge when mixed with fuel and ignited and expanded beyond the compression ratio of the engine produces great torque and power.

The heavier the weight of the air charge and the denser the charge, the earlier (or later) the intake valve can be closed to establish a low compression ratio and retain power, and the less heat and pressure is developed during compression in the cylinder. In this 4-stroke engine the intake charge can be boosted in pressure by as much as 4–5 atmospheres and if the engine's compression ratio is low enough, say 4:1 to 8:1 (higher for diesel fuel), even spark-ignited there would be no problem with detonation. The expansion ratio would still be very large, 14:1 would be a preferable expansion ratio for spark ignition, perhaps 19:1 for diesel operation.

The compression ratio is established by the displaced volume of the cylinder **7** remaining after point x has been reached in the compression stroke (and intake valve **16** is closed) being divided by the volume of the combustion chamber. The expansion ratio in all cases is greater than the compression ratio. The expansion ratio is established by dividing the total displaced volume of the cylinder by the volume of the combustion chamber.

Fuel can be carbureted, or it can be injected in a throttle-body **56** (seen in FIG. **16**), or the fuel can be injected into the inlet stream of air, injected into a pre-combustion chamber as in FIG. **21** or, injected through the intake valve **16**, or it may be injected directly into the combustion chamber. If injected, it should be at or after the piston **22** has reached point x and the intake valve is closed. The fuel can also be injected later and in the case of diesel operation can be injected at the usual point for diesel oil injection, perhaps into a pre-combustion chamber or directly into the combustion chamber or directly onto a glow plug.

At an opportune time the air-fuel charge is ignited and the gases expand against the piston for the power (3rd) stroke. Near bottom dead center at the opportune time exhaust valve(s) **17** open and piston **22** rises in the scavenging (4th) stroke, efficiently scavenging the cylinder by positive displacement, after which the exhaust valve(s) closes.

This completes one cycle of the 4-stroke engine.

The Engine **100**[3] of FIG. **3**

Referring now to FIG. **3**, there is shown a six cylinder reciprocating internal combustion engine **100**[3] in which all of the cylinders *7a–7f* (only one of which is shown in a sectional view) and associated pistons *22a–22f* operate in a 4-stroke cycle and all power cylinders are used for producing power to a common crankshaft **20** via connecting rods *19a–19f*, respectively. An ancillary reciprocating compressor **1** and an ancillary rotary compressor **2** supply pressurized charge air which has been compressed, or allow deliver of air therethrough at atmospheric pressure, to manifolds **13**, **14** and to cylinders *7a–7f*, which cylinders operate in a 4-stroke cycle. Valves **3**, **4**, **5** and **6** and intercoolers **10**, **11** and **12** are used, in the preferred embodiments, to control air charge density, weight, temperature and pressure. The intake