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(54) **COLD START STRATEGY AND SYSTEM FOR GASOLINE DIRECT INJECTION COMPRESSION IGNITION ENGINE**

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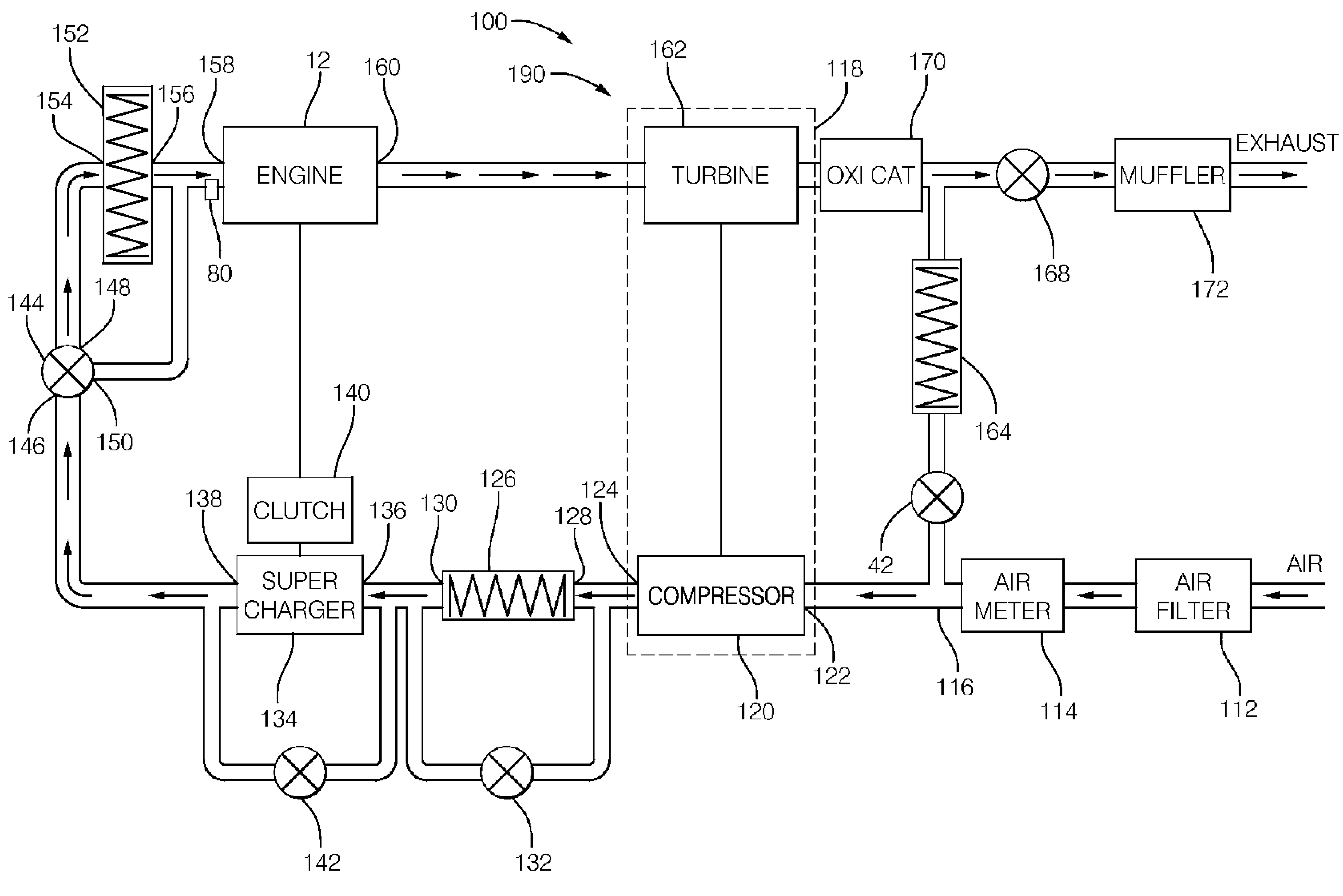
(57) **ABSTRACT**

A method for starting a compression ignition engine having at least one cylinder with a reciprocating piston located therein, an intake valve configured to control the intake of air to an intake port of the cylinder and an exhaust valve configured to control the expulsion of gas from an exhaust port of the cylinder. The method includes the steps of: cranking the engine, conditioning intake air at the intake port of the cylinder to raise the temperature of air in the cylinder, controlling a valve timing the intake valve and/or the exhaust valve to allow the piston to compress the air within the cylinder, thereby increasing the temperature of the air within the cylinder, and injecting fuel into the cylinder when the air within the cylinder has been heated to a temperature sufficient to support compression ignition of a gasoline and air mixture within the cylinder.



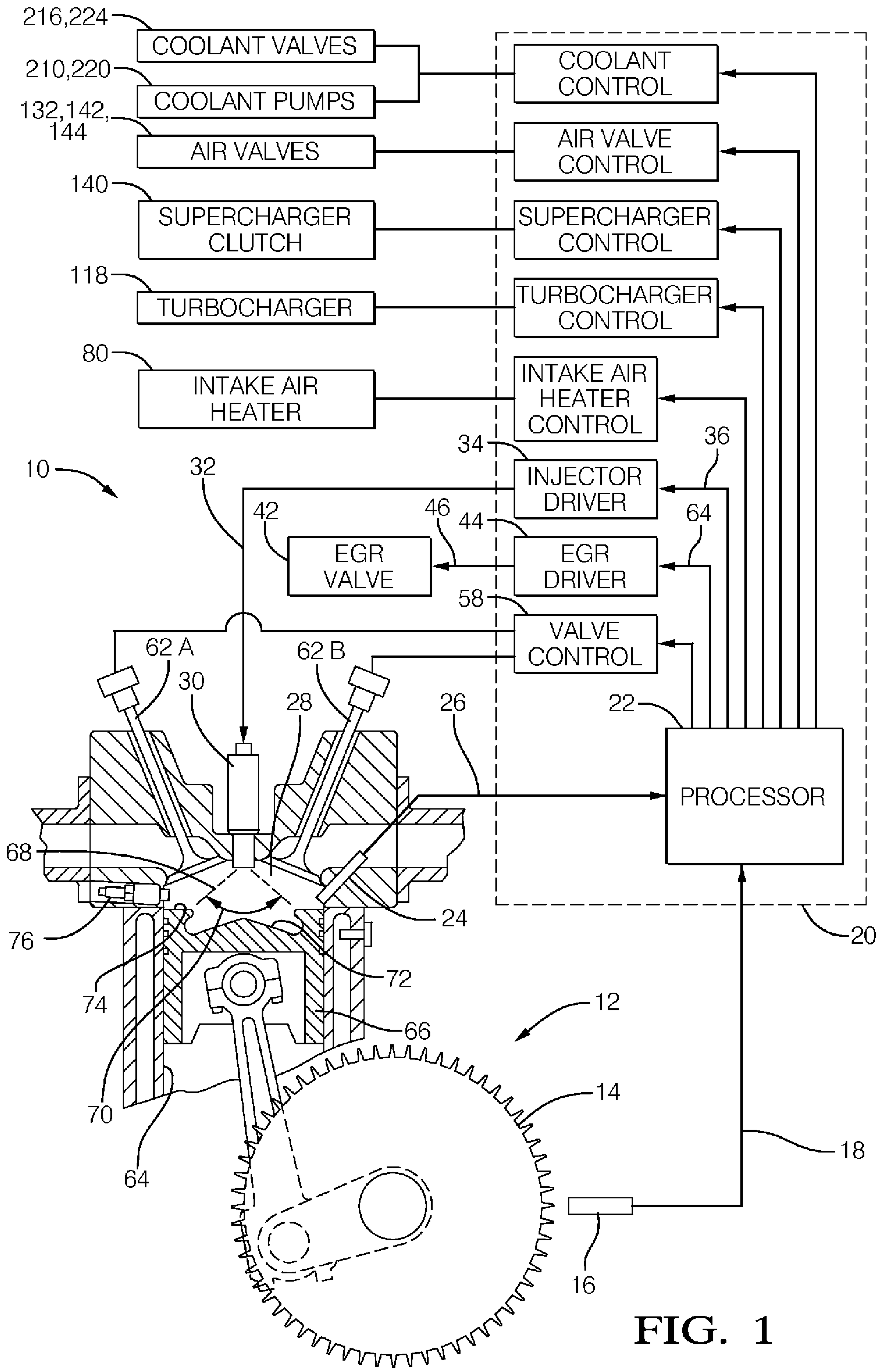

216,224
COOLANT VALVES
210,220
COOLANT PUMPS
132,142, 144
AIR VALVES
140
SUPERCHARGER CLUTCH
118
TURBOCHARGER
80
INTAKE AIR HEATER
COOLANT CONTROL
AIR VALVE CONTROL
SUPERCHARGER CONTROL
TURBOCHARGER CONTROL
INTAKE AIR HEATER CONTROL
34
INJECTOR DRIVER
36
10
32
42
EGR VALVE
46
44
EGR DRIVER
64
58
VALVE CONTROL
62 A
62 B
30
28
26
22
PROCESSOR
68
24
20
76
74
72
12
66
70
14
64
18
16

FIG. 1

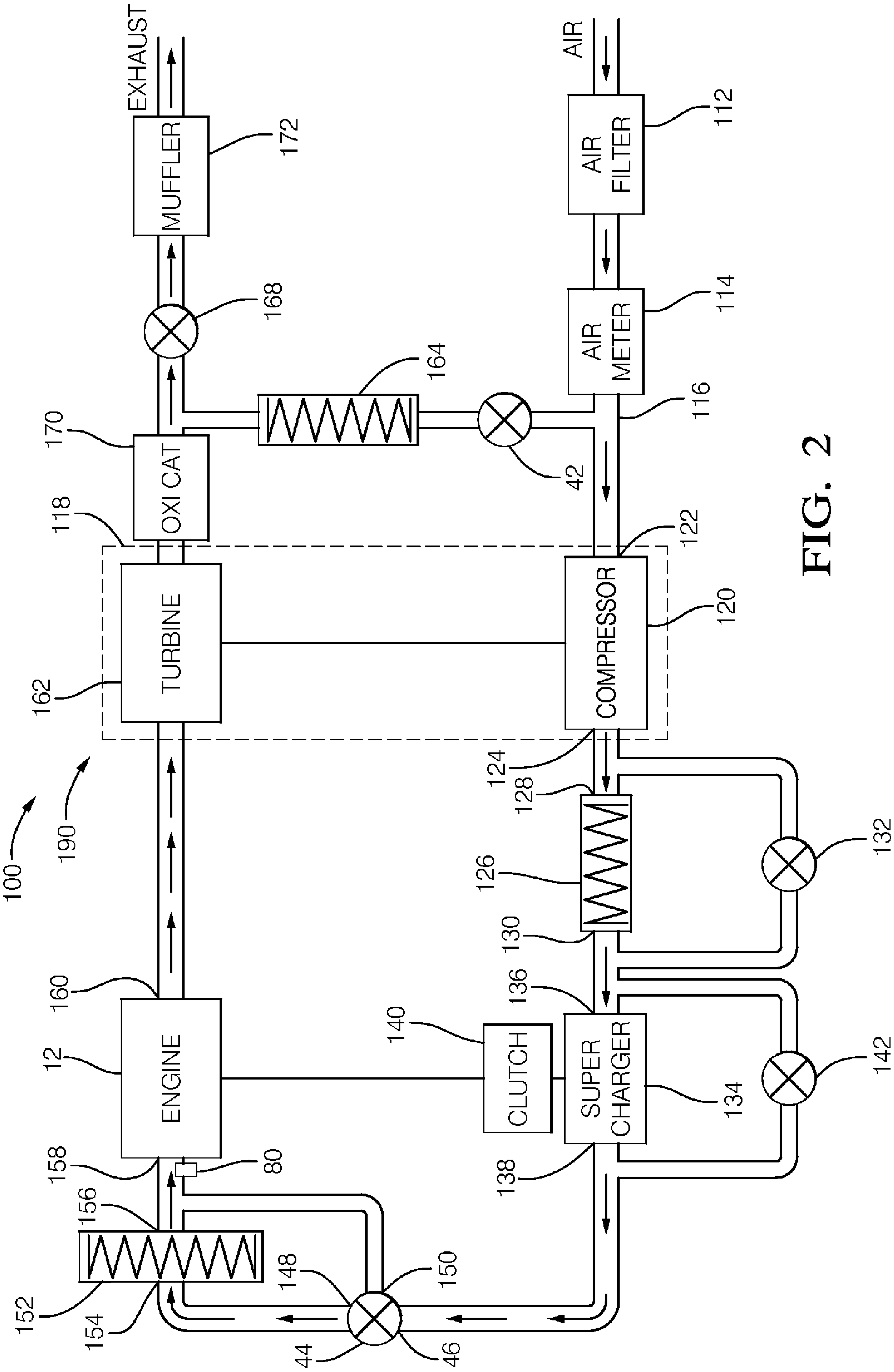

EXHAUST
MUFFLER
172
168
170
OXI CAT
118
164
42
AIR
AIR FILTER
112
AIR METER
114
116
122
TURBINE
162
COMPRESSOR
120
124
128
126
130
132
100
190
160
ENGINE
12
140
CLUTCH
136
SUPER CHARGER
134
142
138
158
80
156
152
154
148
150
144
146

FIG. 2

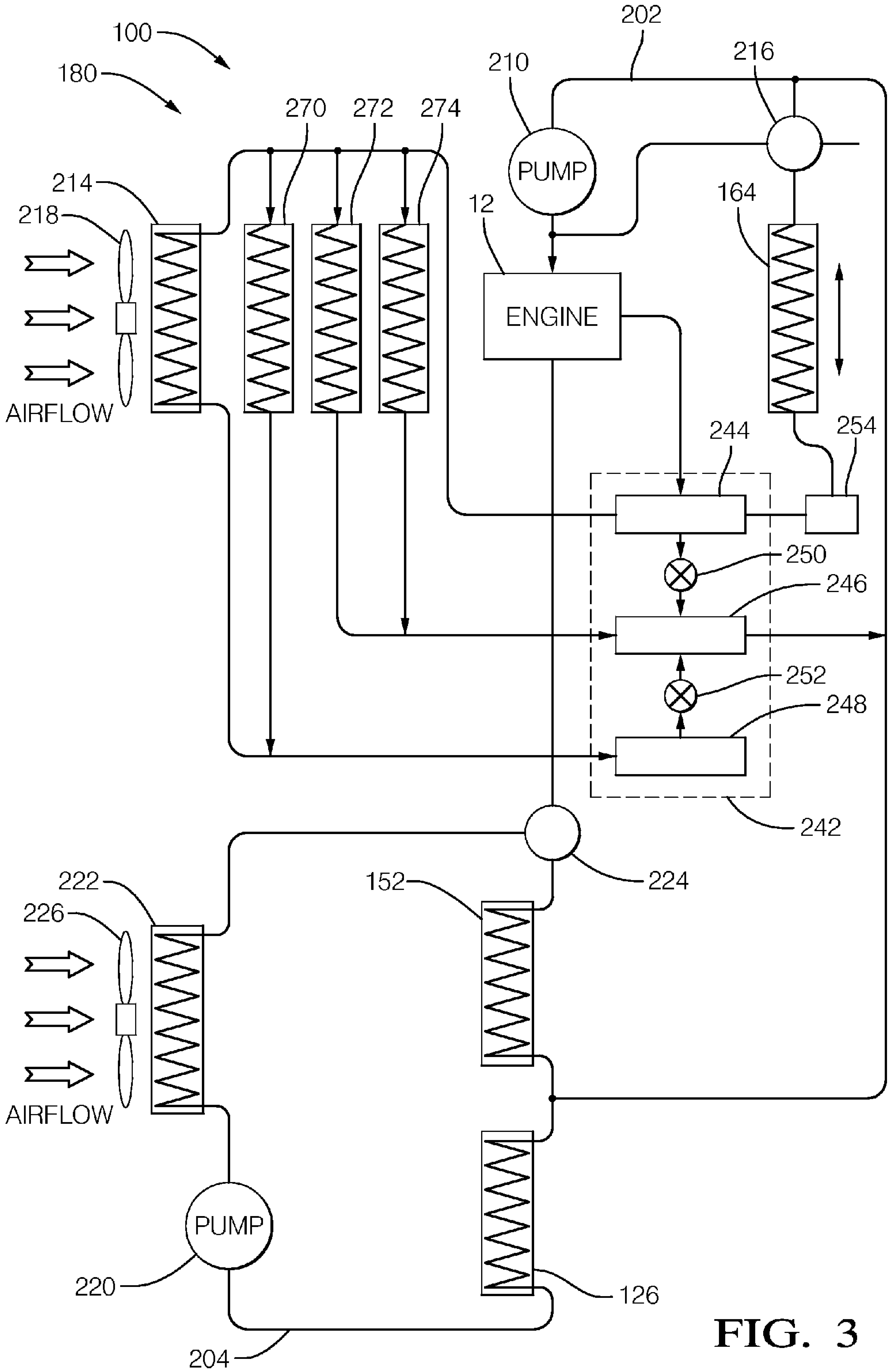

100
180
202
210
216
270
272
274
214
218
PUMP
164
12
ENGINE
AIRFLOW
244
254
250
246
252
248
242
224
222
226
152
AIRFLOW
PUMP
220
126
204

FIG. 3

COLD START STRATEGY AND SYSTEM FOR GASOLINE DIRECT INJECTION COMPRESSION IGNITION ENGINE

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] This invention was made with government support under Contract No. DE-EE0003258 awarded by the Department of Energy. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0002] Gasoline Direct-injection Compression-Ignition (GDCI) is an engine operating mode that shows promise in improving engine emissions performance and efficiency. GDCI provides low-temperature combustion for high efficiency, low NOx, and low particulate emissions over the complete engine operating range. Low-temperature combustion of gasoline may be achieved using multiple late injection (MLI), intake boost, and moderate EGR. GDCI engine operation is described in detail in U.S. Patent Application Publication 2013/0213349A1, the entire contents of which are hereby incorporated herein by reference.

[0003] The autoignition properties of gasoline fuels require higher in-cylinder pressure and temperature compared to diesel fuel to achieve compression ignition. This is especially a concern when cold starting an engine.

[0004] As a result of the autoignition properties of gasoline fuels, improvements in the ability to cold start a GDCI engine are desired.

BRIEF SUMMARY OF THE INVENTION

[0005] In a first aspect of the invention, a method for starting a GDCI engine is provided. The method includes cranking the engine, conditioning intake air provided at the intake port of an engine cylinder to raise the temperature and/or pressure of air in the cylinder, and controlling valve timing to allow compression of air in the cylinder to additionally increase the temperature and/or pressure in the cylinder. When in-cylinder conditions are sufficient to support compression ignition of a gasoline and air mixture within the cylinder, fueling of that cylinder is commenced.

[0006] In a second aspect of the invention, a system for starting a GDCI engine is provided. The system includes means for cranking the engine, means for increasing the temperature and/or pressure of intake air provided at the intake port of an engine cylinder, means for controlling the timing of opening and closing of engine intake and exhaust valves, and means for injecting fuel into the cylinder. The system also includes a controller configured to enable engine control hardware to perform the method steps according to the first aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a schematic view of an embodiment of an engine control system suitable for controlling a GDCI engine.

[0008] FIG. **2** is a block diagram of an embodiment of the gas (air and/or exhaust) paths of an engine system.

[0009] FIG. **3** is a block diagram of an embodiment of the coolant paths of an engine system.

DETAILED DESCRIPTION OF THE INVENTION

[0010] As used herein, the term "cold start" refers to starting the engine when the temperature of the components of the engine and the fluids within the engine are below their respective temperatures when the engine has been operating long enough to reach thermal equilibrium at temperatures above ambient temperature. A "cold start event" refers to the act of performing a cold start of the engine, including the time when an engine start is predicted but before the actual initiation of engine cranking, the time when the engine is cranked, and the transition to a running state where the cranking means is disengaged and the engine rotational speed remains above a minimum threshold.

[0011] FIG. **1** illustrates a non-limiting embodiment of an engine control system **10** suitable for controlling the cold start of a GDCI internal combustion engine **12**. The engine **12** is illustrated as having a single cylinder bore **64** containing a piston **66**, wherein the region above the piston **66** defines a combustion chamber **28**; however it will be appreciated that the system **10** may be adapted to engines having multiple cylinders and combustion chambers. The engine control system **10** may control an engine having multiple combustion chambers by individually controlling each of the multiple combustion chambers, or may control such an engine based on a signal from a sensor that is representative of a typical or average condition in each combustion chamber. The system **10** may include a toothed crank wheel **14** and a crank sensor **16** positioned proximate to the crank wheel **14** such that the crank sensor **16** is able to sense rotational movement of the crank wheel teeth and output a crank signal **18** indicative of a crank angle and a crank speed.

[0012] The engine control system **10** may also include a controller **20**, such as an engine control module (ECM), configured to determine a crank angle and a crank speed based on the crank signal **18**. The controller **20** may include a processor **22** or other control circuitry as should be evident to those in the art. The controller **20** or processor **22** may include memory, including non-volatile memory, such as electrically erasable programmable read-only memory (EEPROM) for storing one or more routines, thresholds and captured data. The one or more routines may be executed by the processor **22** to perform steps for determining a prior engine control parameter and scheduling a future engine control signal such that a future engine control parameter corresponds to a desired engine control parameter. FIG. **1** illustrates the processor **22** and other functional blocks as being part of the controller **20**. However, it will be appreciated that it is not required that the processor **22** and other functional blocks be assembled within a single housing, and that they may be distributed about the engine **12**.

[0013] Continuing to refer to FIG. **1**, the engine control system **10** may include a combustion sensing means **24** configured to output a combustion signal **26** indicative of a combustion characteristic of a combustion event occurring within the combustion chamber **28**. One way to monitor the progress of a combustion event is to determine a heat release rate or cumulative heat release for the combustion event. However, because of the number and complexity of measurements, determining heat release may not be suitable for controlling engines during field use such as when engines are operated in vehicles traveling in uncontrolled environments like public roadways. A combustion detection means suitable for field use may provide an indication of a combustion characteristic that can be correlated to laboratory type measurements such as heat release. Exemplary combustion detection means **24** include, but are not limited to, an ionization sensor configured to sense the ionization level of the combustion products in the combustion chamber **28** or a pressure sensor configured to sense the pressure within the combustion chamber **28**. Another device that may be useful for indicating some aspect of the combustion process is a combustion knock sensor. The combustion detection means **24** may be any one of the exemplary sensors, or a combination of two or more sensors arranged to provide an indication of a combustion characteristic.

[0014] The engine control system **10** includes one or more engine control devices operable to control an engine control parameter in response to an engine control signal, wherein the engine control parameter influences when autoignition occurs. One example of an engine control device is a fuel injector **30** adapted to dispense fuel **68** in accordance with an injector control signal **32** output by an injector driver **34** in response to an injection signal **36** output by the processor **22**. The fuel injection profile may include a plurality of injection events. Controllable aspects of the fuel injection profile may include how quickly or slowly the fuel injector **30** is turned on and/or turned off, a fuel rate of fuel **68** dispensed by the fuel injector **30** while the fuel injector **30** is on, or the number of fuel injections dispensed to achieve a combustion event. Varying one or more of these aspects of the fuel injections profile may be effective to control autoignition.

[0015] The exemplary engine control system **10** includes an exhaust gas recirculation (EGR) valve **42**. While not explicitly shown, it is understood by those familiar with the art of engine control that the EGR valve regulates a rate or amount of engine exhaust gas that is mixed with fresh air being supplied to the engine to dilute the percentage of oxygen and/or nitrogen in the air mixture received into the combustion chamber **28**. The controller **20** may include an EGR driver **44** that outputs an EGR control signal **46** to control the position of the EGR valve **42**. The EGR driver may, for example, pulse width modulate a voltage to generate an EGR control signal **46** effective to control the EGR valve to regulate the flow rate of exhaust gases received by the engine **12**.

[0016] Referring again to FIG. **1**, the engine control system **10** may include other engine management devices. For example the engine control system **10** may include a turbocharger **118**. The turbocharger **118** receives a turbocharger control signal from a turbocharger control block that may control a boost pressure by controlling the position of a waste gate or bypass valve, or controlling a vane position in a variable geometry turbocharger. The engine control system **10** may also include a supercharger driven by the engine through a supercharger clutch **140**, the supercharger clutch **140** being controlled by a supercharger control block in the controller **20**. The engine control system **10** may also include a valve control block **58** that may directly control the actuation of engine intake valve **62**A and exhaust valve **62**B, or may control the phase of a cam (not shown) actuating the intake valve **62**A and/or the exhaust valve **62**B.

[0017] Still with reference to FIG. **1**, the engine control system **10** may include one or more intake air heaters **80** configured to heat air at the intake manifold or intake port of each cylinder. Each intake air heater **80** is controllable by a control signal received from an intake air heater control block in a manner to be discussed in further detail below.

[0018] Although not specifically indicated in FIG. **1**, the engine control system **10** may include additional sensors to measure temperature and/or pressure at locations within the air intake system and/or the engine exhaust system.

[0019] FIG. **2** is a block diagram of a non-limiting embodiment of the gas paths **190** of a GDCI system usable with the engine **12** of FIG. **1**. This diagram depicts the routing and conditioning of gases (e.g. air and exhaust gas) in the system. Referring to FIG. **2**, air passes through an air filter **112** and a mass airflow sensor **114** into an air duct **116**. The air duct **116** channels air into the air inlet **122** of the compressor **120** of a turbocharger **118**. Air is then channeled from the air outlet **124** of the compressor **120** to the air inlet **128** of a first charge air cooler **126**. The air outlet **130** of the first charge air cooler **126** is connected to the air inlet **136** of a supercharger **134**. A first charge air cooler bypass valve **132** is connected between the air inlet **128** and the air outlet **130** of the first charge air cooler **126** to controllably divert air around the first charge air cooler **126**.

[0020] Continuing to refer to FIG. **2**, air at the air outlet **130** of the first charge air cooler **126** is channeled to the air inlet **136** of a supercharger **134**, which is driven by the engine **12** through a controllable clutch **140**. The air from the air outlet **138** of the supercharger **134** is channeled to a first port **146** of a second charge air cooler bypass valve **144**. The second charge air cooler bypass valve **144** in FIG. **2** allows air entering the first port **146** to be controllably channeled to the second port **148**, to the third port **150**, or to be blended to both the second port **148** and to the third port **150**. Air that is channeled through the second port **148** of the second charge air cooler bypass valve **144** enters an air inlet port **154** of a second charge air cooler **152**, through which the air passes by way of an air outlet port **156** of the second charge air cooler **152** to the charge air intake port **158** of the engine **12**. Air that is channeled through the third port **150** of the second charge air cooler bypass valve **144** passes directly to the charge air intake port **158** of the engine **12** without passing through the second charge air cooler **152**. An air intake heater **80** is configured to heat air at the intake port of a cylinder of the engine **12**.

[0021] Still with reference to FIG. **2**, engine exhaust gas exits an exhaust port **160** of the engine **12** and is channeled to the turbine **162** of the turbocharger **118**. Exhaust gas exiting the turbine **162** passes through a catalytic converter **170**. Upon exiting the catalytic converter **170**, the exhaust gas can follow one of two paths. A portion of the exhaust gas may pass through an EGR cooler **164** and an EGR valve **42**, to be reintroduced into the intake air stream at air duct **116**. The remainder of the exhaust gas that is not recirculated through the EGR system passes through a backpressure valve **168**, and a muffler **172**, to be exhausted out a tail pipe.

[0022] It will be appreciated from the foregoing description of FIG. **2** that the focus of FIG. **2** is on the transport and conditioning of gas constituents, i.e. air into the engine **12** and exhaust gas out of the engine **12**. Some of the components in FIG. **2** affect the temperature and/or the pressure of the gas flowing through the component. For example the turbocharger compressor **120** and the supercharger **134** each increase both the temperature and the pressure of air flowing therethrough. The first charge air cooler **126**, the second charge air cooler **152**, and the EGR cooler **164** are each heat exchangers that affect the temperature of the gas (air or exhaust gas) flowing therethrough by transferring heat from the gas to another medium. In the embodiment of FIGS. **2** and **3**, the other heat transfer medium is a liquid coolant, discussed in further detail in relation to FIG. **3**. In an alternate embodiment, a gaseous coolant may be used in lieu of a liquid coolant.

[0023] FIG. **3** depicts an embodiment of coolant paths **180** of the system **100** for conditioning intake air into an engine **12**. FIG. **3** includes several components such as the engine **12**, the first charge air cooler **126**, the second charge air cooler **152**, and the EGR cooler **164** that were previously discussed with respect to their functions in the gas paths **190** of the system **100** depicted in FIG. **2**. The coolant system **180** may further include an oil cooler **270**, a heat exchanger **272** to provide cooling for the turbocharger **122** and a heater core **274**, a temperature sensing device, a pressure sensing device, and/or other components not shown in FIG. **2**.

[0024] Referring to FIG. **3**, the coolant paths **180** of the system **100** for conditioning intake air includes a first coolant loop **202**. The first coolant loop **202** includes a first coolant pump **210** configured to urge liquid coolant through coolant passages in the engine **12** and through a first radiator **214**. The first coolant pump **210** may conveniently be a mechanical pump driven by rotation of the engine **12**. The first radiator **214** may conveniently be a conventional automotive radiator with a controllable first air supply means **218** configured to urge air over the first radiator **214**. Preferably the first air supply means **218** comprises a variable speed fan, but the first air supply means **218** may alternatively comprise, by way of non-limiting example, a single speed fan, a two speed fan, a fan of any sort in conjunction with one or more controllable shutters, or the like, without departing from the inventive concept.

[0025] Continuing to refer to FIG. **3**, the coolant paths **180** of the system **100** includes a thermostat crossover assembly **242** within which is defined a first chamber **244**, a second chamber **246**, and a third chamber **248**. A first thermostat **250** allows fluid communication between the first chamber **244** and the second chamber **246** when the temperature of the coolant at the first thermostat **250** is within a first predetermined range. A second thermostat **252** allows fluid communication between the third chamber **248** and the second chamber **246** when the temperature of the coolant at the second thermostat **252** is within a second predetermined range. It will be appreciated that, while the first chamber **244**, the second chamber **246**, the third chamber **248**, the first thermostat **250**, and the second thermostat **252** are depicted as housed in a common enclosure, these components may be otherwise distributed within the system **180** without departing from the inventive concept.

[0026] The embodiment depicted in FIG. **3** further includes the EGR cooler **164**, one coolant port of which is connected to a four-way coolant valve **216**. The other coolant port of EGR cooler **164** is fluidly coupled to the first chamber **244** through an orifice **254**.

[0027] Continuing to refer to FIG. **3**, the coolant paths **180** of the system **100** further includes a second coolant loop **204**. The second coolant loop **204** includes a second coolant pump **220** configured to urge liquid coolant through a second radiator **222**, the second charge air cooler **152**, a three-way coolant valve **224**, and the first charge air cooler **126**. The second radiator **222** may conveniently be a conventional automotive radiator with a controllable second air supply means **226** configured to urge air over the second radiator **222**. Preferably the second air supply means **226** comprises a variable speed fan, but the second air supply means **226** may alternatively comprise, by way of non-limiting example, a single speed fan, a two speed fan, a fan of any sort in conjunction with one or more controllable shutters, or the like, without departing from the inventive concept. Alternately, the second radiator **222** may be positioned in line with the first radiator **214** such that the first air supply means **218** urges air over both the second radiator **222** and the first radiator **214**, in which case the second air supply means **226** would not be required.

[0028] Coolant communication between the first coolant loop **202** and the second coolant loop **204** is enabled by the three-way coolant valve **224** and a conduit **240**. Control of the four-way coolant valve **216** and the three-way coolant valve **224** may be employed to achieve desired temperature conditioning of intake air. Operation of a similar system is disclosed in U.S. patent application Ser. No. 13/469,404 titled "SYSTEM AND METHOD FOR CONDITIONING INTAKE AIR TO AN INTERNAL COMBUSTION ENGINE" filed May 11, 2012, the entire disclosure of which is hereby incorporated herein by reference.

[0029] The GDCI combustion process has demonstrated very high thermal efficiency and very low NOx and particulate matter emissions. The GDCI combustion process includes injecting gasoline fuel into the cylinder with appropriate injection timing to create a stratified mixture with varying propensity for autoignition. Heat and pressure from the compression process produces autoignition of the air/fuel mixture in the cylinder with burn duration long enough to keep combustion noise low, but with combustion fast enough to achieve high expansion ratio for all fuel that is burned.

[0030] A particular challenge in GDCI combustion is cold starting the engine. Gasoline fuel has characteristics such that it is resistant to autoignition. As a result, the in-cylinder pressure and temperature for gasoline need to be relatively high compared to diesel fuel to achieve compression ignition. In order to achieve robust combustion in a GDCI engine that has not yet warmed up, a cold start strategy and associated hardware are required.

[0031] A method for starting a GDCI engine includes cranking the engine **12**. Engine cranking may be achieved by conventional means, such a starter motor or a belt-alternator-starter (BAS) system.

[0032] The method for starting the GDCI engine **12** further includes conditioning the intake air provided at the intake port of the cylinder to raise the temperature of the air in the cylinder. Conditioning the intake air may be achieved by providing supplemental heat, for example by using an electric heater **80** disposed in an intake manifold of the engine. Advantageously, the electric heater **80** may be energized to preheat the heater **80** prior to cranking the engine **12** when the controller **20** determines that a cold start may occur soon. For example, a signal indicating a vehicle door unlocking, opening, or closing, or a signal indicating the presence of an occupant in the vehicle driver seat, may trigger preheating the electric heater **80**.

[0033] Advantageously, in a multiple cylinder engine, each of the cylinders **64** may be provided with an individual heater **80**, with each heater **80** individually controllable to provide an appropriate amount of heat to the intake air to its corresponding cylinder **64**. By way of non-limiting example, a four cylinder engine may be equipped with four individual heaters **80**, with the heaters **80** configured so that each heater **80** heats intake air to one of the four engine cylinders **64**. Mounting means for the heaters **80** is advantageously provided downstream of the charge air cooler **152** and upstream of the intake port of the cylinder **64**. Combustion quality may be monitored in each individual cylinder **64**, for example by combustion detection means **24**. Each individual heater **80** may be controlled based on the combustion quality in its corresponding cylinder **64**. Control of each heater **80** may be achieved, for example, by using solid state relays (not shown) to control current through each heater **80**. The heat delivered by each heater **80** may be controlled, for example, by pulse width modulation of the current through the heater **80**.

[0034] Application of electrical power to each heater **80** may advantageously be controlled based on various times and/or events within the cold start event. For example, the power applied to the heater **80** while preheating the heater **80** may be controlled to provide a controlled ramp-up to achieve rapid heating while avoiding thermal shock. Application of power to the heater **80** may be suspended for a time interval corresponding to the maximum current draw of the cranking means in order to allow more rapid increase in engine rotational speed. Electrical power to the heater **80** may be controlled to achieve a predetermined temperature of the heater **80**, or alternatively to achieve a predetermined intake air temperature to the cylinder **64**.

[0035] For extremely cold ambient conditions, the heaters **80** may be powered by an energy source external to the engine/vehicle system, for example by electricity provided by an electric utility. Application of electrical power to the heaters **80** may be at a constant rate as long as the external power is available, scheduled at a predetermined duty cycle, or controlled to achieve a predetermined temperature of the heater **80** or a predetermined air temperature at the intake port of a cylinder **64**.

[0036] It is known that all cylinders of a multi-cylinder internal combustion engine do not operate at precisely the same conditions. Sources of variability may include variation in compression ratio due, for example, to geometric differences, leakage, or deposits within a combustion chamber **28**. Other sources of variability may include differences in fuel delivery due to tolerances associated with the fuel injector **30**, cylinder-to-cylinder temperature differences, and the like. For GDCI cold starts using a plurality of intake air heaters **80** to condition intake air to the combustion chambers **28**, part-to-part variability between individual heaters **80** may contribute to further cylinder-to-cylinder variability. In an embodiment of the present invention, the control parameters associated with each individual heater **80** that produce the desired combustion characteristics, as described above, may be retained in non-volatile memory, for example in the controller **20**. These "learned" values may then be used as initial values in determining heater control parameters to be used to control that individual heater **80** during a subsequent cold start event.

[0037] Additionally or alternatively, the engine supercharger **134** may be engaged to compress air provided to the cylinder **64**, with the compression process contributing heat to the air. Simulation was performed to evaluate the effectiveness of using the supercharger **134** to preheat the air to achieve a temperature of **800** degrees K in the cylinder after compression and before initiation of combustion. Over a range of ambient temperatures ranging from −25° C. to +25° C., the simulation results indicate that using the supercharger **134** to boost the temperature and pressure of the intake air stream results in a reduction of approximately **70** watts per engine cylinder **64** in electrical power required to be provided by the electric heater **80**, at any ambient temperature.

[0038] In an embodiment of the method of the invention, the supercharger clutch **140** may be engaged throughout the duration of the cranking of the engine **12**. In an alternative embodiment, engagement of the supercharger clutch may be delayed, for example for a predetermined time after initiation of cranking or until engine cranking has achieved a predetermined engine speed.

[0039] The method for starting the GDCI engine **12** further includes injecting fuel into the cylinder when the air within the cylinder has been heated to a temperature sufficient to support compression ignition of the gasoline and air mixture within the cylinder **64**. Determination of when the air has been sufficiently heated may be based on a time duration, wherein the time duration is based on ambient temperature and/or on a temperature measured at the engine **12**. A non-limiting example of a temperature measured at the engine **12** is a coolant temperature measurement.

[0040] In an embodiment of the invention, if the engine is equipped with a second charge air cooler bypass valve **144**, the second charge air cooler bypass valve **144** is controlled so that the air exiting the supercharger **134** bypasses the second charge air cooler **152**, to prevent cooling of the supercharger flow during an engine cold start.

[0041] In an embodiment of the invention, the first coolant pump **210** is controlled so as not to circulate coolant to cool the cylinder **64** during an engine cold start.

[0042] In an embodiment of the invention, the second coolant pump **220** and/or the three-way valve **224** is controlled so as not to circulate coolant to cool the second charge air cooler **152** during an engine cold start.

[0043] In an embodiment of the invention, fuel pressure in the fuel supply line that feeds the injector **30** is measured, with the fuel pressure required to reach a predetermined threshold value before fuel is first injected into the cylinder. The threshold value may be based on ambient temperature and/or on a temperature measured at the engine **12**.

[0044] In an embodiment of the invention, timing of the intake valve **62**A and/or the exhaust valve **62**B is controlled to effectively eliminate compression of the air in the cylinder **64** when engine cranking is initially commenced, to reduce the load on the starter and allow more rapid increase of engine speed during cranking. Valve timing of the intake valve **62**A and the exhaust valve **62**B may then be controlled to achieve a maximum effective compression ratio for the engine **12** to provide the highest compression heating before initiation of fuel injection.

[0045] In an embodiment of the invention, the backpressure control valve **168** and/or a variable geometry turbocharger **118** are used to increase exhaust backpressure after combustion is initially achieved within the cylinder **64**. Timing of the exhaust valve **62**B can then be controlled to increase exhaust rebreathing into the cylinder **64** to increase temperature of the air/fuel charge in the cylinder **64** and promote robust autoignition for subsequent engine cycles.

[0046] In a further aspect of the invention, a system is provided for starting a GDCI engine. The system includes means for performing the steps of the method as described above. The system also includes a controller configured to control engine control hardware to perform the steps of the method as described above.

[0047] While this invention has been described in terms of preferred embodiments thereof, it is not intended to be so limited, but rather only to the extent set forth in the claims that follow.

We claim:

1. A method for starting a compression ignition engine, the engine having at least one cylinder with a reciprocating piston located therein, an intake valve configured to control the intake of air to an intake port of the cylinder and an exhaust valve configured to control the expulsion of gas from an exhaust port of the cylinder; the method comprising the steps of:
 - cranking the engine;
 - conditioning intake air provided at the intake port of the cylinder to raise the temperature of air in the cylinder;
 - controlling a valve timing of at least one of the intake valve and the exhaust valve to allow the piston to compress the air within the cylinder to a pressure above the pressure of the intake air provided at the intake port of the cylinder, thereby increasing the temperature of the air within the cylinder; and
 - injecting fuel into the cylinder when the air within the cylinder has been heated to a temperature sufficient to support compression ignition of a gasoline and air mixture within the cylinder.

2. The method of claim **1**, further comprising:
 - controlling the valve timing of at least one of the intake valve and the exhaust valve such that the air in the cylinder is not additionally compressed by movement of the piston for a period of time from when cranking of the engine begins until engine speed reaches a first threshold value; and
 - controlling the valve timing to provide compression of the air in the cylinder after the engine speed reaches the first threshold value.

3. The method of claim **2** wherein the step of controlling the valve timing to provide compression of the air in the cylinder comprises controlling the valve timing to achieve a maximum effective compression ratio in the cylinder.

4. The method of claim **1** wherein the engine includes a supercharger configured to controllably compress intake air to the engine, the supercharger driven by the engine through a clutch, and the step of conditioning intake air provided at the intake port of the cylinder to raise the temperature of air in the cylinder comprises controlling the supercharger to compress intake air to the engine, thereby raising the temperature of the intake air.

5. The method of claim **4**, wherein the step of controlling the supercharger further comprises:
 - cranking the engine with the clutch disengaged until the engine speed reaches a second threshold value; and
 - engaging the clutch after the engine speed reaches the second threshold value.

6. The method of claim **1**, wherein the engine additionally comprises a charge air cooler configured to transfer heat from the intake air to a coolant and a charge air cooler bypass valve configured to controllably route the intake air through the charge air cooler, the method additionally comprising controlling the charge air cooler bypass valve to control flow of the intake air through the charge air cooler so as to inhibit cooling the intake air while the engine is being started.

7. The method of claim **1**, wherein the engine additionally comprises a charge air cooler configured to transfer heat from the intake air to a coolant the method additionally comprising inhibiting coolant flow through the charge air cooler so as to inhibit cooling the intake air while the engine is being started.

8. The method of claim **1**, wherein exhaust gases from the engine are routed through an engine exhaust system, the exhaust system comprising a backpressure control means, the method further comprising controlling the backpres sure control means to increase exhaust backpres sure to a level higher than the pressure of the intake air at the intake port of the cylinder to promote rebreathing of engine exhaust after combustion is initially achieved within the cylinder.

9. The method of claim **1**, wherein the engine additionally comprises a system configured to route a coolant through the engine to transfer heat from the at least one cylinder to the coolant, the method additionally comprising controlling coolant flow through the engine so as to inhibit cooling the cylinder while the engine is being started.

10. The method of claim **1**, wherein the engine further comprises a heater configured to heat air at the intake port of the cylinder, and the step of conditioning intake air comprises controlling the heater to preheat intake air to the cylinder during a cold start event.

11. The method of claim **10**, wherein the heater is controlled so as to preheat intake air to the cylinder prior to cranking the engine during the cold start event.

12. The method of claim **10**, wherein the engine comprises a plurality of cylinders each configured with a corresponding individual heater configured to heat air at its intake port, and wherein each of the plurality of heaters is independently controllable.

13. The method of claim **12**, wherein combustion in each cylinder is monitored, and each individual heater is controlled based on the combustion in its corresponding cylinder.

14. The method of claim **13**, wherein a heater control parameter associated with combustion in the corresponding cylinder is retained in memory in a controller and used as a basis for controlling the corresponding heater in a subsequent cold start event.

15. The method of claim **10**, wherein the heater is controlled such that power is not applied to the heater during a time interval corresponding to a maximum current draw of a means used to crank the engine.

16. The method of claim **10**, wherein the heater is controlled to achieve a predetermined temperature of the air at the intake port of the cylinder.

17. The method of claim **10**, wherein the heater is configured to accept electrical power from an energy source external to a vehicle on which the engine is mounted.

18. A system for starting a compression ignition engine, the engine having at least one cylinder with a reciprocating piston located therein, an intake valve configured to control the intake of air to an intake port of the cylinder and an exhaust valve configured to control the expulsion of gas from an exhaust port of the cylinder; the system comprising;
 - means for cranking the engine;
 - means for increasing the temperature of intake air provided at the intake port of the cylinder;
 - valve timing means to control the opening and closing of at least one of the intake valve and the exhaust valve;
 - means for injecting fuel into the cylinder; and
 - a controller configured to control at least one actuator so as to perform a method comprising the steps of:
 - cranking the engine;
 - conditioning intake air provided at the intake port of the cylinder to raise the temperature of air in the cylinder;
 - controlling a valve timing of at least one of the intake valve and the exhaust valve to compress the air within the cylinder to a pressure above the pressure of the intake air

provided at the intake port of the cylinder, thereby increasing the temperature of the air within the cylinder; and

injecting fuel into the cylinder when the air within the cylinder has been heated to a temperature sufficient to support compression ignition of a gasoline and air mixture within the cylinder.

19. The system of claim **18** further comprising a supercharger configured to controllably compress intake air to the engine, the supercharger driven by the engine through a clutch, and the step of conditioning intake air provided at the intake port of the cylinder to raise the temperature of air in the cylinder comprises controlling the supercharger to compress intake air to the engine, thereby raising the temperature of the intake air.

20. The system of claim **19** wherein the step of controlling the supercharger further comprises:

cranking the engine with the clutch disengaged until the engine speed reaches a second threshold value; and

engaging the clutch after the engine speed reaches the second threshold value.

21. The system of claim **18** additionally comprising a charge air cooler configured to transfer heat from the intake air to a coolant and a charge air cooler bypass valve configured to controllably route the intake air through the charge air cooler, the method additionally comprising controlling the charge air cooler bypass valve to control flow of the intake air through the charge air cooler so as to inhibit cooling the intake air while the engine is being started.

22. The system of claim **18** additionally including an engine exhaust system, the exhaust system comprising a backpressure control means, the method further comprising controlling the backpressure control means to increase exhaust backpressure to a level higher than the pressure of the intake air at the intake port of the cylinder to promote rebreathing of engine exhaust after combustion is initially achieved within the cylinder.

23. The system of claim **18** wherein the engine additionally comprises a system configured to route a coolant through the engine to transfer heat from the at least one cylinder to the coolant, the method additionally comprising controlling coolant flow through the engine so as to inhibit cooling the cylinder while the engine is being started.

24. The system of claim **18**, wherein the engine further comprises a heater configured to heat air at the intake port of the cylinder, and the step of conditioning intake air comprises controlling the heater to preheat intake air to the cylinder during a cold start event.

25. The system of claim **24**, wherein the engine comprises a plurality of cylinders each configured with an individual heater configured to heat air at its intake port, and wherein each of the plurality of heaters is independently controllable.

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