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valves **16** are timed to control the compression ratio of the engine **100**^{3}. The combustion chambers are sized to establish the expansion ratio of the engine.

The engine **100**^{3} shown in FIG. **3** 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-thannormal, 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 power cylinder **7** which allows greater fuel economy, 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 **100**^{3} to allow for a flatter torque curve and high power and with low levels of both fuel consumption and polluting emissions.

Brief Description of Operation of the Engine **100**^{3} of FIG. **3**

The engine **100**^{3} of this invention shown in FIG. **3** 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 **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 **100**^{3} 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, **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 manifolds **13**, **14**. The intake valve **16** is then closed at a point which seals cylinder **7**, thus establishing 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** on both compressors **1** and **2** are, preferably, opened so that the intake air is returned to the intake conduits **110** and **8** of the compressors **1** and **2** without being compressed. During this time the by 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 **1** to raise the charge-air pressure and, in addition, by either cutting in the second stage of compression by compressor **2**, if needed, in the same manner, that of closing ABV valve **6**, or by increasing the speed of compressors **1** or **2**, or both. At the same time, shutter valves **3** and **5** would 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**^{3} of FIG. **3**

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 **1** or **2** through the intake valve **16** into the cylinder **7**. During the intake stroke of piston **22** the intake valve **16** closes (at point x). From this point the cylinder 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, sealing the cylinder **7**, 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** can be held open through the intake stroke passed bottom dead center, and through part of the compression (2nd) stroke for a significant distance, 10% to perhaps 50% or more of the compression stroke pumping some of the charge-air back into intake manifold, and the intake valve **16**, **16'** then closes to establish a low compression ratio in the cylinders of the engine.

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** on both compressors **1** and **2** are, preferably, opened so that the intake air is returned to the intake conduits **110** and **8** of the compressors **1** and **2** 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, pref-

erably the shutter valve **3** to compressor **1** is opened, the air bypass valve (ABV) **4** is closed and ABV **6** remains open. This causes the atmospheric pressure intake air to cease re-circulating through the compressor **1**; and the compressor **1**, alone, begins to compress the charge-air to a higher-than-atmospheric pressure, while the closed shutter valves **3** and **5** directs the charge-air through conduits **104, 110, 111,** and **121/122** bypassing the air coolers **10, 11** and **12**, in FIG. **3**, with the charge-air going directly to the manifolds **13** and **14** and to power cylinders **7***a*–**7***f* where the denser heated 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 valves (ABV) **4** and **6** are closed and the shutter valves **3** and **5** are opened on both compressors. This causes the compressors **1** and **2** to compress all of the air charge and shutter valves **3** and **5** direct the air charge away from conduit **8** and through the compressors **1** and **2**, and the compressed charge-air is then supplied through conduits **105, 106, 110, 112, 113, 114** and **115** to the manifolds **13** and **14** and to the cylinders **7***a*–**7***f* via 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.

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 would still be very 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 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, 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 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 the piston **22** 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 **100**^{4} of FIG. **4**

Referring now to FIG. **4**, there is shown a six cylinder reciprocating internal combustion engine **100**^{4} having two atmospheric air intakes **8** and **9** and corresponding intake conduits **15**-A, **15**-B, in which all of the cylinders (only one (**7**) of which is shown in a sectional view) **7***a*–**7***f* 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. A compressor **2**, in this figure a Lysholm type rotary compressor, is shown which, with air conduits as shown, supplies pressurized air to one or more cylinder intake valves **16**-A. An air inlet **8** and an ancillary air inlet **9** and inlet conduits **15**-A, **15**-B selectably supply air charge at atmospheric pressure or air which has been compressed to a higher pressure to separate intake valves **16**-A and **16**-B opening to the same cylinder **7***a*–**7***f* (for example, shown here opening to cylinder **7***f*). Intercoolers **10, 11** and **12** and control valves **3, 5** and **6** are used, in the preferred embodiments, to control the air charge density, weight, temperature and pressure. The intake valves **16***a*-B–**16***f*-B which receive air through manifold **14**-B and intake conduits **15***a*-B to **15***f*-B, are timed to control the compression ratio of the engine **100**^{4}. The combustion chambers are sized to establish the expansion ratio of the engine. Because of noticeable similarities between the engine **100**^{4} of FIG. **4** and that of FIG. **7** (where the auxiliary air inlet **9** system has been shown in phantom, for informational value), reference will be made as deemed helpful to FIG. **7** for certain common components.

The engine **100**^{4} shown in FIG. **4** is characterized by a more extensive expansion process, a low compression ratio and capable 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 in normal engines with similar or lower maximum cylinder pressure in comparison to conventional engines. Engine control module (ECM) **27** (refer, for example to FIG. **7**) and variable valves **3, 5,** and **6** on conduits, as shown, provide a system for controlling the charge pressure, density, temperature, and mean and peak pressure within the cylinder which allows greater fuel economy, production of greater power and torque at all RPM, with low polluting emissions for both spark and compression ignited engines. In alternate embodiments, a variable valve timing system with the ECM **27** can also control the time of opening and closing of the intake valves **16**-A and/or **16**-B, to further provide an improved management of conditions in the combustion chambers to allow for a flatter torque curve, and higher power, with low levels of both fuel consumption and polluting emissions.

Brief Description of Operation of the Engine **100**^{4} shown in FIG. **4**

The new cycle engine **100**^{4} of FIG. **4** is a high efficiency engine that attains both high power and torque, with low fuel consumption and low polluting emissions. The new 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 an ancillary compressor **2**. The temperature rise at the end of compression can be suppressed by use of air coolers **10, 11, 12,** which cool the intake air, by the late injection of temperature adjusted air, and by a shorter compression stroke.

During operation, a primary air charge is supplied to the cylinder **7** through intake valve **16**-B at atmospheric pressure or air which has been increased by perhaps one-half to one atmosphere through an ancillary air inlet **9** which can be

carbureted. This charge can be compressed, fuel added if not present, ignited at the appropriate point near top dead center for the power stroke—providing high fuel economy and low polluting emissions.

When more power is desired, a secondary air charge originating from air inlet **8** is, preferably, introduced into the power cylinder **7** during the compression stroke by a second intake valve **16**-A which introduces a higher pressure air charge after the first intake valve **16**-B has closed in order to increase the charge density when needed. After the secondary air charge has been injected, intake valve **16**-A quickly closes. The primary air charge may be boosted to a higher pressure by cutting in a second ancillary compressor, in series with compressor **2**, (see for example, compressor **1** in FIG. **7**, where the primary compressor to be used in the engine of FIG. **4** is the compressor **2**—shown in FIG. **4** and FIG. **7**, for example, as a Lysholm rotary type) between air inlet **8** and manifold **13**, **14**, and can be intercooled. The temperature, pressure, amount and point of injection of the secondary charge, if added, is adjusted to produce the desired results. An intake valve disabler (there are several on the market, for example, Eaton Corp. and Cadillac), in preferred embodiments, may be used to disable intake valve **16**-A when light-load operation does not require a high mean effective cylinder pressure. Alternatively, the air bypass valve (ABV) **6** is opened to re-circulate the charge-air back through the compressor **2** in order to relieve the compressor of compression work during light-load operation.

Alternatively, a one-way valve, one type of which is shown as **26** in FIG. **6** can be utilized to provide a constant or a variable "pressure ratio" in the cylinder **7**, while improving swirl turbulence. In this alternate method of operation the intake valve **16**-A would close very late and valve **26** would close only when the pressure in the cylinder **7** nearly equates or exceeds the pressure in conduit **15**-A. Thus, the pressure in conduit **15**-A, controlled by compressor speed, along with valves **3**, **5** and **6** (and valve **4** in FIG. **7**) would regulate the pressure, density, temperature and turbulence of the combustion process. A spring-retracted disc type, metal or ceramic, or any other type of automatic valve could replace valve **26**.

Another alternate method of providing a low compression ratio, with a large expansion ratio and reduced polluting emissions is thus:

The air pressure supplied to intake runner-conduit **15**-A is produced at an extremely high level, and intake valve **16**-A is, in alternate embodiments, replaced by a fast-acting, more controllable valve such as but not limited to a high speed solenoid valve (not shown), which valve is, preferably, either mechanically, electrically or vacuum operated under the control of an engine control module (ECM). In such an embodiment, a smaller, denser, temperature-adjusted, high-pressure charge, with or without accompanying fuel, can, selectively, be injected, tangentially oriented, much later in the compression stroke, or even during the combustion process, in order to increase charge density, to reduce peak and overall combustion temperatures, and to create the desired charge swirl turbulence in the combustion chamber (s).

One suggested, preferred method of operation of the new-cycle engine **100**[4] 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 one compressor (not shown) and has had its temperature adjusted by bypass systems and charge-air coolers (not shown) is drawn into the cylinder **7** (intake stroke) through air inlet **9**, manifold **14**-B, intake conduits **15**-B, and intake valves **16***a*-B-**16***f*-B by intake stroke of piston **22**.
2. (a) After the intake stroke is complete the intake valve **16**-B (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 **14**-B.

   (b) Alternatively, the intake valve **16**-B is closed early, during the intake stroke before the piston reaches bottom dead center. The trapped air charge is then expanded to the full volume of the cylinder **7**.
3. (a) The compression (2nd) stroke now begins and, at the point the intake valve **16**-B is closed to seal cylinder **7** in either **2**(a) or **2**(b) operation, compression begins (for a small compression ratio). This makes it possible to lessen the temperature rise during the compression stroke.

   (b) When greater power is required a secondary compressed, temperature-adjusted air charge is injected into the cylinder **7** by intake valve **16**-A which opens and closes quickly during the compression stroke at the point at which the intake valve **16**-B which introduced the primary air charge closes, or later in the stroke, to produce a more dense, temperature controlled charge in order to provide the torque and power desired of the engine.

   (c) Alternatively, when greater power is required, the secondary air charge can be increased in density and weight by causing shutter valves **5** and **3** to direct all or part of the air charge through one or more of intercoolers **10**, **11** and **12** to increase the charge density and/or by increasing compressor speed or by cutting in a second stage of auxiliary compression, the latter two actions thereby pumping in more air on the backside. Alternatively, the timing of the closing of intake valve **16**-B on either the inlet or compression stroke can be altered temporarily to retain a larger charge, and at the same time the timing of intake valve **16**-A can be temporarily altered to open and close earlier during the compression stroke to provide a larger dense, temperature-adjusted air charge.
4. Compression continues, fuel is added if not present, the charge is ignited and combustion produces a large expansion of the combusted gases against the piston **22** producing great energy in either mode 3(a), (b), or (c). This energy is absorbed and turned into high torque and power, especially in mode (c).
5. Near bottom dead center of the piston, exhaust valves **17***a*–**17***f*, **17***a*'–**17***f* open and the cylinder **7** is efficiently scavenged by the (4th) stroke of piston **22**, after which valve(s) **17** close.

Detailed Description of the Operation of the Engine **100**[4] of FIG. **4**

During the intake (1st) stroke of the piston **22** low pressure air flows through air conduit **15**-B from the atmospheric air inlet **9** through manifold **14**-B of air at atmospheric pressure or which has been boosted in pressure (or, alternatively, the low pressure air can be supplied by a pressure regulator valve **25** and conduit **15**-B from compressed air line **15**-A as shown in FIG. **5**), through an intake valve **16**-B into the cylinder **7**. During the intake stroke of piston **22**, the intake valve **16**-B closes (point x). From this point the air charge in the cylinder is expanded to the maximum volume of the cylinder. Then, during the compression (2nd) stroke, no compression of the charge takes

place until the piston **22** returns to point x where the inlet valve was closed. (At point x, the remaining displaced volume of the cylinder is divided by the volume of the combustion chamber, establishing the compression ratio of the engine.) At any point in the compression stroke of piston **22** at the time or after the piston **22** reaches point x a second inlet valve **16**-A is, selectively, opened in order to inject a secondary pressurized air charge at a temperature, density and pressure deemed advantageous to the engine load, torque demand, fuel economy and emissions characteristics desired. Alternatively, during the intake of charge-air by intake valve **16**-B, the intake valve **16**-B is held open past bottom dead center for a significant distance, 10% to perhaps 50% or more of the compression stroke, thus pumping some of the charge back into the intake manifold **14**-B, and then closed to establish a low compression ratio in the cylinder. During the compression stroke, at or after the time intake valve **16**-B is closed, a secondary charge of high pressure, temperature-adjusted air which has been compressed by compressor **2** is, selectively, injected by a second intake valve **16**-A, which opens and closes quickly, into the same cylinder **7**. Alternatively, when greater torque and power are needed, the density of the secondary charge-air is greatly increased by increasing the speed of the primary compressor **2** or by cutting in another stage of compression, as in item **1**, FIG. **7**, and/or by routing the air charge through inter-coolers.

For light-load operation a shut-off valve, or a valve disabler **31** (such as shown in FIG. **7**) on the high pressure intake valve **16**-A, preferably, temporarily restrains the intake air, or holds the valve closed. This would add to the fuel economy of the engine. Alternatively, during light-load operation the shutter valve **5** is closed and the air bypass valve ABV **6** is opened so that part or all of the air pumped by compressor **2** would be returned to the inlet conduit of the compressor **2** for a low, or no pressure boost. Therefore, when secondary intake valve **16**-A opens, the pressure of the air in conduit **15**-A is approximately the same as, or not much greater than that from the initial charge. In an alternate embodiment, an ancillary automatic valve **26**, FIG. **6**, is arranged, as shown in FIG. **6**, to prevent any back-flow of charge-air into conduit **15**-A if the cylinder pressure should exceed the pressure in conduit **15**-A before intake valve **16**-A closed during the compression stroke of piston **22**.

If an ancillary one-way valve (see valve **26** of FIG. **6**) is present, the pressure ratio in cylinder **7** can be fully controlled by adjusting the pressure of the charge air passing through intake valve **16**-A. The pressure ratio can then be controlled by valves **3**, **5**, **6** and by compressor speed and any throttle valve that may be present. In the use of valve **26**, intake valve **16**-A must be kept open until very late in the compression stroke, perhaps until piston **22** nears or reaches top dead center.

Fuel can be carbureted in FIG. **4**, FIG. **4**-B, FIG. **5**, FIG. **7** and FIG. **33**, 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 or, injected through intake valves **16**-A, **16**-B, (**16**-B only if **16**-B does not remain open past bottom dead center), or it may be injected directly into the combustion chamber at point x during the intake stroke, (during the intake stroke only if intake valve **16**-B closes before bottom dead center), or at the time or after the piston **22** has reached point x in the compression stroke. The fuel can be injected with or without accompanying air. In the case of diesel operation, fuel 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.

After the temperature-and-density-adjusting-air charge has been injected, if used, compression of the charge continues and with fuel present, is ignited at the opportune time for the expansion (3rd and power) stroke. (The compression ratio is established by the displaced volume of the cylinder remaining after point x has been reached on the compression stroke, being divided by the volume of the combustion chamber. The expansion ratio is determined by dividing the cylinders total clearance volume by the volume of the combustion chamber.) Now the fuel-air charge is ignited and the power, (3rd) stroke of piston **22** takes place as the combusted gases expand. Near bottom dead center of the power stroke the exhaust valve(s) **17**, **17'** opens and the cylinder **7** is efficiently scavenged on the fourth piston stroke by positive displacement, after which exhaust valve(s) **17** closes.

This completes one cycle of the 4-stroke engine.

It can be seen that the later the point in the compression stroke that point x is reached (the earlier or later the inlet valve is closed), the lower is the compression ratio of the engine and the less the charge is heated during compression. It can also be seen that the later the temperature-density-adjusting charge is introduced, the less work will be required of the engine to compress the charge, the later part of which has received some compression already by an ancillary compressor **2**.

The Engine $100^{4\text{-}B}$ of FIG. 4-B

Referring now to FIG. **4**-B there is shown a six cylinder 4-stroke internal combustion engine similar in construction to the engine of FIG. **4** with the exception that the engine of FIG. **4**-B is so constructed and arranged that compressor **2** receives charge-air from manifold **14**-B through opening **8**-B (shown in FIG. **7**) and conduit **8** which air enters through common air intake duct **9**. Intake runners **15***a*-C to **15***f*-C distributes the atmospheric pressure air to the intake valves **16**-B of each power cylinder. This arrangement allows the provision of air to intake valves **16**-A and **16**-B at different pressure levels since the charge-air from conduits **15**-A is selectively pressurized by compressor **2**. The operation of the engine of FIG. **4**-B is the same as that of the engine of FIG. **4**.

The Engine 100^{5} of FIG. 5

Referring now to FIG. **5**, there is shown a six cylinder 4-stroke internal combustion engine 100^{5} similar to the engines 100^{4} of FIG. **4** and engine $100^{4\text{-}B}$ of FIG. **4**-B with the exception that there are shown alternative ways that the dual atmospheric air inlets can be eliminated, preferably by providing the low pressure charge-air to intake valves **16**-B by way of conduits **15***a*-D to **15***f*-D all leading from the common air inlet conduit **8**, or from an optional air manifold **35**-M, situated between inlet conduit **8** and the inlet of conduits **15***a*-D to **15***f*-D, which manifold would also supply air to compressor **2** through conduit **8**-A. Providing the low pressure charge-air to intake valve **16**-B by way of conduit **15**-D, or by conduit **15**-B (shown in phantom) would eliminate a second air filter and air induction system and would work well with either the first system described which involves closing the primary intake valve **16**-B during the intake stroke of the piston **22** or alternatively closing the primary intake valve **16**-B during the 2nd or compression stroke. Alternatively, as shown, the low pressure charge-air can be supplied by placing a pressure-dropping valve **25** in conduit **15**-B routed for leading from the pressurized air conduit **15** (**15**-A) to the low pressure cylinder inlet valve

16-B in order to drop the inducted air pressure down to the level that could be controlled by the system of compression ratio adjustment described herein, preferably down to 1.5 to 2.0 atmospheres (absolute pressure which is a boost of 0.5 to 1.0 atmosphere) and perhaps down to atmospheric pressure.

The operation of the engine 100^5 of FIG. 5 would be the same as the operation of the engine 100^4 of FIG. 4 although the low pressure primary air supply is supplied differently. Because of noticeable similarities between the engine 100^5 of FIG. 5 and that of FIG. 7, reference will be made as deemed helpful to FIG. 7 for certain common components.

During light-load operation of this 4-stroke cycle engine (FIG. 4, FIG. 4-B and FIG. 5) such as vehicle cruising or light-load power generation, the secondary air charge is, alternatively, eliminated by disabling high pressure intake valve 16A temporarily (there are several valve disabling systems available, e.g., Eton, Cadillac, etc.) or air can be shut off to intake valve 16-A and the engine still produce greater fuel economy and power than do conventional engines.

Alternatively and preferably, during light load operation such as vehicle cruising, the compressor 2 can be relieved of any compression work by closing the shutter valve 5 and opening the air bypass valve 6 which circulates the air pumped back into the compressor 2 and then the air in intake conduits 15-A and 15-B or 15-D are approximately equal. Therefore, no supercharging takes place during this time. In one embodiment, automatic valve 26, FIG. 6, prevents backflow of air during the compression stroke if compression pressure in the cylinder approximates or exceeds the pressure in conduit 15-A before the intake valve 16-A closes.

For increased power the secondary air charge may be increased by shutter valves 3 and 5 being preferably opened to direct the air charge to intercoolers 10, 11 and 12, which makes the charge denser and/or by increasing the speed of compressor 2 or by adding a second stage of pre-compression by compressor 1 in FIG. 7, the latter two actions thereby pumping in more air on the backside. There is shown in FIG. 7 that the primary compressor 2 is a Lysholm rotary type and a secondary compressor 1 is a rotary compressor of the turbo type, although any type of compressors can be used in the engines of this invention.

Referring now to FIG. 6 there is shown the same 4-stroke engine and a similar operating system as described for the engines of FIG. 4, FIG. 4-B, FIG. 5, FIG. 7 and FIG. 33, except that the engine of FIG. 6 has an added feature in that the secondary intake valve 16-A has an auxiliary valve 26 which is automatic to prevent charge-air back-flow from cylinder 7. This feature will prevent any back-flow from occurring during the compression stroke of the engine of this invention. This feature can also be used to establish the pressure ratio of the engine, either variable or constant. If secondary charge air is being received through intake valve 16-A, the intake valve 16-A can be kept open during the compression stroke to near top dead center of piston 22, since automatic valve 26 closes at such time the pressure in cylinder 7 approximates the pressure in intake runner conduit 15-A. Therefore, the pressure differential between cylinder 7 and intake runner 15-A will allow closure of automatic valve 26, even though intake valve 16-A may still be open, allowing the pressure ratio of cylinder 7 to be controlled by the pressure of any charge air coming through intake runner 15-A, which in turn is controlled by valves 3, 5, and 6 and compressor speed and perhaps a throttle valve, if present, for engines having a single stage of pre-compression. Valves 3, 4, 5 and 6 and compressor speed and any throttle valve present would control the pressure ratios for engines having two stages of pre-compression. If no charge is passing from intake valve 16-A, automatic valve 26 will be already closed and the pressure ratio is set by the compression ratio of the engine and the density and temperature of the charge received by cylinder 7 through intake valve 16-B. The compression ratio is still set by the point in cylinder 7 that the primary intake valve 16-B is closed. The pressure ratio is set by the density and temperature of the air present in cylinder 7 whether it enters through valve 16-B, 16-A or both, and by the compression ratio.

Any type of automatic valve can be used for item 26, perhaps a spring-retracted disc type which can be made of metal or ceramics.

The Engine 100^1 of FIG. 7

Referring now to FIG. 7, there is shown a schematic drawing of a six cylinder engine 100^7 operating in a 4-stroke cycle. The engine is similar in structure and operation to the 4-stroke engine of FIG. 4, FIG. 4-B and FIG. 5 and shows alternative air induction systems utilizing air intake 9 (in phantom) or air intake 8', or both. FIG. 7 also shows three intercoolers 10, 11 and 12 and dual manifolds 13 and 14 plus alternative intake manifold 14-B. The need for dual atmospheric air intake (8' and 9 in FIG. 7) can be eliminated by providing air from port 8-B of manifold 14-B directly to air intake conduit 8' shown schematically, in FIG. 7.

One alternate air induction system shown in FIG. 7 supplies unpressurized charge-air to intake valve 16-B of the engine of FIG. 4-B and of FIG. 7 by providing atmospheric pressure air to the intake runners 15*a*-C to 15*f*-C leading from manifold 14-B in FIG. 4-B and FIG. 7 which receives atmospheric air through induction port 9, and then distributes the unpressurized air to intake valves 16-B of each power cylinder. Then, high pressure air enters through intake valve 16-A after piston 22 has reached point x during the compression stroke (the point in which intake valve 16-B closes and compression begins). Intake valve 16-A then closes, compression continues, fuel is added if not present and the charge is ignited near top dead center (TDC) and the power (3rd) stroke occurs.

A second alternate air induction system shown in FIG. 7 supplies low pressure intake air as also shown in FIG. 5 of alternatively receiving air from high pressure conduit 15-A through conduit 15-B with the optional pressure reducing valve 25, (shown in phantom in FIG. 5 and FIG. 7). The secondary high pressure air charge is injected by intake valve 16-A at the same time or later that the piston 22 reaches the point at which the intake valve 16-B closes and compression begins. Intake valve 16-A then quickly closes, compression continues, fuel is added if not present and the charge is ignited at the appropriate place for the power (3rd) stroke.

A third alternate and preferred air induction system shown in FIG. 7 supplies the primary air charge to intake valve 16-B as follows: Charge-air which has been pressurized to a low pressure by compressor 1, perhaps from 0.3 Bar to as much as 2 Bar or more, can selectively (and intermittently or continuously) be supplied to low pressure intake valves 16-B of the engine of FIG. 7 by way of conduit 32 leading from conduit 110 to the intake valves (16*a*-B through 16*f*-B) which conduit receives charge-air at atmospheric pressure or which has been pressurized and in any case has had its temperature optimized, all controlled by compressor 1 and intercooler 10 with the charge-air paths being controlled by

valves **5** and **6** with the corresponding conduits. In this case the valve **33** is optional. After cylinder **7** has been charged and the compression ratio established by the closing of intake valve **16**-B during the first or second stroke of piston **22**, the high pressure intake valve **16**-A opens on the compression stroke at the point which valve **16**-B closes, to inject the dense, temperature adjusted air charge and then it closes, as compression continues and near top dead center, fuel being present, the charge is ignited and the power (3rd) stroke occurs. The use of this system also eliminates the need for dual atmosphere air intakes.

A fourth alternate air induction system shown in FIG. **7** supplies the primary charge-air to the low pressure intake valves **16**-B by having charge-air coming selectively from intake system **9**, manifold **14**-B and intake runners **15**-C (shown in phantom) or from conduit **32** which would direct air to power cylinder **7** at whatever level of pressure and temperature was needed at any particular time. With this arrangement, opening valve **33** at such a time that compressor **1** was compressing the charge passing through it would have the effect of increasing the density of the primary charge-air which in this case could also have its temperature as well as it pressure adjusted by compressor **1** and control valves **5** and **6**. A one-way valve **34** would prevent the higher pressure air escaping through conduit **15**-C. When less power was needed compressor **1** could be "waste gated" by opening, partially or completely control valve **6** and closing shutter valve **5**. Alternatively, valve **33** could be closed by the engine control module (ECM) and the primary charge-air would be drawn into cylinder **7** at atmospheric pressure through intake duct **9** (shown in phantom). The piston **22** now begins its second stroke, the intake valve **16**-B now closes, if not closed on the intake stroke, to establish the compression ratio and in all cases the heavy secondary charge enters through valve **16**-A which opens at the time, or after, piston **22** has reached the point where intake valve **16**-B had closed, valve **16**-A then quickly closes, compression continues and the charge is ignited near top dead center and the power (3rd) stroke occurs.

With this fourth alternate air induction system the low pressure intake valve **16**-B can (a) receive charge-air at atmospheric pressure or (b) can receive charge-air which has been compressed and cooled through conduit **32** or conduit **15**-B. The high pressure intake valve **16**-A (which opens at the time, or later, at which compression begins) can receive charge-air which (a) has been compressed and cooled in a single stage by compressor **1** or compressor **2**, (b) has been compressed and cooled in two stages or more to a very high density or (c) which has had its temperature and pressure adjusted by control valves **5** and **6**, all in order to provide better management of combustion characteristics in regard to power, torque and fuel economy requirements and in regard to emissions control. By incorporating an optional one-way valve (see valve **26** shown in FIG. **6**), the engines of FIG. **4**, FIG. **4**-B, FIG. **5** and FIG. **7** could have either a constant or a variable pressure ratio, the charge density, pressure, temperature and turbulence and the time of closing of valve **26** being controlled by valves **3**, **5** and **6** and by compressor speed and by any throttle valve present in engines having one stage of pre-compression, and by the addition of valve **4**, in engines having two stages of pre-compression. In either case the intake valve **16**-A should be held open very late in the compression stroke, perhaps to near top dead center of piston **22**.

One advantage to compressing the charge-air going to the low pressure intake valve **16**-B in addition to highly compressing the secondary air charge is that during much of the duty cycle of such engines the charge density could be dramatically increased while keeping peak pressures and temperatures low, for high mean effective cylinder pressure. This system could provide all power necessary for vehicular travel in hilly country with perhaps the high pressure intake valves **16**-A being deactivated by a valve deactivator indicated by **31** in FIG. **7**, or by compressor **2** and/or compressor **1** being partially or wholly bypassed by control valves **3** and **4** and/or control valves **5** and **6** to vary the pressure and temperature going into manifolds **13** and **14** and then to intake valves **16**-A. For utmost power, the valve deactivators could be turned off or eliminated.

Also shown in FIG. **7** is a suggested engine control system consisting of an engine control module (ECM) **27**, two shutter valves **3** and **5**, two air bypass valves **4** and **6**, the optional pressure reducing valves **25** (**25***a*–**25***f*) on air conduits **15**-B (**15***a*-B–**15***f*-B), and a scheme of controlling the pressure, temperature and density by controlling air bypass valves **4** and **6** and shutter valves **3** and **5**. As illustrated, air bypass valve **4** is closed to allow compressor **2** to fully compress the charge and shutter valve **3** is slightly open allowing part of the air to flow uncooled (hollow arrows) and some of the air cooled (solid arrows) to the manifolds **13** and **14**, all of which could be controlled by the ECM **27** in order to provide an air charge at optimum density, temperature and pressure. The hollow arrow **4**-A in conduit **120** shows how ABV **4** can be partially opened to allow some of the air to bypass and return to compressor **2** in order to finely adjust the pressure of the secondary air charge that is injected to adjust the charge density and temperature. Alternatively, all of the air charge can be directed through the intercoolers **10**, **11** and **12** or through bypass conduits **121** and **122**, to the manifolds **13** and **14**.

For high power with a low compression ratio and low polluting emissions, the air bypass valves (ABV) **4** and **6** are closed and the shutter valves **3** and **5** would be opened so that the compressors **2** and **1** raise the pressure of the air charge which is directed by shutter valves **3** and **5** through the intercoolers for maximum density. During the intake stroke the low pressure intake valve **16**-B opens, piston **22** sucks in low pressure air, the intake valve **16**-B closes before bottom dead center or after bottom dead center during the compression stroke. During the compression stroke, at the point the intake valve **16**-B closed or later, intake valve **16**-A opens to inject the secondary, dense, cooled air charge and then closes. Compression continues for a low compression ratio. Fuel is added, if not present, and the charge is ignited at the appropriate point near top dead center, (ignition can be before, at, or after top dead center) for the power (3rd) stroke with a large expansion ratio with high torque, then exhaust valve(s) **17** open and the scavenging (4th) stroke occurs, after which exhaust valve(s) **17** closes.

In these designs, fuel can be carbureted, throttle body injected, port injected, injected into the cylinder and can be introduced at any point between the air intake and the piston crown. The fuel air mixture can be stratified, or from a stoichiometric to a very lean mixture for spark ignition, to a very rich mixture for diesel operation. The engine power can be controlled by fuel metering alone or the air supply can be properly adjusted to the proper fuel-air ratio by a throttle valve or can be "metered" by control valves **4** and **6** when using two stages of pre-compression and by control valve **4** when using a single stage of pre-compression.

In any of the engines of this invention, the problem common to normal engines of incomplete mixing of fuel, air and residual gas, with consequent variation in conditions at the ignition point is minimized and in some cases eliminated

by the late air charge injection at high velocity. This problem, hereby addressed by the present invention, is extreme in current engines when gaseous fuel is injected directly into the cylinder where the spark may occur in mixtures of varying fuel-air ratios, hence with various rates of flame development.

(Concerning the importance of finding a solution to this particular problem, engine researchers at Massachusetts Institute of Technology state "The elimination of cycle-to-cycle variation in the combustion process would be an important contribution to improved [engine] performance. If all cycles were alike and equal to the average cycle, maximum cylinder pressures would be lower, efficiency would be greater, and most of all, the detonation limit would be higher, thus allowing appreciable increase in efficiency and/or mean effective cylinder pressure with a given fuel.")

The cyclic variation spoken of is minimized and, potentially, eliminated in the engine of each of the embodiments (including two-stroke embodiments and four-stroke embodiments) of the current invention by the significant swirl turbulence produced by the injection of high-pressure air. In addition, in any of the engines of this invention the swirl turbulence can be oriented tangentially to the cylinder wall by shrouding the inlet valve **16**, and especially valve **16**-A, or by the use of a one-way valve (such as valve **26** in FIG. **6** and FIG. **10**). Even engines that receive an air charge during the intake stroke of the piston using a shrouded intake valve have a tendency to reduce unwanted cyclic variation and have a decrease in octane requirement and an increase in knock-limited indicated mean effective (cylinder) pressure (klimep). The engine of the present invention, by injecting the charge-air, especially through a shrouded valve during the compression stroke, creates a much greater swirl turbulence to further eliminate unwanted cycle-to-cycle variation for cleaner, more complete combustion of the fuel.

The intake valve can rotate during operation and still have a flow tangential to the cylinder wall by using a conventional poppet valve and having the side of the valve head which is opposite the desired direction of the air flow being shrouded as it opens by a thickened section of the face of the engine's head forming a crescent shaped collar or projection to direct the air flow in the desired direction while the valve is open.

In the diesel combustion system, the better mixing process of the present invention allows much richer fuel-air ratios for greater smoke-limited power, and smoke and particulates are virtually eliminated to an extremely rich fuel-air ratio.

The swirl turbulence produced by high pressure charge injection during the compression stroke is not dampened by the compression stroke and the later the charge is injected, the smaller the volume of charge required to produce the desired swirl turbulence. In any reciprocating internal combustion engine operating in accordance with the method of the present invention, a very high pressure, temperature-controlled air charge can, selectively, be injected tangentially oriented, very late in the compression stroke, for example, just prior to, during or with fuel injection and, with extremely high pressures, even during the combustion process.

Since the secondary air charge in the engine of FIG. **4** through FIG. **7**, FIG. **9**, FIG. **9**-B and FIG. **15** through FIG. **20** is compressible to an extremely high level of pressure, the intake valve **16**-A is, in alternate embodiments, replaced by a more controllable and fast-acting valve, such as, but not limited to, a high-speed solenoid valve (not shown). This valve is, preferably, operated either mechanically, electrically or by vacuum and is, preferably, controlled by an engine control module (ECM) as illustrated in FIG. **7**, FIG. **9**-B, FIG. **15** through FIG. **20** and FIG. **33**. In this system the secondary air charge can, selectively, be injected very late in the compression stroke of piston **22** in order to increase charge density, and swirl turbulence, and to reduce peak and overall combustion temperatures and to lessen the production of polluting emissions. The injection could be performed in a tangentially oriented fashion. This would greatly increase swirl turbulence and prevent undesirable cyclic variations which are common in normal engines and most troubling in gaseous or diesel fueled engines.

The use of this system should result in lower maximum cylinder pressures and temperatures. Efficiency should be greater and the detonation limit higher, thus allowing an appreciable increase in efficiency and mean effective cylinder pressure with a given fuel. All of the engines of this invention operate with a more complete expansion process as compared to the typical prior art engines, thereby providing further improvements in efficiency and emissions characteristics.

In accordance with the present invention, the 4-stroke engines of the present invention (for example, FIG. **1**, FIG. **2**, FIG. **3**, FIG. **4**, FIG. **4**-B, FIG. **5**, FIG. **7** and FIG. **33**) are designed, as are the 2-stroke engines of the present invention (for example, FIGS. **8**–**11**, **25** and **33**), to use an expansion ratio larger than the compression ratio. In order to accomplish this result, the expansion ratio is set by selecting the appropriate combustion-chamber volume and the compression ratio is reduced below this value by very early or very late closing of the inlet valve.

The Engine 100^8 of FIG. 8

Referring now to FIG. **8**, there is shown a six cylinder reciprocating internal combustion engine 100^8 for gasoline, diesel, alcohol, natural gas, hydrogen or hybrid dual-fuel operation and having six cylinders ***7a***–***7f*** (only one, ***7f***, is shown in a sectional view) in which the pistons ***22a***–***22f*** are arranged to reciprocate. Another cylinder is indicated only by the presence of the lower end of the cylinder liner ***7a***. A cut-a-way view shows a double-acting compressor cylinder **1**. Pistons ***22a***–***22f*** are connected to a common crankshaft **20** in a conventional manner by means of connecting rods ***19a***–***19f***, respectively. The engine 100^8 of FIG. **8** is adapted to operate in a 2-stroke cycle so as to produce six power strokes per revolution of the crankshaft **20**. To this end compressor **1** takes in an air charge at atmospheric pressure, (or alternatively an air charge which previously had been subjected to compression to a higher pressure via an admission control valve **6** through an intake conduit **102**, leading from compressor **2** by way of bypass control valve **6** and shutter valve **5** and bypass conduit **104** or through the intercooler **10**). During operation of the engine of FIG. **8**, the air charge is compressed within the compressor **1** by its associated piston **131**, and the compressed charge is forced through an outlet into a high-pressure transfer conduit **109** which leads to bypass valve **3** which is constructed and arranged to channel the compressed charge through intercoolers 11 and 12 or through bypass conduit **111** in response to signals from the engine control module (ECM) **27**. This module directs the degree of compression, the amount and the direction of the flow of the compressed charge through the intercooler and/or the bypass conduit into manifolds **13** and **14**. Manifolds **13** and **14** are constructed and arranged to distribute the compressed charge by means of branch intake conduits ***15a***–***15f*** and to inlet valves **16** and **16'**, and to the remaining five power cylinders. Alternatively, an

ancillary compressor **2** receives atmospheric air through inlet opening **8**, pre-compresses the air charge into conduit **101** leading to control valve **5** which in response to signals from ECM **27** will direct the compressed charge through intercooler **10** or bypass conduit **104** to compressor **1**. The ECM **27** can also control valves **4** and **6** to direct part or all of the charge passing through compressors **1** and **2** back through conduits **120** and **103** in order to adjust the amount of compression of compressors **1** and **2** ranging in either or both compressors from full compression to no compression, thus during light-load operation either compressor **1** or compressor **2** could supply the needed compressed air to the cylinders.

The Engine **100**[8] of FIG. **8** has camshafts **21** which are arranged to be driven at the same speed as the crankshaft in order to supply one working stroke per revolution for the power pistons. The reciprocating compressor can have one or more double-acting cylinders one is pictured **1** and can have more than one stage of compression, and the crankshaft **20** would supply two working strokes per revolution, for one or more compressors, as described hereinafter. The reciprocating compressor could alternatively be driven by a short crankshaft which would be rotated by a step-up gear on the main crankshaft driving a smaller gear on the ancillary crankshaft. The ancillary rotary compressor **2** could be driven by V-pulley operated by a ribbed V-belt and could have a step-up gear between the V-pulley and the compressor drive shaft. The rotary compressor **2** could also have a variable speed drive as in some aircraft engines.

Description of the Operation of the Engine **100**[8] of FIG. **8**.

Charge-air is induced into the inlet opening **8** of compressor **2**, from there it passes through the compressor **2** where the charge is then inducted into conduit **101** to shutter valve **5** where the charge is directed either through intercooler **10** or through air bypass valve **6** where a portion or all of the charge can be directed back through the compressor **2** where the charge is re-circulated without compression, or valve **6** can direct the air charge into the inlet of compressor **1** where the air charge is pumped out the outlet duct of compressor **1** which leads to shutter valve **3** where the charge is directed either through intercoolers **11** and **12** or through air bypass valve **4** or a portion through both, leading to manifolds **13** and **14** which distribute the charge-air to the intake valves **16** and to the intake valve of each power cylinder **7** of the engine **100**[8]. (Bypass valve **4** can direct part or all of the air charge to manifolds **13** and **14**, or can recirculate part or all of the air charge through conduit **120** back to conduit **106** and into the inlet of compressor **1**.) The engine control module (ECM) **27** controls valves **3**, **4**, **5**, and **6**, in order to adjust the pressure, temperature and density of the charge that is inducted into the engine's combustion chambers **130**. The same ECM **27** can control a variable-valve-happening control system to adjust the time of opening and closing of the inlet valves **16** and exhaust valves **17** of the power cylinders in relationship to the angle of rotation of crankshaft **20**, in order to adjust the compression ratio and charge density of the engine for optimum performance in regard to power, torque, fuel economy and characteristics of fuel being supplied.

The operation of the power cylinder **7** is in this manner:

Alternate Method **1**

Near the end of the power stroke in cylinder **7**, the exhaust valve(s) **17**, **17'** open and, with the exhaust valve still open, the piston **22** begins the second or exhaust stroke. During the exhaust stroke, perhaps as early as 70° to 60° before top dead center the exhaust valves **17**, **17'** close. At the point the exhaust valves are closed the compression ratio is established, the intake valves **16**, **16'** are opened at that point or later in the compression stroke, the compressed air and/or air-fuel charge is injected into the combustion chamber **130** of the power cylinder **7**, intake valve **16**, **16'** closes at perhaps 60° before top dead center, with the swirl and squish turbulence accompanying the high-pressure air injection, the piston **22** continues towards the end of its stroke thus compressing the charge producing a very low compression ratio, which can be as low as 2:1. If fuel is not already present as a mixture, fuel is injected into the incoming air stream or it is injected into a pre-combustion chamber or directly into the combustion chamber after closure of the intake valve. The fuel can be injected into the midst of the charge swirl for a stratified charge combustion process, or it can be injected onto a glow plug if diesel fuel is to be ignited. The fuel-air mix is ignited by compression or spark, the latter at the opportune time for greatest efficiency and/or power. Generally, the fuel would be injected and ignited before top dead center of the piston. The fuel can be injected later and perhaps continuously during the early part of the expansion stroke for a mostly constant-pressure combustion process and especially for diesel fuel. The fuel air mixture is ignited preferably before the piston reaches top dead center and the combusted charge expands against the piston as it moves toward bottom dead center. At near bottom dead center of the piston stroke, the exhaust valve(s) is opened and the exhausted mixture is scavenged by positive displacement by the piston **22** during the scavenging stroke. If the intake valve **16**, **16'** is opened earlier some valve overlap with the exhaust valve may be required for scavenging. If the intake valves **16**, **16'** are opened late no valve overlap would be needed, exhaust valve(s) **17**, **17'** closing at approximately the same time that intake valve(s) **16**, **16'** open. The expansion ratio of the engine could be about 19:1, for diesel fuel, 14:1 for gaseous fuel or gasoline, which expansion ratio is established by dividing the cylinder displacement volume by the volume of the combustion chamber.

Alternate operation method **2**

Near the end of the power stroke in cylinder **7** the exhaust valve(s) **17**, **17'** open, and with exhaust valve **17**, **17'** still open, begins its second or scavenging-charging stroke. At a point near mid-stroke, (e.g., about 90° before top dead center,) the exhaust valve **17**, **17'** still being open, the intake valve opens with a small valve overlap to admit high pressure scavenging and charging air. One or more intake valves **16** can be recessed, as in item **30** in FIG. **11**, in order to direct the first inlet air down and along the cylinder **7** wall in order to loop-scavenge the cylinder during the very small overlap of valves **16**, **16'** and **17**, **17'**. The exhaust valve **17**, **17'** remains open to the point at which compression should begin and then receives the air charge as it closes, intake valve(s) **16**, **16'** closing soon after, with the cylinder adequately scavenged and charged with temperature-adjusted fresh air now at high pressure. The piston **22** continues its stroke to compress the charge producing a low compression ratio, ideally 13:1 to 4:1, depending on the type of fuel used. The compression ratio is established by the point in the stroke of piston **22** in which the exhaust valve(s) **17**, **17'** closes, and is calculated when the remaining displaced volume of the cylinder is divided by the volume of the combustion chamber.

As piston **22** continues to rise from point x, where the exhaust valve closes establishing the compression ratio, and where compression of the charge started, the pressure starts

to rise at the same point. The dense cooled air charge with the short compression stroke will produce a low compression ratio with a very heavy charge, with low maximum cylinder pressure but with high effective mean cylinder pressure for great torque and power.

The pressure ratio will be established by the density, pressure and temperature of the incoming charge, the length of time inlet valve(s) **16, 16'** are open and the point the exhaust valve(s) **17, 17'** closes. The later the exhaust valves **17, 17'** close, the less the charge-air expands after injection, the less work is required to compress the charge and the less overlap of inlet and exhaust valve is required and the lower is the compression ratio.

At some point, perhaps as early as 150–120 degrees before piston top dead center position, cylinder **7** would be adequately scavenged and the exhaust valve **17, 17'** could be closed before, or no later than, the time the intake valves **16, 16'** are opened to admit, in this case, the entire air charge, most of the exhausted gases having been displaced by scavenging. (In some cases some residual exhaust gases are beneficial and experiments will show at what point both intake and exhaust valves can be closed without any overlap.) In this instance the "effective" compression ratio could be as low as 3:1 or even 2:1, again producing low maximum cylinder pressure and temperature but with high mean effective pressure. Fuel can be injected as early as at the point the exhaust valve closes and can be as early as about 150°–120° before the end of the compression stroke. The fuel-air mixture is ignited before, at, or after, top dead center and the expansion (2nd) stroke takes place. The expansion ratio is established by dividing the cylinder's displaced volume by the combustion chamber volume and could be about 19:1 for diesel applications, and 14:1 for gasoline or gaseous fuels.

An engine control module (ECM) **27** can manage temperatures and densities of the charge being introduced into the cylinder **7** or combustion chamber **130** and the timing of the inlet into the combustion chamber and can thus adjust charge densities, turbulence, temperatures and pressures providing a means of restraining peak temperatures and pressures yet with a mean effective cylinder pressure higher than in a normal engine, when needed, and further providing for lower levels of unwanted polluting emissions.

A suggested light-load, fuel efficient operation system as indicated on line B(bp) in FIG. **13**, would be thus: A nominal compression ratio of 13:1 could be chosen, with an expansion ratio of 19:1. The latter would establish the volume of the combustion chamber, the former would establish the maximum charge pressure (not maximum cylinder pressure), about 530 psi when compressed adiabatically. The ECM **27** would signal shutter valves **5** and air bypass control valve **6** to re-circulate the air being pumped through compressor **2**, back through the compressor **2** without being compressed or for any type compressor, open a waste-gate valve to bypass the compressor. Shutter valve **5** bypasses the intercooler **10** and directs the charge into the inlet of compressor 1. Compressor **1** would compress the charge adiabatically to say, 7:1 compression ratio. ECM **27** controls would bypass intercoolers **11** and **12** and introduce the charge into manifolds **13** and **14** with the heat-of-compression retained. If the exhaust valves **17, 17'** are closed and the inlet valve **16, 16'** of cylinder **7** are opened near the end of the compression stroke of piston **22** the effective compression ratio can be as low as 2:1, producing a "nominal" compression ratio of 14:1. (If the exhaust valves **17, 17'** are closed and the inlet valve **16, 16'** are opened earlier in the exhaust stroke, the injected charge-air should be of lower pressure and the "effective" compression ratio, that in-cylinder compression producing heat, would be greater. If the intake valves **16, 16'** opened at mid-stroke, after exhaust valves **17, 17'** close, and a nominal compression ratio of 13:1 were desired with an effective compression ratio of 4:1, then the charge introduced into the cylinder at mid-stroke should be compressed 4:1.) The uncooled charge is then compressed in the cylinder with an effective compression ratio of 4:1, and in either case, with a pressure of about 530 psi and a temperature above 900° F. The fuel/air charge is then ignited and expanded against the piston to the full volume of the power cylinder with an expansion ratio of 19:1.

At such a time that great power was required, the ECM **27** could signal the air bypass valve **4** and **6** to close. Compressor **2** then begins to compress the air charge to a higher pressure, at the same time ECM **27** would open shutter valves **3** and **5** to send the charge-air through the intercoolers **10**, 11 and **12**. Therefore, as the charge-air is cooled, and could be to as low as 150–200° F., more air is now pumped into the engine on the back side by the additional compression stage **2**, to prevent a substantial pressure drop in the charge-air due to the cooling of the charge before combustion. The air charge in the combustion chamber is now compressed 2:1 (line B(ic), FIG. **13**) and is maintained near the design pressure, in this case about 500–530 psi, although cooled, to significantly increase the density of the charge and the torque and power of the engine. The cooler air charge provides lower peak temperature and pressure and coupled with the high turbulence causes production of less unburned hydrocarbons, NO_x, and other polluting emissions and with smoke and particulates being virtually eliminated to a very rich fuel-air mixture. The air-fuel charge is now ignited and expanded to the full volume of the cylinder with an expansion ratio of 19:1 although the effective compression ratio is only 2:1 (see line B (ic) in FIG. **13**).

With either operation scheme the engine can be supercharged to a higher state than can conventional engines because in most cases the inlet valve is closed at the time of combustion chamber charging and a cooler air charge prevents detonation and reduces polluting emissions. Also in most cases residence time of the fuel is less than that required for pre-knock conditions to occur.

When less power is needed, as during vehicle cruising or light-load power generation, the engine operation could revert to light-load operation, e.g., one stage of compression could be cut out and the first cooler **10** bypassed by the air charge being re-circulated by shutter valve **5** and by bypass valve **6**. Shutter valve **3** and air bypass valve **4** could direct all of the charge from compressor **1** passed intercoolers **11** and **12** with the heat-of-compression retained, into manifolds **13** and **14** and to the cylinder for the less dense, more fuel efficient operation mode.

Still referring to FIG. **8**, there is shown a view of a cylinder head of the engine of FIG. **8** through FIG. 11 and FIG. **25**, showing optional pressure balanced intake valves with cooling being provided by conduits with intake conduit **29** and outlet conduit **29'**, one-way valves (not shown) which allow expansions **28** on the valve stems, as they reciprocate with intake valves **16** to pump a cooling and lubricating oil or oil-air mixture through the spaces above the valve stem expansions.

Pressure-balanced intake valves **16, 16'** in FIGS. **8, 11**, and **25**, and **16-A** in FIGS. **9** and **10** provide for rapid intake valve closure and allows large non-restricting intake valves and smaller than normal valve return springs. (When the intake valve is opened, pressure equilibrium almost imme-

diately takes place below the valve head within the combustion chamber and above the valve head within the intake runner, then the pressure in the intake runner acting on the piston-like arrangement on the valve stem tends to cause the valve stem to follow the down-slope of the cam profile for rapid valve closure. Also, a new "Magnavox" pressure operated, "square wave" intake valve could be used in the engines of this invention.)

The operation of the pressure balanced intake valves is in this manner:

The pressure balanced intake valves have expansions **28** on the valve stems, the lower surface of which are exposed to gases in conduit **15A**. When the valve stem is depressed by a cam **21** and intake valve(s) **16** opens in FIG. **8** through FIG. **11**, or FIG. **25** any pressure in conduit **15A** is equilibrated with pressure in the combustion chamber and at that time the only reactive force is by any pressure in conduit **15A** which is against the underside of valve stems expansions **28**, causing a rapid closure of the valve. One-way valves (not shown) on inlet and outlet channels **29** and **29'** are preferably provided for oil or oil-air mixture induction through spaces above expansions **28**, and alternatively through the valve stem expansions **28**. The oil inlet could be at a low point in the cylinder head where oil would collect to supply the cooling system. Alternatively, oil inlet line **29** could be connected to an oil or oil-air mix supply line. The inlet conduit **29** and the exit conduit **29'** from the cooling system would be fitted with one-way valves and the exit conduit **29'** could be higher than the inlet conduit **29** or could be connected to an oil discharge line leading to the engine oil reservoir. The valve stem expansions **28** could also have a channel through them with a one-way valve on each side. Since historically exhaust valves have been difficult to cool, this same system would provide adequate cooling for the exhaust valves even though there is not great pressure in the exhaust conduit. This system would then be applied to exhaust valves **17** from which exhaust ports **18** originate, or to the exhaust valves of any engine to provide long life for the exhaust valves and the valve seats.

On large engines the lines from the pumps described here can converged into larger lines and the oil pumping provided by them could replace the conventional oil pump on said engine.

The Engine **100^9** of FIG. **9**

Referring now to FIG. **9**, there is shown a six cylinder reciprocating internal combustion engine having one atmospheric air intake, in which all of the cylinders **7***a*–**7***f* (only one (**7f**) is shown in a sectional view) and associated pistons **22***a*–**22***f* operate in a 2-stroke cycle and all power cylinders are used so as to produce six power strokes per revolution of crankshaft **20** for producing power to a common crankshaft **20** via connecting rods **19***a*–**19***f*, respectively. A primary compressor **1**, in this figure a double-acting reciprocating type, is shown which, with air conduits as shown, supplies pressurized air to one or more cylinder intake valves **16-A** and **16-B** (the latter only if a primary charge to valve **16-B** comes from conduit **15**). A secondary compressor **2** of the Lysholm type is shown in series with compressor **1**. An air inlet **8** and associated compressors **1** and/or **2** with inlet conduits and manifolds **13** and **14** supply charge-air, which has been compressed to a higher than atmospheric pressure, to the air intake runner **15-A** and intake valve **16-A** to cylinder **7**. A second conduit **32** directs an air charge from conduit **110** through optional shut-off valve **33** to intake valve **16-B** to supply lower pressure air to the same cylinder. Alternatively a second conduit **15-B** from conduit **15-A** can be fitted with a pressure control valve **25** (both in phantom) and can direct the lower pressure air charge to the intake valve **16-B**. Intercoolers **10**, **11** and **12** and control valves **3**, **4**, **5** and **6** are used to help control the density, weight, temperature and pressure of the charge air. The intake valves are timed to control the compression ratio of the engine. The combustion chambers are sized to establish the expansion ratio of the engine.

The engine of FIG. **9**, FIG. **11** and FIG. **25** have cam shafts **21** fitted with cams and are arranged to rotate at engine crankshaft speed in order to supply one power stroke for each power piston for each crankshaft rotation.

The engine **100^9** shown in FIG. **9** is characterized by a more complete expansion process and a lower compression ratio than typical engines, and is capable 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 in normal engines with similar or lower maximum cylinder pressure. Engine control module (ECM) **27** and variable valves **3**, **4**, **5** and **6** on conduits as shown provide a system for controlling the charge pressure, density, temperature, and mean and peak pressure within the cylinder which allows greater fuel economy, production of greater power and torque at all RPM, with low polluting emissions for both spark and compression ignited engines. In alternate embodiments, a variable valve timing system with the ECM **27** can also control the time of opening and closing of the intake valves **16-A** or **16-B** or both, to further provide an improved management of conditions in the combustion chamber to allow for a flatter torque curve, higher power and with low levels of both fuel consumption and polluting emissions.

Brief Description of Operation of Engine **100^9** shown in FIG. **9**

The new cycle engine **100^9** of FIG. **9** is a high efficiency engine that attains both high power and torque, with low fuel consumption and low polluting emissions.

The new 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 by at least one ancillary compressor. The temperature rise at the end of compression can be suppressed by use of air coolers, which cools the compressed air, and by a shorter compression stroke.

During operation air is supplied to an intake valve **16-B** of the power cylinder **7** which has been increased in pressure by perhaps one-third to one atmosphere or more through an air intake conduit **32** leading from ancillary compressor **2**, or the air enters by conduit **15-B** and a pressure control valve **25**. A second air conduit **15A** selectively supplies charge-air at a higher pressure to a second intake valve **16-A** leading to the same power cylinder **7**. (In this design the intake valve **16-B** admits the low pressure air after exhaust valves **17** open near bottom dead center in the power stroke, and exhaust blowdown has occurred.) Exhaust blowdown occurs after exhaust valve(s) **17** open and now intake valve **16-B** opens and closes quickly to inject low pressure scavenging air. The cylinder **7** is further scavenged by loop scavenging as piston **22** begins its compression stroke. Intake valve **16-B** is now closed and piston **22** rises in the compression stroke to the point where compression should begin at which point exhaust valve **17** closes sealing cylinder **7** and establishing the compression ratio. Compression continues and at near top dead center, at a point deemed appropriate, fuel