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METHOD FOR DETECTING EXHAUST BACKFLOW IN AN INTERNAL COMBUSTION ENGINE

Abstract

A method for detecting exhaust backflow in an air intake plenum of an internal combustion engine (ICE) is disclosed. The method includes: a) determining a maximum gas pressure in the air intake plenum after an opening of an intake valve of the ICE while the intake valve is open; b) determining a reference pressure; c) comparing, by a control unit, the maximum gas pressure to the reference pressure; and d) concluding, by the control unit, a presence of exhaust backflow in the air intake plenum in response to the maximum gas pressure being greater than the reference pressure. A vehicle having a control unit is also disclosed. The control unit has a processor and a memory. The memory stores computer-readable instructions which, when executed, cause the processor to perform the method.

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Background/Summary

[0001] CROSS-REFERENCE [0002] The present application claims priority to U.S. Provisional Patent Application No. 63/555,158, filed Feb. 19, 2024, the entirety of which is incorporated herein by reference.

TECHNICAL FIELD
[0003] The present technology relates to methods for detecting exhaust backflow in internal combustion engines.
BACKGROUND
[0004] Many jurisdictions require that off-road vehicles having internal combustion engines (ICEs) and that are to operate over forest-covered land, grass-covered land or brush-covered land be provided with a spark arrestor in their exhaust system. The spark arrestor helps prevent sparks from exiting the exhaust system which could set fire to the forest, grass, and/or brush.
[0005] To be effective, the spark arrestor is typically provided at or near the outlet of the exhaust system. However, this can lead to the spark arrestor becoming clogged by mud and dirt when the off-road vehicle operates in muddy and dirty conditions. As would be understood, this restricts the flow of exhaust gases out of the exhaust system. This results in an increase in exhaust back pressure, which can lead to engine knock and cause other issues with the ICE. A similar increase in exhaust back pressure could happen as a result of damage to one or more components of the exhaust system, such as a muffler or a catalytic converter.
[0006] As such, it would be desirable to determine if the spark arrestor gets clogged and/or a component of the exhaust system is damaged in order to prevent these issues from happening. One solution consists in using a knock sensor to sense engine knock. Another solution consists in using an exhaust pressure sensor for sensing exhaust gas pressure in the exhaust system. However, both of these solutions rely on sensors that many ICEs and exhaust systems are not provided with. As such, adding these sensors increases the cost of the vehicle and require programming the ICE's control unit to account for this additional data input.
[0007] There is therefore a desire to determine if the spark arrestor gets clogged and/or a component of the exhaust system is damaged without relying on a knock sensor or an exhaust pressure sensor.
SUMMARY
[0008] It is an object of the present technology to ameliorate at least some of the inconveniences present in the prior art.
[0009] Typically, when the spark arrestor provided in an exhaust system is not clogged, the gas pressure in an air intake plenum of the internal combustion engine (ICE) drops dramatically when an intake valve of the ICE opens. This is due to the piston moving down in the cylinder of the ICE which sucks the air from the plenum into the combustion chamber of the ICE. It has been found that when the spark arrestor gets clogged, the increase in exhaust back pressure in the exhaust system can lead to exhaust gas flowing back into the air intake plenum when the intake valve opens. A similar increase in exhaust back pressure has been observed as a result of damage to components of the exhaust system that cause the flow of exhaust gases out of the exhaust system to be restricted. The exhaust backflow leads to a momentary increase in gas pressure in the air intake plenum when the intake valve opens, instead of the expected drop in gas pressure. As such, a pressure sensor provided in the air intake plenum, which most vehicles are already provided with, can be used to determine this increase in gas pressure when the intake valve opens and conclude the presence of exhaust backflow. This exhaust backflow is indicative of a clogged spark arrestor or

of a damaged exhaust system component. It is contemplated that detecting the presence of exhaust backflow in this manner may also be useful in determining other issues with the ICE or the exhaust system.

[0010] According to one aspect of the present technology, there is provided a method for detecting exhaust backflow in an air intake plenum of an ICE. The method comprises: a) determining a maximum gas pressure in the air intake plenum after an opening of an intake valve of the ICE while the intake valve is open; b) determining a reference pressure; c) comparing, by a control unit, the maximum gas pressure to the reference pressure; and d) concluding, by the control unit, a presence of exhaust backflow in the air intake plenum in response to the maximum gas pressure being greater than the reference pressure.

[0011] In some embodiments, determining the maximum gas pressure comprises sensing gas pressure in the air intake plenum with a pressure sensor.

[0012] In some embodiments, comparing the maximum gas pressure to the reference pressure comprises determining a ratio of the maximum gas pressure over the reference pressure.

[0013] In some embodiments, concluding the presence of exhaust backflow comprises concluding the presence of exhaust backflow in response to the ratio being greater than 1.02.

[0014] In some embodiments, the maximum gas pressure is a first maximum gas pressure; the reference pressure is a second maximum gas pressure; and the second maximum gas pressure is a maximum pressure of a pressure oscillation in the air intake plenum prior to the opening of the intake valve while the intake valve is closed.

[0015] In some embodiments, the reference pressure is an average gas pressure in the air intake plenum over a predetermined range prior to the opening of the intake valve while the intake valve is closed.

[0016] In some embodiments, the predetermined range is between a first crank angle and second crank angle. The first crank angle is 180 degrees of crank angle or less before the opening of the intake valve. The second crank angle is a crank angle at the opening of the intake valve.

[0017] In some embodiments, the reference pressure is an ambient air pressure; and determining the reference pressure comprises sensing the ambient air pressure with an ambient air pressure sensor disposed outside of the air intake plenum.

[0018] In some embodiments, the method also comprises: prior to step a), determining an engine speed; and performing steps a), b), c) and d) only in response to the engine speed being greater than a predetermined engine speed.

[0019] In some embodiments, the method also comprises: prior to step a), determining an air charge of a cylinder of the ICE provided with the air intake valve; and performing steps a), b), c) and d) only in response to the air charge being greater than a predetermined air charge.

[0020] In some embodiments, the method further comprises: prior to step a), determining a position of a throttle valve disposed upstream of the air intake plenum; and performing steps a), b), c) and d) only in response to the position of the throttle valve being greater than a predetermined position of the throttle valve.

[0021] In some embodiments, the method further comprises storing a fault code in a memory in response to concluding the presence of exhaust backflow.

[0022] In some embodiments, the method further comprises sensing gas pressure in the air intake plenum over a full engine cycle prior to step a).

[0023] In some embodiments, the method further comprises providing a visual indication on a display of a vehicle powered by the ICE in response to concluding the presence of exhaust backflow.

[0024] In some embodiments, the method further comprises limiting a torque of the ICE in response to concluding the presence of exhaust backflow.

[0025] In some embodiments, the method further comprises retarding an ignition angle of the ICE in response to concluding the presence of exhaust backflow.

[0026] In some embodiments, the method further comprises operating the ICE in a limp home mode in response to concluding the presence of exhaust backflow.
[0027] According to another aspect of the present technology, there is provided a vehicle having: an internal combustion engine (ICE) defining at least one cylinder; an exhaust system selectively fluidly connected to the at least one cylinder; at least one exhaust valve selectively fluidly connecting the at least one cylinder to the exhaust system; an air intake plenum selectively fluidly connected to the at least one cylinder; at least one intake valve selectively fluidly connecting the air intake plenum to the at least one cylinder; a pressure sensor connected to the air intake plenum configured for sensing gas pressure in the air intake plenum; and a control unit comprising a processor and a memory. The processor is communicatively coupled to the pressure sensor for receiving a signal representative of gas pressure in the air intake plenum. The memory stores computer-readable instructions which, when executed, cause the processor to perform the above method.
[0028] In some embodiments, the at least one cylinder is a single cylinder.
[0029] In some embodiments, the exhaust system comprises a spark arrestor; and concluding the presence of exhaust backflow is indicative of the spark arrestor being clogged.
[0030] In the context of the present specification, unless expressly provided otherwise, the words “first”, “second”, “third”, etc. have been used as adjectives only for the purpose of allowing for distinction between the nouns that they modify from one another, and not for the purpose of describing any particular relationship between those nouns.
[0031] It must be noted that, as used in this specification and the appended claims, the singular form “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise.
[0032] For purposes of the present application, terms related to spatial orientation when referring to a vehicle and components in relation to the vehicle, such as “vertical”, “horizontal”, “forwardly”, “rearwardly”, “left”, “right”, “above” and “below”, are as they would be understood by a driver of the vehicle sitting thereon in an upright driving position, with the vehicle steered straight-ahead and being at rest on flat, level ground.
[0033] Embodiments of the present technology each have at least one of the above-mentioned object and/or aspects, but do not necessarily have all of them. It should be understood that some aspects of the present technology that have resulted from attempting to attain the above-mentioned object may not satisfy this object and/or may satisfy other objects not specifically recited herein.
[0034] Additional and/or alternative features, aspects, and advantages of embodiments of the present technology will become apparent from the following description, the accompanying drawings, and the appended claims.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0035] For a better understanding of the present technology, as well as other aspects and further features thereof, reference is made to the following description which is to be used in conjunction with the accompanying drawings, where:
[0036] FIG. **1** is a right-side elevation view of an all-terrain vehicle (ATV);
[0037] FIG. **2** is a top plan view of an internal combustion engine (ICE) and of an exhaust system of the ATV of FIG. **1**;
[0038] FIG. **3** is a right side elevation of the ICE of FIG. **2**;
[0039] FIG. **4** is a longitudinal cross-section of the ICE of FIG. **3**;
[0040] FIG. **5** is a perspective view, taken from a bottom, rear, left side, of a cylinder head and associated components of the ICE of FIG. **3**;
[0041] FIG. **6** is a top view of a muffler of the exhaust system of FIG. **2**, with a body of the muffler

being illustrated as see-through such that internal components of the muffler are visible;

[0042] FIG. **7** is a schematic illustration of various components of the ATV;

[0043] FIG. **8** is a flow-chart of a method for detecting exhaust backflow in an air intake plenum of the ICE of FIG. **3**; and

[0044] FIG. **9** is a graph of gas pressure profiles in the air intake plenum of the ICE of FIG. **3**, with one gas pressure profile illustrating gas pressure during regular operation and one gas pressure profile illustrating gas pressure when a spark arrestor of the muffler of FIG. **6** is clogged.

DETAILED DESCRIPTION

[0045] The present disclosure is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the drawings. The disclosure is capable of other embodiments and of being practiced or of being carried out in numerous ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of “including”, “comprising”, or “having”, “containing”, “involving” and variations thereof herein, is meant to encompass the items listed thereafter as well as, optionally, additional items.

[0046] The present technology will be described with reference to a four-wheeled straddle-seat all-terrain vehicle **20** (hereinafter “ATV”) shown in FIG. **1**. It is contemplated that the present technology could be applied to other vehicles, such as, but not limited to, off-road side-by-side vehicles (SSVs) and motorcycles, and to other applications using an ICE where the detection of exhaust backflow may be useful.

[0047] Referring to FIG. **1**, the ATV **20** has a frame **22** having a front end **24** and a rear end **26** defined consistently with a forward travel direction of the ATV **20**. The ATV **20** has two front wheels **30** and two rear wheels **30**. Each of the four wheels **30** is provided with low-pressure balloon tires adapted for off-road conditions and traversing rugged terrain. It is contemplated that the ATV **20** could have six or more wheels **30** or only three wheels **30**. The two front wheels **30** are suspended from the frame **22** by left and right front suspension assemblies **32**. The two rear wheels **30** are suspended from the frame **22** by left and right rear suspension assemblies **34**.

[0048] A straddle seat **40** is connected to the frame **22** for accommodating a driver of the ATV **20**. Footrests **42** are provided on either side of the straddle seat **40** and are disposed vertically lower than the straddle seat **40** to support the driver's feet. The footrests **42** are connected to the frame **22**. A steering assembly **44** is rotationally mounted to the frame **22** and is operatively connected to the two front wheels **32** to steer the ATV **20**. The steering assembly **44** includes a handlebar **46** connected to a steering column assembly **48**, that is connected to steering linkages (not shown) operatively connected to left and right front wheels **30**.

[0049] A throttle operator **50**, in the form of a thumb-actuated throttle lever, is mounted to the handlebar **46**. Other types of throttle operators, such as a finger-actuated throttle lever and a twist grip, are also contemplated. A gear shifter **52** located near the handlebar **46** operates a sub-transmission **54** (FIG. **3**) and enables the driver to select one of a plurality of gear configurations for operation of the ATV **20**. In the present embodiment, the gear configurations include park, neutral, reverse, low, and high. It is contemplated that the sequence and/or number of gear configurations could be different than as shown herein. A driving mode selector button (not shown) also enables the driver to select 2×4 or 4×4 operation of the ATV **20**. A display **56**, including a number of gauges, indicator lights and buttons, is disposed forwardly of the handlebar **46**. It is contemplated that the display **56** may be or may include one or more screens, which may or may not be touchscreens.

[0050] Fenders **58** are disposed over the wheels **30** to protect the driver and/or passenger from dirt, water and other debris being projected by the rotating wheels **30**. The fenders **58** also define a portion of the wheel well in which each one of the wheels **30** rotates and, in the case of the front wheels **30**, steers. Fairings **60** extend over the frame **22** of the ATV **20** to protect certain components of the ATV **20**.

[0051] A fuel tank **62** is supported by the frame **22**. The fuel tank **88** is disposed below the straddle seat **40** near a rear of the ATV **20**. It is contemplated that the fuel tank **62** could be disposed elsewhere in other embodiments.

[0052] An internal combustion engine **100** (hereinafter "ICE", schematically illustrated in FIG. **1**, but shown in detail in FIGS. **2** to **5**) is connected to the frame **22** for powering the ATV **20**. The ICE **100** is disposed under the straddle seat **40**. The wheels **30** are operatively connected to the ICE **100** via a continuously variable transmission **102** (FIG. **2**, hereinafter "CVT"), the sub-transmission **54** and a driveline (not shown). The ICE **100** drives the CVT **102** which drives the sub-transmission **54**. The sub-transmission **54** drives the driveline which drives two or four of the wheels **30** depending on whether 2×4 or 4×4 operation is selected. The fuel tank **62** is rearward of the ICE **100**.

[0053] The ATV **20** further includes other components such as brakes, a radiator, headlights, and the like. As it is believed that these components would be readily recognized by one of ordinary skill in the art, further explanation and description of these components will not be provided herein.

[0054] Referring now to FIGS. **3** to **5**, the ICE **100** will be described in more details. The ICE **100** is a mono-cylinder, four stroke, internal combustion engine. The ICE **100** thus has a single cylinder **104** (FIG. **4**). The cylinder **104** is defined by a cylinder liner **106**. The ICE **100** is connected to the frame **22** and is disposed such that the cylinder **104** is inclined towards the rear end **26** of the frame **22**. It is contemplated that in some embodiments, the ICE **100** could have more than one cylinder **104**.

[0055] The ICE **100** has a crankcase **108**, a cylinder block **110** connected to the crankcase **108**, a cylinder head **112** connected to the cylinder block **110**, and a cylinder head cover **114** connected to the cylinder head **112**. The cylinder liner **106** extends inside the crankcase **108** and the cylinder block **110**. A piston **116** is disposed inside the cylinder **104**. The piston **116** reciprocates inside the cylinder **104** when the ICE **100** is in operation. The piston **116** is connected by a connecting rod **118** to a crankshaft **120**. The crankshaft **120** is rotationally supported inside the crankcase **108**. Reciprocation of the piston **116** causes rotation of the crankshaft **120**, which then drives the CVT **102**. The cylinder **104**, the cylinder head **112** and the piston **116** define a combustion chamber **122** therebetween. The combustion chamber **122** has a minimum volume when the piston **116** is closest to the cylinder head **112**. This is known as the top dead center (TDC) position of the piston **116**. The combustion chamber **122** has a maximum volume when the piston **116** is furthest from the cylinder head **112**. This is known as the bottom dead center (BDC) position of the piston **116**.

[0056] The ICE **100** has an air intake port **124** defined in a front portion of the cylinder head **112**. The air intake port **124** faces forward and upward. The ICE **100** has an exhaust port **126** defined in a rear portion of the cylinder head **112**. The exhaust port **126** faces rearward and downward. Intake and exhaust valves **128**, **130** (schematically shown in FIG. **4**) are opened and closed to permit and prevent fluid communication between the combustion chamber **122** and the intake and exhaust ports **124**, **126**, respectively. The intake and exhaust valves **128**, **130** are opened by cams (not shown) mounted to camshafts **132** that are driven by the crankshaft **120**. The intake and exhaust valves **128**, **130** are closed by springs (not shown). It is contemplated that the ICE **100** could have one or two intake valves **128** and one or two exhaust valves **130**. A spark plug **134** is provided in the cylinder head **112** to ignite an air-fuel mixture in the combustion chamber **122**.

[0057] An air intake plenum **136** is connected to the cylinder head **112** and is fluidly connected to the air intake port **124**. The intake valve **128** selectively fluidly connects the air intake plenum **136** with the combustion chamber **122**, and therefore with the cylinder **104**. A fuel injector **138** is connected to the air intake plenum **136** for injecting fuel in the air intake plenum **136** and the air intake port **124**. It is contemplated that in alternative embodiments the fuel injector **138** could be connected to the cylinder head **112** for injecting fuel directly inside the combustion chamber **122**. A pressure sensor **140** is connected to the air intake plenum **136** for sensing gas pressure inside the air intake plenum **136** upstream of the fuel injector **138**.

[0058] A throttle body **142** is connected to the air intake plenum **136** such that during operation of the ICE **100**, air flows from the throttle body **142**, to the air intake plenum **136**, to the air intake port **124** and to the combustion chamber **122**. The throttle body **142** has a throttle valve **144** (FIG. **4**) that is actuated by an electric motor **146**. The position of the throttle valve **144** controls a flow of air to the combustion chamber **122**. It is contemplated that in an alternative embodiment the throttle valve **144** could be actuated via a cable connected to the throttle operator **50**.

[0059] It is contemplated that other components could be fluidly connected to the throttle body **142**, upstream of the throttle body **142**, such as, but not limited to, an airbox and an air filter.

[0060] With reference to FIG. **2**, an exhaust system **150** of the ATV **20** will now be described. The exhaust system **150** is fluidly connected to the exhaust port **126**. The exhaust valve **130** selectively fluidly connects the exhaust system **150** with the combustion chamber **122**, and therefore with the cylinder **104**.

[0061] The exhaust assembly **150** includes an exhaust pipe **152** and a muffler **154**. The exhaust pipe **152** has a forward portion **156** that is connected to cylinder head **112** and is fluidly connected to the exhaust port **76**. The exhaust pipe **152** has a rearward portion **158** that is connected to the muffler **154**. The muffler **154** is connected to the frame **22**, near the rear end **26** of the frame **22**, by rods **160**. The muffler **154** extends laterally.

[0062] With reference to FIG. **6**, the muffler **154** will now be described in more detail. The muffler **154** has a muffler body **162** closed at a left end thereof by a left end cap **164** and at a right end thereof by a right end cap **166**. Left and right walls **168**, **170** are disposed inside the muffler body **162** to separate the muffler body **162** into three chambers **172**, **174**, **176**. A left chamber **172** is defined laterally between the left end cap **164** and the left wall **168**. A middle chamber **174** is defined laterally between the left wall **168** and the right wall **170**. A right chamber **176** is defined laterally between the right end cap **166** and the right wall **170**. The rearward portion **158** of the exhaust pipe **152** is connected to the muffler body **162** at a front left portion thereof to supply exhaust gas to the left chamber **172**. An aperture **178** fluidly communicates the left chamber **172** with the middle chamber **174**. A pipe **180** fluidly communicates the left chamber **172** with the right chamber **176**. The pipe **180** has apertures **182** along a contour of a right portion thereof that is received inside the right chamber **176**. A flame arrestor **184** is disposed inside the right chamber **176**. The flame arrestor **184** is offset from the pipe **180**. In the present embodiment, the flame arrestor **184** is a metal mesh tube, but other types of flame arrestors are contemplated. The flame arrestor **184** is connected to a tail pipe **186** that extends through the right end cap **166**. During regular operation, the flame arrestor **184** permits the passage of exhaust gas from the right chamber **176** to the tail pipe **186** but helps prevent sparks from exiting the tail pipe **186**. However, mud and dirt entering the tail pipe **186** from outside the ATV **20** could cause the holes in the mesh of the flame arrestor **184** to become clogged, thereby restricting the passage of exhaust gas from the right chamber **176** to the tail pipe **186** which results in an increase in exhaust back pressure. Should the flame arrestor **184** become significantly clogged, this could lead to engine knock and other issues. It is contemplated that the muffler **154** could have a construction that is different from the one described above. For example, it is contemplated that the muffler **154** could have only one, two or more than three chambers.

[0063] Turning now to FIG. **7**, additional components of the ATV **20** will be described. The ATV **20** has a control unit **200** that receives signals from various sensors, some of which are described below, and uses these signals to control operation of various components of the ATV **20**, such as the ICE **100**. The control unit **200** has a processor **202** and a non-transitory memory **204** that stores the computer-readable instructions in a non-transitory medium (not shown) included in the memory **204**. When executed, the computer-readable instructions cause the processor to perform the computer-readable instructions. It is contemplated that the processor **202** could be multiple processors. The processor **202** may be a general-purpose processor or may be a specific-purpose processor comprising one or more preprogrammed hardware or firmware elements (e.g., application-specific integrated circuits (ASICs), electrically erasable programmable read-only memories (EEPROMs), etc.) or other related elements. It is contemplated that the memory **204** could be multiple memories. The non-transitory medium of the memory **204** may be a semiconductor memory (e.g., read-only memory (ROM) and/or random-access memory (RAM)), a magnetic storage medium, an optical storage medium, and/or any other suitable type of memory. While the control unit **200** is represented as being one entity in this embodiment, it is understood that the control unit **200** could include separate entities for controlling components separately.

[0064] The previously described pressure sensor **140** is communicatively coupled to the processor **202** for sending a signal representative of gas pressure in the air intake plenum **136** to the processor **202**. A crankshaft position sensor **206** senses a position of the crankshaft **120**. The position of the crankshaft **120** is expressed as a crank angle. As the ICE **100** is a four-stroke engine, a full combustion cycle of the ICE occurs over two full rotations of the crankshaft **120**, the crank angle has a value from 0 to 720 degrees, with the 0 degree position and the 720 degrees position being the same. The crankshaft position sensor **206** senses crank angles over 360 degrees. A signal from an additional sensor, such as a camshaft position sensor, or computational methods are used by the processor **202** to determine if the crankshaft **120** is in the first rotation of the combustion cycle (i.e., 0 degree to 360 degrees) or the second rotation of the combustion cycle (i.e., 360 degrees to 720 degrees). The crankshaft position sensor **206** is communicatively coupled to the processor **202** for sending a signal representative of the position of the crankshaft **120** (i.e., the crank angle) to the processor **202**. Based on the change in crank angle over time, the processor **202** can determine an engine speed of the ICE **100**. The engine speed corresponds to the speed of rotation of the crankshaft **120** and is expressed in revolutions per minute (RPM). An ambient air pressure sensor **208** senses an ambient air pressure (i.e., the air pressure of the environment in which the ATV **20** operates). The ambient air pressure sensor **208** is communicatively coupled to the processor **202** for sending a signal representative of the ambient air pressure to the processor **202**. It is contemplated that the ambient air pressure sensor **208** could be omitted in some embodiments. A throttle position sensor (TPS) **210** senses a degree of opening of the throttle valve **144**, referred to herein as throttle position (TP). The TPS **210** is communicatively coupled to the processor **202** for sending a signal representative of the TP to the processor **202**. A temperature sensor **212** senses a temperature of one of ambient air temperature, a temperature of the air in the air intake plenum **136** being supplied to the combustion chamber **122**, and a temperature of the exhaust gas in the exhaust system **150**. The temperature sensor **212** is communicatively coupled to the processor **202** for sending a signal representative of the sensed temperature to the processor **202**. It is contemplated that more than one temperature sensor **212** could be provided, each of which would sense a different one of the temperatures mentioned above. It is contemplated that the temperature sensor **212** could be omitted in some embodiments. It is contemplated that the ATV **20** could have additional sensors.

[0065] Based on the information provided at least by the above sensors, and using the instructions stored in the memory **204**, the processor **202** controls various components of the ATV **20** by sending signals to these components. The processor **202** is communicatively coupled to the display **56** for controlling the information displayed on the display **56**, such as vehicle speed, engine speed, fuel level, and various error messages or icons. The processor **202** is communicatively coupled to the fuel injector **138** for controlling an injection timing and a quantity of fuel to be injected. The processor **202** is communicatively coupled to the spark plug **134** for controlling an ignition timing. The processor **202** is communicatively coupled to the throttle valve motor **146** for controlling a position of the throttle valve **144**. It contemplated that the processor **202** could be communicatively coupled to other components of the ATV **20** for controlling their operations.

[0066] Turning now to FIG. **8**, and with reference to FIG. **9**, a method **300** for detecting exhaust backflow in the air intake plenum **136** of the ICE **100** will be described. The presence of exhaust backflow in the air intake plenum **136** can be indicative of the spark arrestor **184** being clogged. The presence of exhaust backflow in the air intake plenum **136** can also be indicative of damage to components of the exhaust system **150** that cause the flow of exhaust gases out of the exhaust system **150** to be restricted. The method **300** will be described below for the purpose of indicating if the spark arrestor **184** is clogged. The computer-readable instructions for performing the method **300** are stored in the memory **204** and, when executed, cause the processor **202** to perform the method **300**.

[0067] FIG. **9** illustrates gas pressure profiles in the air intake plenum **136** as measured by the pressure sensor **140** with the ICE **100** operating at a constant engine speed and at a constant TP. One gas pressure profile, corresponding to the solid line **302**, illustrates gas pressure in the air intake plenum **136** during regular operation (i.e., with the spark arrestor **184** being unclogged or minimally clogged). The other gas pressure profile, corresponding to the dashed line **304**, illustrates gas pressure in the air intake plenum **136** when the spark arrestor **184** is clogged.

[0068] With reference to the solid line **302**, during regular operation when the intake valve **128** opens at crank angle P**1**, the gas pressure inside the air intake plenum **136** drops rapidly until the intake valve **128** closes at crank angle P**2**. In the present embodiment, the crank angle P**2** corresponds to the BDC position of the piston **116**. After the intake valve **128** closes, the gas pressure inside the air intake plenum **136** increases rapidly, as shown between crank angle P**2** and 720 degrees of crank angle. The gas pressure inside the air intake plenum **136** then oscillates with decaying amplitude that averages near ambient pressure, illustrated by dash-dot line **306**, as shown between 0 degree of crank angle and P**1**. However, with reference to the dashed line **304**, with the spark arrestor **184** clogged, when the intake valve **128** opens at crank angle P**1**, the gas pressure inside the air intake plenum **136** first increases rapidly and then drops rapidly until the intake valve **128** closes at crank angle P**2**. As can be seen in FIG. **9**, the rest of the pressure profile illustrated by the line **304** is similar to the pressure profile illustrated by the line **302**.

[0069] Turning to FIG. **8**, the method **300** begins at step **306** where pressure inside the air intake plenum **136** is sensed by the pressure sensor **140** over a full engine cycle (i.e., 720 degrees). This establishes a baseline pressure profile. Then at step **308**, the functions related to the detection of exhaust backflow are disabled. Then at step **310**, one or more of engine speed (RPM), throttle position (TP) and air charge are determined by the processor **202** using the corresponding sensors. The air charge is a quantity of air in the combustion chamber **122** when the piston **116** is at BDC. The air charge is based on air temperature, air pressure and throttle position, and can be determined by the processor **202** by a mathematical model and/or lookup tables stored in the memory **204**. Then at step **312**, the processor **202** determines if the one or more of the engine speed (RPM), throttle position (TP) and air charge determined at step **310** are within a predetermined range. If the values are outside of the predetermined range, the difference in gas pressure inside the air intake plenum **136** after opening the intake valve **128** between an unclogged spark arrestor **184** and a clogged spark arrestor **184** may be too small to detect by the pressure sensor **140**. The range will depend on the specific construction of the ICE **100**, the air intake plenum **136**, and the exhaust system **150** and the sensitivity of the pressure sensor **140**. For the engine speed, at step **312** the processor **202** determines if the engine speed is greater that a predetermined engine speed, moves to step **314** if it is, and moves back to step **306** if it is not. For the throttle position, at step **312** the processor **202** determines if the throttle position is greater that a predetermined throttle position, moves to step **314** if it is, and moves back to step **306** if it is not. For the air charge, at step **312** the processor **202** determines if the air charge is greater that a predetermined air charge, moves to step **314** if it is, and moves back to step **306** if it is not. It is contemplated that the processor **202** could additionally check if the engine speed, the throttle position and the air charge are also below an upper threshold. For embodiments where more than one of the engine speed, the throttle position and the air charge are determined at step **310** and compared to a range at step **312**, the processor moves to step **314** only if all of them are within their respective ranges, and moves back to step **306** otherwise. At step **314** the functions related to the detection of exhaust backflow are enabled and the processor **202** continues to step **316**. It is contemplated that in some embodiments, one or more of steps **306** to **314** could be omitted. It is also contemplated that all of steps **306** to **314** could be omitted and that the method **300** would begin at step **316**.

[0070] At step **316**, the processor **202** determines a maximum gas pressure Pmax in the air intake plenum **136** after the opening of the intake valve **128** while the intake valve **128** is open (i.e., between P**1** and P**2** in FIG. **9**) and determines a reference pressure Pref. The maximum gas pressure Pmax is determined based on the gas pressure sensed by the pressure sensor **140**. With reference to FIG. **9**, for regular operation (i.e., unclogged spark arrestor **184**) this corresponds to point Pmax**1** and when exhaust backflow is present (i.e., clogged spark arrestor **184**) this corresponds to point Pmax**2**. The difference between Pmax**1** and Pmax**2** depends on how clogged the spark arrestor **184**, with the difference increasing the more the spark arrestor **184** is clogged. The reference pressure Pref can be determined in different ways, some of which will be described below. In one embodiment, the reference pressure Pref is the ambient air pressure **306** sensed by the ambient air pressure sensor **208**. In another embodiment, the reference pressure Pref is an average gas pressure sensed by the pressure sensor **140** in the air intake plenum **136** over a predetermined range prior to the opening of the intake valve **128** at P**1** while the intake valve **128** is closed. In some embodiments, the predetermined range corresponds to the one full pressure oscillation prior to the opening of the intake valve **128** at P**1**. In other embodiments, the predetermined range is between crank angles P**3** and P**1** in FIGS. **9**, and P**3** is less than 180 degrees of crank angle before P**1**. In another embodiment, the reference pressure Pref is the maximum gas pressure of the one full pressure oscillation prior to the opening of the intake valve **128** at P**1** while the intake valve **128** is closed. In FIG. **9**, this corresponds to Pref**1** or Pref**2** depending on the pressure profile (i.e., line **302** or **304**). It is contemplated that the processor **202** could select the reference pressure Pref differently depending on the situation. For example, the processor **202** could use the ambient air pressure as the reference pressure Pref, but could switch to one of the other two methods of determining the reference pressure Pref should the ambient air pressure sensor **208** fail.

[0071] From step **316**, the processor **202** moves to step **318**. At step **318**, the processor **202** compares the maximum gas pressure Pmax determined at step **316** (i.e., Pmax**1** or Pmax **2**) to the reference pressure Pref. In the present embodiment, this is achieved by calculating a ratio of the maximum gas pressure Pmax over the reference pressure Pref. If this ratio is less than or equal to a predetermined value X, then at step **320** the processor **202** concludes that exhaust backflow is not present in the air intake plenum **136**, which is indicative of an unclogged spark arrestor **184**, and then returns to step **306**. If the ratio calculated at step **318** is greater than the predetermined value X, then at step **320** the processor **202** concludes that exhaust backflow is present in the air intake plenum **136**, which is indicative of a clogged spark arrestor **184**, and then moves to step **324**. In some embodiments, the predetermined value X is 1.02. In other embodiments, the predetermined value is 1.05. Other values of X are contemplated depending on the sensitivity of the pressure sensor **140**. In an alternative embodiment, it is contemplated that at step **318**, instead of calculating a ratio, the processor **202** could determine if the maximum pressure Pmax is greater than the reference pressure Pref, or if the maximum pressure Pmax is greater than the reference pressure Pref by a predetermined amount. If the maximum pressure Pmax is greater than the reference pressure Pref (or greater by the predetermined amount), the processor **202** moves to step **322**, otherwise the processor **202** moves to step **320**.

[0072] At step **324**, a fault code is stored the memory **204** indicative that exhaust backflow is present based on a signal received from the processor **202**. Then at step **326** the processor **202** sends a signal to the display **56** to provide a visual indication of the findings of the presence of exhaust backflow. This message could be words such as “clean spark arrestor” or “check spark arrestor”, or an icon representative of a clogged spark arrestor **184**. Alternatively, at step **326** the processor **202** could control the ICE **100** in such a way as to limit performance of the ICE **100** to reduce the likelihood of engine knock occurring due to the exhaust backflow caused by the clogged spark arrestor **184**. It is contemplated that the processor **202** could both limit performance of the

ICE **100** and display a message on the display **56** at step **326**. At step **326**, performance of the ICE **100** can be achieved by entering a “limp home” operation mode where maximum torque, engine speed and/or engine acceleration are limited, which can be accompanied by the display **56** displaying the words “limp home” or a corresponding icon. Performance of the ICE **100** can be limited by limiting a torque of the ICE **100**, by retarding an ignition angle of the ICE **100**, by reducing a quantity of fuel injected in the combustion chamber **122**, by modifying a timing of the fuel injection, by limiting a maximum opening of the throttle valve **144**. It is contemplated that the order of steps **324** and **326** could be reversed. It is also contemplated that steps **324** and **326** could be performed in parallel. It is also contemplated that one of steps **324** and **326** could be omitted. From step **326**, the processor **202** goes back to step **306**.

[0073] Modifications and improvements to the above-described embodiments of the present invention may become apparent to those skilled in the art. The foregoing description is intended to be exemplary rather than limiting. The scope of the present technology is therefore intended to be limited solely by the appended claims.

Claims

1. A method for detecting exhaust backflow in an air intake plenum of an internal combustion engine (ICE) comprising: a) determining a maximum gas pressure in the air intake plenum after an opening of an intake valve of the ICE while the intake valve is open; b) determining a reference pressure; c) comparing, by a control unit, the maximum gas pressure to the reference pressure; and d) concluding, by the control unit, a presence of exhaust backflow in the air intake plenum in response to the maximum gas pressure being greater than the reference pressure.

2. The method of claim 1, wherein determining the maximum gas pressure comprises sensing gas pressure in the air intake plenum with a pressure sensor.

3. The method of claim 1, wherein comparing the maximum gas pressure to the reference pressure comprises determining a ratio of the maximum gas pressure over the reference pressure.

4. The method of claim 3, wherein concluding the presence of exhaust backflow comprises concluding the presence of exhaust backflow in response to the ratio being greater than 1.02.

5. The method of claim 1, wherein: the maximum gas pressure is a first maximum gas pressure; the reference pressure is a second maximum gas pressure; and the second maximum gas pressure is a maximum pressure of a pressure oscillation in the air intake plenum prior to the opening of the intake valve while the intake valve is closed.

6. The method of claim 1, wherein the reference pressure is an average gas pressure in the air intake plenum over a predetermined range prior to the opening of the intake valve while the intake valve is closed.

7. The method of claim 6, wherein: the predetermined range is between a first crank angle and second crank angle; the first crank angle being 180 degrees of crank angle or less before the opening of the intake valve; and the second crank angle is a crank angle at the opening of the intake valve.

8. The method of claim 1, wherein: the reference pressure is an ambient air pressure; and determining the reference pressure comprises sensing the ambient air pressure with an ambient air pressure sensor disposed outside of the air intake plenum.

9. The method of claim 1, further comprising: prior to step a), determining an engine speed; and performing steps a), b), c) and d) only in response to the engine speed being greater than a predetermined engine speed.

10. The method of claim 1, further comprising: prior to step a), determining an air charge of a cylinder of the ICE provided with the air intake valve; and performing steps a), b), c) and d) only in response to the air charge being greater than a predetermined air charge.

11. The method of claim 1, further comprising: prior to step a), determining a position of a throttle valve disposed upstream of the air intake plenum; and performing steps a), b), c) and d) only in response to the position of the throttle valve being greater than a predetermined position of the throttle valve.

12. The method of claim 1, further comprising storing a fault code in a memory in response to concluding the presence of exhaust backflow.

13. The method of claim 1, further comprising sensing gas pressure in the air intake plenum over a full engine cycle prior to step a).

14. The method of claim 1, further comprising providing a visual indication on a display of a vehicle powered by the ICE in response to concluding the presence of exhaust backflow.

15. The method of claim 1, further comprising limiting a torque of the ICE in response to concluding the presence of exhaust backflow.

16. The method of claim 1, further comprising retarding an ignition angle of the ICE in response to concluding the presence of exhaust backflow.

17. The method of claim 1, further comprising operating the ICE in a limp home mode in response to concluding the presence of exhaust backflow.

18. A vehicle comprising: an internal combustion engine (ICE) defining at least one cylinder; an exhaust system selectively fluidly connected to the at least one cylinder; at least one exhaust valve selectively fluidly connecting the at least one cylinder to the exhaust system; an air intake plenum selectively fluidly connected to the at least one cylinder; at least one intake valve selectively fluidly connecting the air intake plenum to the at least one cylinder; a pressure sensor connected to the air intake plenum configured for sensing gas pressure in the air intake plenum; and a control unit comprising a processor and a memory, the processor being communicatively coupled to the pressure sensor for receiving a signal representative of gas pressure in the air intake plenum, the memory storing computer-readable instructions which, when executed, cause the processor to perform the method of claim 1.

19. The vehicle of claim 18, wherein the at least one cylinder is a single cylinder.

20. The vehicle of claim 18, wherein: the exhaust system comprises a spark arrestor; and concluding the presence of exhaust backflow is indicative of the spark arrestor being clogged.