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The engine takes in a primary fuel-air charge characterized by having a low "effective" compression ratio and low heat-of-compression for that portion of charge followed by the injection of a supplementary, supercharging air portion late in the compression stroke. The secondary charge, also having a low "effective" compression ratio for low heat-of-compression producing totally very low heat-of-compression.

Method of Operation

The engine **1** receives the air or fuel-air mix in two portions from two different sources and are introduced at different times.

1) For the supercharging air, a compressor **15** receives air through inlet port **16** and optionally mixes the air with fuel in carburetor **51**-C. The air or fuel-air charge is directed by conduit through intercooler **17**, through compressor **18**, intercooler **19**, conduit **20** to injection valve **21** which is alternatively an expansion valve such as **10** in FIGS. **2**-B and **2**-D. The secondary, supercharging air is highly compressed, cooled or "chilled" before injecting by valve **21** into the primary air stream late in the compression process of the primary air or fuel-air in compression chamber **5**-C. The late injection of the cool, high pressure, supercharging charge into the relatively cool primary charge assures great charge density, turbulence and efficiency for economical and enduring operation with ultra low polluting emissions.

2) For the primary air, atmospheric or pressure boosted air of fuel-air mix is drawn into compression chamber **5**-C by way of air inlet port **3**-B by suction action as vane **4** rotates past air inlet **3**-B. If valve **14** on air return **13** is closed, compression begins as soon as vane **4** passes inlet port **3**-B.

If valve **14** is slightly or somewhat open, part or all of the charge passed before vane **4** is returned to suction inlet of **3**-B, thus reducing the "effective" compression ratio even further than illustrated.

The compression chamber **5**-C of the elliptical stator **8** is illustrated as being of lower volume than that of the expansion chamber **5**-E, therefore, always producing an "effective" compression ratio lower than the expansion ratio. Alternatively, both compression chamber **5**-C volume and expansion chamber **5**-E volume are equal for equal compression and expansion ratios. Any variation of these two volumes are within the scope of the invention. Air return conduit **13** and adjustable valve **14** allow the selective choice of compression ratios on engines with equal volumes of the two chambers or any variation ad infinitum.

Combustion Systems

Preparation and presentation of the air or fuel-air charge to a combustion chamber is similar for two different combustion systems.

Combustion System A: The primary air charge is received and compression begins and continues as rotor **2** rotates preferably with the very low "effective" compression ratio described here for low heat-of-compression. During the compression process in chamber **5**-C, a vane **4**, in compressing its air charge, approaches inlet of **22** injector valve **21**, which is alternatively an expansion valve of type **10**, FIG. **2**-B or **2**-D. Valve **21** opens and injects through port **22** a dense, cooled or "chilled" supercharging air into the flow of the cool primary air or fuel-air charge, just before vane **4** passes. Compression continues and as vane **4** nears outlet port **23**, which is fitted with a valve **25** which optionally is a one-way valve. The entire charge, initial and supercharge combined, is pressed through port **23** and valve **25** into combustion recess **5'**. (A seal **24** created by close proximity of rotor **2** and stator **8**, prevents compressed charge passing between rotor **2** and stator **8**, forcing it to pass into port **23** through valve **25**). As rotor motion continues, vane **4** rotates past stator recess **5'** and combustion chamber **5**-A in rotor **2** as the charge is ignited by spark plug **12**-A or HCCI while chamber **5**-A is open to chamber **5'**. The combustion chamber **5**-A, as it passes opening to combustion recess **5'** and is ignited, is sealed on its following side by seal **24**. The forward end of combustion**5**-A is sealed against pressure leak by the extending vane **4** and its optional vane seals **10**. The charge expands against vane **4** in chamber **5**-E, producing power, scavenging, air intake and compression of charge.

Combustion System B: An alternate method of introducing and igniting the fuel-air charge of engine of FIG. **30** is as follows: The chief difference in combustion system B is that the combustion chamber **5**-B (in phantom) in rotor **2** rotates past opening of combustion recess **5'** in stator **8** until the combustion chamber **5**-B is filled with charge and the back side sealed by proximity with rotor **2** (see FIG. **30**) and the charge is ignited by plug **12**-B.

Both air charges have been prepared and during the compression process, the primary air charge has been combined with the supercharging air and together have been made more dense and cool by the injection of the supercharging air. Together, they have been pumped through port **23** into combustion recess **5'**, ready for induction into combustion chamber **5**-B. The combustion chamber **5**-B of FIG. **30** (in phantom) in rotor **2**-B is immediately behind and opens on its leading end against vane **4**-B (also in phantom). Vane **4**-B rotates past combustion chamber opening **5'** which opens to face of rotor **2** and opening of combustion chamber **5**-B, to inject charge into **5**-B. In this system, spark plug **12**-A, combustion chamber **5**-A and vane **4** are replaced by their counterparts **12**-B, **5**-B and **4**-B or can function in conjunction with them if spaced equal distance apart. Chamber **5'** in stator **8** is open on the underside or has a port **5"** slideably in contact with the outer surface of rotor **2**, which with the underside of chamber **5'** being sealed by its proximity with rotor **2**, injects fuel-air charge into combustion chamber **5**-B as in rotating vane **4**-B passes port **5"** to chamber **5'** which opens to combustion chamber **5**-B to inject charge from port of chamber **5'**. Now, in the alternate system B, combustion chamber **5**-B has passed the opening to chamber **5'** with the following end of combustion chamber **5**-B being sealed by close proximity of stator **8** inter surface and rotor **2** top surface, just after closure of chamber **5**-B by stator **2**. The leading end of combustion chamber **5**-B is sealed by further extension of vane **4**-B. At the point where the back-side of chamber **5**-B is sealed by the proximity of stator inter facing, the fuel-air charge is ignited by spark plug **12**-B, producing the power surge by providing pressure against vane **4**-B which has a larger surface area than the back side of combustion chamber **5**-B and is movable. Rotor **2** rotates with vane(s) 4-B extending further into expansion chamber **5**-E, providing optionally an extended expansion ratio.

Method of Operation

Air is received by engine of FIG. **30** from two sources and put into the engine combustion chamber at two different times and at two different pressure levels and temperatures.

The primary charge enters compression chamber **5**-C of stator **8** at inlet port **3**-B as vane **4**-B rotates by inlet port **3**-B,

drawing in air or fuel-air charge. If valve **14** in conduit **13** is open, even partly, some or all of the air pumped to that point is returned to inlet port **3**-B, further reducing the "effective" compression ratio of the engine, which when ignited, expands the charge to a larger than normal volume, producing an extended expansion ratio. The compression chamber **5**-C can be smaller than the expansion chamber as shown in FIG. **30** or the two chambers can optionally be equal in volume or the compression chamber **5**-C may be of larger volume. The first situation producing an expansion ratio greater than the compression ratio and with the equal volume chambers producing equal compression and expansion ratios, excepting that with equal or larger volume compression chamber **5**-C, if valve **14** is wholly or partly open, the compression chamber will selectively produce an "effective" compression ratio less than the expansion ratio for an extended expansion ratio.

(The "effective" compression ratio is derived by dividing the volume of the expansion chamber by the volume of charge that produces heat during compression. That is, the volume of the compressing charge at the point where it begins to be compressed (producing heat), divided into the volume of the expansion chambers).

The preferably low compression air or fuel-air charge is being compressed in compression chamber **5**-C. Some time during the compression process, preferably late, at a point before vane **4**-B passes supercharge inlet port **22**, a very dense, cooled or chilled air or fuel-air charge is injected into the compression chamber **5**-C ahead of vane **4**-B. Compression continues and the entire charge is compressed into port **23** through optional valve **25**. Adjacent surfaces of rotor **2** and stator **8** are sealed against gas pressure at point **24** to just past port to to combustion recess **5'** and combustion chamber **5**-B, which follows adjacent to vane **4**-B, is filled with high pressure charge as rotor turns. In combustion system A, a one way valve **25** at channel **23** allows the charge to be ignited at the point the back side of combustion chamber **5**-A is sealed at point **24** by proximity of stator and rotor surfaces. The leading side of combustion chamber **5**-A is always sealed by extension of vane **4**. In combustion system B, the one way valve in channel **23** is optionally eliminated, allowing vane **4**-B to rotate past combustion recess **5'** outlet **5"** and combustion chamber **5**-B to be filled and the charge ignited as soon as back-side of combustion chamber **5**-B is sealed by stator **8** and rotor **2** inner surfaces meeting. The charge in system B is now expanding against the larger and less resistant surface vane **4**-B for the power pulse.

In system A or B, the rotor is now rotating with vanes **4**, or **4**-B, extending further into compression chamber **5**-E. Then at near the point the vanes are completely retracted, the stator **8** and vanes **4** come together with rotor **2** and scavenge the power chamber of exhausted fuel-air charge through port **17** and conduit **18**. The exhaust is now preferably ducted by exhaust conduit **18** to drive turbine on turbo-charger **15** which pumps air into the engine's supercharging system.

The total charge is now more dense than that of current engines, and with low"effective" compression ratios for both portions of charge is much cooler, producing greater power and torque and efficiency with ultra low polluting emissions.

The supercharging portion of air may be "compression chilled" by expanding through an expansion valve **10** as described for engines of FIG. **2**-B and FIG. **2**-C. This further reduces polluting emissions and increases power.

In all Designs, the first stage of compression of the supercharging air is followed by (a) air intercooler with optional bypass system consisting of a valve R and conduit X and (b) another compressor with its optional bypass system and (c) another intercooler with its optional bypass system. These are followed by a conduit **20** to convey the now dense and cool supercharging air or fuel-air charge to an injector valve **21** which injects the supercharging air through port **22** into the cool primary air charge during the compression process.

Control valves R and injector valves **21** or **10** in all Designs are alternatively operated and controlled by signals received by ECM-**27**, FIG. **2** which then adjust valve controls to produce charge density and temperatures to that required for spark ignition or HCCI operation.

The value of the new working cycle of the engine of FIG. **30** has been discussed under the description of the engine of FIG. **25** and **26** which produce the following results and advantages:

Results

1) Low peak temperatures and pressures.
2) A cool and much denser fuel-air charge.
3) Higher efficiency.
4) Greater torque.
5) Improved engine durability.

Advantages

1) Lower polluting emissions.
2) Increased vehicle range.
3) Longer engine life.
4) Greater reliability.
5) Lower RPM (due to increased torque)

The engine of this invention will selectively develop greater torque and power than engines of current technology while providing increased fuel efficiency and lower polluting emissions.

Referring now to FIG. **31**, there is shown a perspective view, with portions in cross-section and others schematically, of an air injected rotary engine in which a rotor **2** rotates on a central axis, having an elliptical stator **8** and an elliptical path for the vane **4** tips to follow. Vane tips **4** are chastened by track **6**, FIG. **32** which guides the vane tips within 2–3 mils of the stator's inner surface, thus preventing any "rubbing" friction in the engine. As in engine of FIG. **30**, vane seals are lightly spring loaded.The engine operates much in the fashion of engine of FIG. **30** in that an adjustable compression ratio system provides variation in volume of the compression chamber **5**-C as compared to the volume of the expansion chamber **5**-E, whether or not volumes of compression chamber **5**-C and expansion chamber **5**-E are equal, which volume ratios are optional.

Doubly Compressed—Doubly Cooled

The chief difference in the engine construction operation from engine of FIG. **30** is that only one source of air **3**-B is provided and the first stage of compression is accomplished in the engine compression chamber. In this engine, the compression chamber **5**-C is preferably the same volume or even greater than that of the expansion chamber **5**-E with port **14"** and valve **14** with conduit **13** selectively varying the "effective" compression ratio in regard to power, torque, efficiency and emissions characteristics demands of the engine, all preferably controlled by ECM-**27** as described for engine of FIG. **2**. The expansion of this engine can be selectively varied from less than the compression ratio to much greater than the effective compression ratio.

The engine is alternatively supercharged by pre-compressing the air entering inlet port **3**-B or by constructing the compression chamber with a much larger volume than that of the expansion chamber. Thus, the engine is

supercharged while operating with valve **14** closed. If the port **14'** is at a point of equal volume fully open, the compression ratio and expansion ratio would be equal. If volume of compression chamber **5**-C is higher and outlet port **14'** is higher, opening valve **14**, more or less, variably or selectively, produces equal compression and expansion ratios or a low "effective" compression ratio with extended expansion ratio.

In an alternate design, compressor **18** and intercooler **19** are eliminated and the charge, compressed in a single stage, is directed as shown after intercooling to compression recess through inlet valve **23'** or by way of conduit **20'** (in phantom) tp compression chamber **5**-C where the charge, now cooled, will be recompressed, perhaps with effective compression ratio of 2:1 or 3:1. The entire charge is then compressed into combustion recess **5'** by way of port **23"**, also in phantom. The charge is then introduced into combustion chamber **5**-A or **5**-B, according to instructions for combustion systems A or B for engines of FIG. **30** and FIG. **31**.

Operation

Air or fuel-air charge is taken in at port **3**-B by suction of vane **4** on rotor **2** as the vane is rotated past port **3**-B. The "effective" compression ratio is selectively chosen by (a) the volume of the compression chamber **5**-C in regard to the need and the volume of the expansion chamber **5**-E, by (b) the point where port **14'** is placed in the compression chamber or by (c) whether valve **14** is open and to what extent.

If valve **14** is closed, compression begins as soon as vane **4** passes port **3**-B. If port **14** is open, compression begins after that point, and depending on how much charge is returned, compression continues and the entire charge is compressed into outlet and optional valve **21** to conduit **16**, which in turn conveys the charge to intercooler **17**, compressor **18**, intercooler **19**, by conduit **20** to air injector valve **22**, and the entire charge now being doubly compressed and intercooled is injected into recess **5'** for induction into combustion chamber **5**-A or **5**-B and ignited as described for alternate combustion systems A and B of engine of FIG. **30**.

Also in this system, bypass valves R_1, R_2 and R_3 with conduits X_1, X_2 and X_3 are in the manner of valves **3, 4, 5** and **6** of engine of FIG. **2**, controlled by ECM-**27** to produce optimum temperature at the point of charge ignition for spark ignition or HCCI operation.

In any engine of this invention, fuel is optionally carbureted or injected at any point feasible. After the air or fuel-air has been introduced into chamber **5'**, the operation of the engine of FIG. **31** is the same as that of engine of FIG. **30**, utilizing alternate combustion system A or system B with components spark plug **12**-A, combustion chamber **5**-A and vane **4** being replaced by counter parts spark plug **12**-B, combustion chamber **5**-B and vane **4**-B. The two systems can be in conjunction with each other if spaced properly.

In operating in system A in both FIGS. **30** and **31**, valve **23**, which is optionally one-way, prevents charge back-flow or backfiring at the time charge ignition. Combustion chamber **5**-A and vane **4** are in the position shown and with combustion chamber **5**-A filled, the charge is ignited for the power surge, which also scavenges the chamber, induces and compresses a new charge which is pressed into chamber **5'**.

In alternate system B, operation in engine of FIGS. **30** and **31**, the charge is introduced into combustion chamber **5**-B as it passes bottom port of chamber **5'** and as shown with backside of combustion chamber **5**-B, sealed by proximity of stator and rotor interfaces and with vane **4**-B, by extension sealing the leading side of combustion chamber **5**-B, the charge is ignited by spark plug **12**-B for the power surge, producing three power surges per revolution and is scavenged, receives fresh air charge, compresses charge and loads chamber **5'** for the next ignition.

In either combustion system, A or B, there is an alternate system for engine of FIG. **31** of introducing the charge from conduit **20** to combustion recess **5'**. Alternatively, conduit **20**, valve **23** and port **22** open into compression chamber **5**-C just after valve-port **21** and before port **23** in FIG. **30**. Now, optional port **23"** in engine of FIG. **31** conveys the air or fuel-air charge from compression chamber **5**-C into combustion recess **5'**. This is the same means of introducing the charge to recess **5'** as done in engine of FIG. **30**. Thus, the doubly compressed and intercooled charge is now further compressed for perhaps an effective compression ratio of 2:1 or 3:1.

The advantages of this engine are the same as those for engine of FIG. **30** with only a little less power than that of engine receiving the supercharging portion of air from the external source.

As described and depicted earlier for the engines of FIGS. **24, 24**-B, **25** and **25**-B, the secondary or supplementary or doubly compressed air or fuel-air charge is alternatively as sole or supplementary charge, injected directly into the combustion chambers of engines of FIGS. **24, 25, 26, 30** and **31** for all Operational Designs of the engines of this invention.

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

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

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

What is claimed is:

1. A method of operating an internal combustion engine having a crankshaft driven by at least one piston moving through at least a compression stroke and an expansion stroke aided by combustion taking place within a cylinder, said method comprising the steps of

introducing air through a first port into a cylinder;

closing the first port at a point selected from the group consisting of a point prior to the beginning of the compression stroke and a point after the compression stroke has begun, thereby capturing a first, light air

charge in the cylinder and thereby defining an effective compression ratio lower than or equal to the expansion ratio;

compressing air outside the cylinder;

cooling the compressed air outside the cylinder; and

introducing the cooled, compressed air through a second port into the cylinder at some point after compression has begun,

wherein the second port is open only while the first port is closed.

2. The method of claim **1**, further comprising the step of:

varying the point-in-time during travel of the piston at which the cooled, compressed air is introduced through the second port during at least two of the power cycles.

3. The method of claim **2**, wherein the step of varying the point-in-time includes the steps of:

introducing cooled, compressed air through the second port during a first of the plurality of power cycles when the piston is at a first point in its compression process; and

introducing cooled, compressed air through the second port during a second of the plurality of power cycles when the piston is at a second point in its compression process, the second point being closer to top-dead-center than the first point.

4. The method of claim **1**,

wherein the step of introducing air through a first port includes the step of introducing during each power cycle air through the first port into the cylinder;

wherein the step of introducing cooled, compressed air includes introducing during each power cycle cooled, compressed air through a second port into the cylinder, including the steps of varying the volume of the air introduced through the first port and varying the pressure at which the cooled, compressed air is introduced into the second port during at least two of the power cycles.

5. The method of claim **1**, further comprising the steps of:

expelling from the cylinder, during the compression stroke, at least a portion of any air in the cylinder;

after the expelling step, introducing the cooled, compressed air into the cylinder after compression has begun within the cylinder;

mixing the air charge with fuel; and

igniting the mixture near top dead center of the compression process.

6. The method of claim **5**, wherein the introducing step includes the step of introducing the cooled, compressed air at the end of the compression process.

7. The method of claim **5**, wherein the cylinder is devoid of air immediately before the cooled, compressed air is first introduced.

8. The method of claim **5**, wherein there is no appreciable pressure in the cylinder when the cooled, compressed air is first introduced.

9. The method of claim **5**, wherein the pressure in the cylinder is approximately ambient at the moment the cooled, compressed air is first introduced.

10. The method of claim **1**, wherein the second port is open only during the compression stroke.

11. The method claim **1**, wherein the second port is open during a compression stroke of the piston.

12. The method of claim **1**, wherein said second port opens during the compression stroke, including at the beginning of the compression stroke or at any time thereafter during the compression stroke.

13. The method of claim **1**, wherein said second port opens prior to the beginning of the compression stroke and closes after the compression stroke has begun.

14. The method of claim **1**,

wherein introducing the cooled, compressed air includes opening the second port and closing the second port; and

wherein the method further comprises varying the point in time during travel of the piston at which the second port is closed during at least two of the power cycles.

15. An internal combustion engine, comprising an engine block defining at least one cylinder therein, a first inlet port and a second inlet port communicating between said cylinder and a source of air, an exhaust port through which exhausted gases are expelled from said cylinder, a piston movably mounted within said cylinder, at least one compressor in fluid communication via a conduit between said source of air and at least said second port; said second port being open only while said first port is closed, said engine further comprising a cooler operatively connected between said second port and an outlet to said at least one compressor; and said engine being further characterized by a power cycle having an effective compression ratio lower than or equal to the expansion ratio and by the presence in the cylinder of a cool, dense, heavy air charge which charge was pre-compressed and pre-cooled outside the cylinder and was introduced into the cylinder at some point after the compression process has begun.

16. The engine of **15**, wherein said piston moves through at least an intake stroke and a compression stoke, said engine further comprising control mechanism selectively timed to close said first port prior to completion of the piston intake stroke.

17. The engine of claim **15**, wherein said piston moves through at least an intake stroke and a compression stoke, said engine further comprising control mechanism selectively timed to close said first port only after the compression stroke has begun.

18. The engine of claim **15**, further comprising means for directing low pressure air through said first port and into said cylinder and for directing air highly compressed by said at least one compressor through said second port and into said cylinder during a compression stroke of said piston.

19. The engine of claim **15**, wherein said second port is open only during a compression stroke of said piston.

20. The engine of claim **15**, wherein said second port is open only after compression has begun during a compression stroke of said piston.

21. The engine of claim **15**, wherein said second port opens during the compression stroke, including at the beginning of the compression stroke or at any time thereafter during the compression stroke.

22. The engine of claim **15**, wherein said piston moves through at least an intake stroke and a compression stroke, said engine further comprising control mechanism configured to selectively vary the point in time during travel of the piston at which the second port is closed during at least two of the power cycles.

23. A method of operating an internal combustion engine having a crankshaft driven by at least one piston moving through at least a compression stroke and an expansion stroke aided by combustion taking place within a cylinder, said method comprising the steps of

supplying air through a first port into a cylinder;

compressing air outside the cylinder;

cooling the compressed air outside the cylinder; and

supplying the cooled, compressed air through a second port into the cylinder,

wherein the second port is open only while the first port is closed and

wherein the step of supplying the cooled, compressed air includes the steps of opening the second port prior to the beginning of the compression stroke and closing the second port after the compression stroke has begun.

24. An internal combustion engine, comprising an engine block defining at least one cylinder therein, a first inlet port and a second inlet port communicating between said cylinder and a source of air, an exhaust port through which exhausted gases are expelled from said cylinder, a piston movably mounted within said cylinder, at least one compressor in fluid communication via a conduit between said source of air and at least said second port; said second port being open only while said first port is closed, said engine further comprising a cooler operatively connected between said second port and an outlet to said at least one compressor; and wherein said piston moves through at least an intake stroke and a compression stoke, said engine further comprising control mechanism selectively timed to close said first port at a point selected from the group consisting of a point prior to the completion of the piston intake stroke and a point after the compression stroke has begun.

25. An internal combustion engine, comprising an engine block defining at least one cylinder therein, a first inlet port and a second inlet port communicating between said cylinder and a source ol air, an exhaust port through which exhausted gases are expelled from said cylinder, a piston movably mounted within said cylinder, at least one compressor in fluid communication via a conduit between said source of air and at least said second port; said second port being open only while said first port is closed, said engine further comprising a cooler operatively connected between said second port and an outlet to said at least one compressor; and, wherein said second port is open during at least a portion of an intake stroke of the piston.

26. The engine of claim **25**, wherein said piston moves through at least an intake stroke and a compression stroke, said engine further comprising control mechanism selectively timed to open said second port during the intake stroke.

27. An internal combustion engine, comprising an engine block defining at least one chamber therein, a first inlet port and a second inlet port communicating between said chamber and a source of air, an exhaust port through which exhausted gases are expelled from said chamber, a piston movably mounted within said chamber, at least one compressor in fluid communication via a conduit between said source of air and at least said second port; said second port being open only while said first port is closed, said engine further comprising a cooler operatively connected between said second port and an outlet to said at least one compressor, wherein said chamber is defined by at least one chamber wall and by the piston, and wherein said first inlet port and said second inlet port communicate with said chamber through separate apertures formed in said chamber wall.

28. The engine of claim **27**, wherein said chamber wall includes at least a cylinder wall portion and a head wall portion, and said first inlet port communicates with said chamber through an aperture in said cylinder wall portion.

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