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(54) Title of the Invention: **Secondary air injection system and control method**
Abstract Title: **SECONDARY AIR INJECTION SYSTEM AND CONTROL METHOD**

(57) A secondary air injection system 3 for an internal combustion engine, wherein the secondary air injection system comprises: an injector valve assembly 44 configured to control an injection of unburned air via an injection port 23 into an exhaust port 10c of the internal combustion engine, to mix with exhaust gas. Wherein the injector valve assembly is configured to commence injecting the unburned air into the exhaust port 10c prior to each opening of an exhaust valve 30 within the exhaust port 10c. The atmospheric oxygen in the unburned air promotes oxidization of unburned and partially burned fuel already in the exhaust and helps to raise the exhaust temperatures for catalyst and particulate filter requirements. A control system and control method are also disclosed.

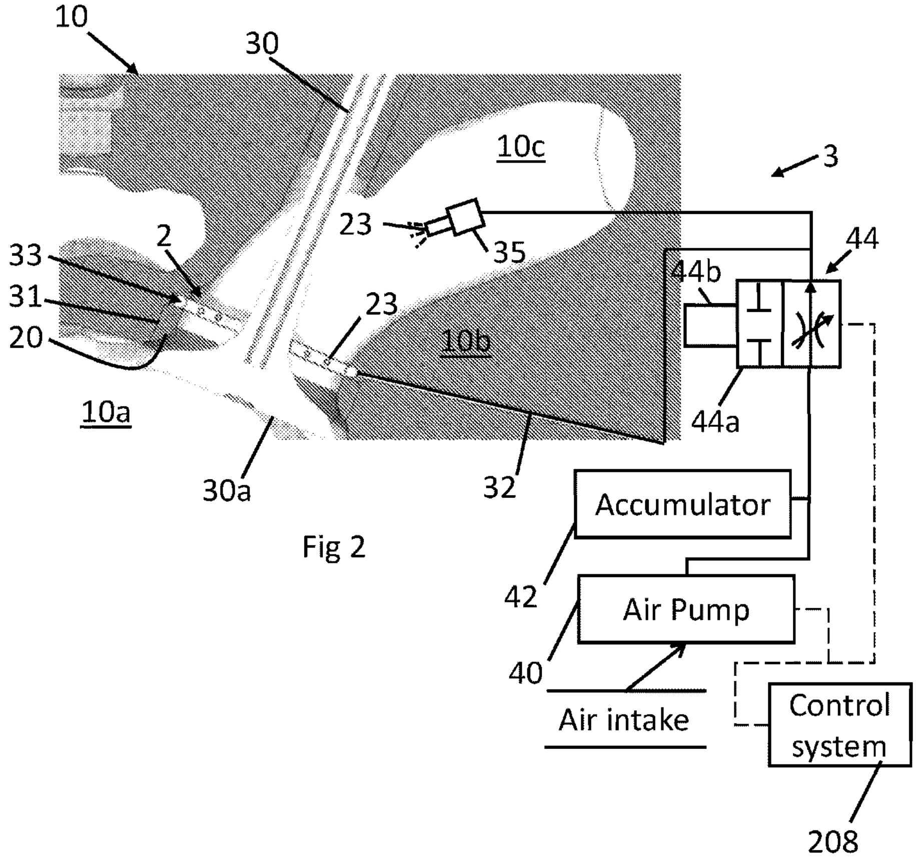

Fig 2

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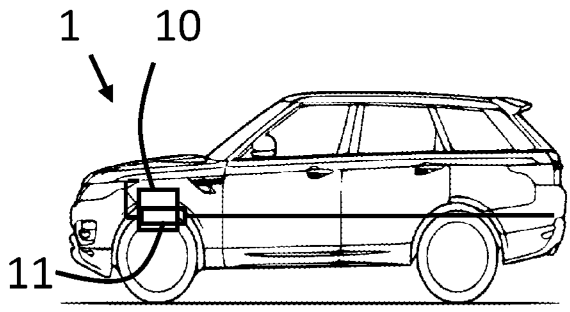

Fig 1

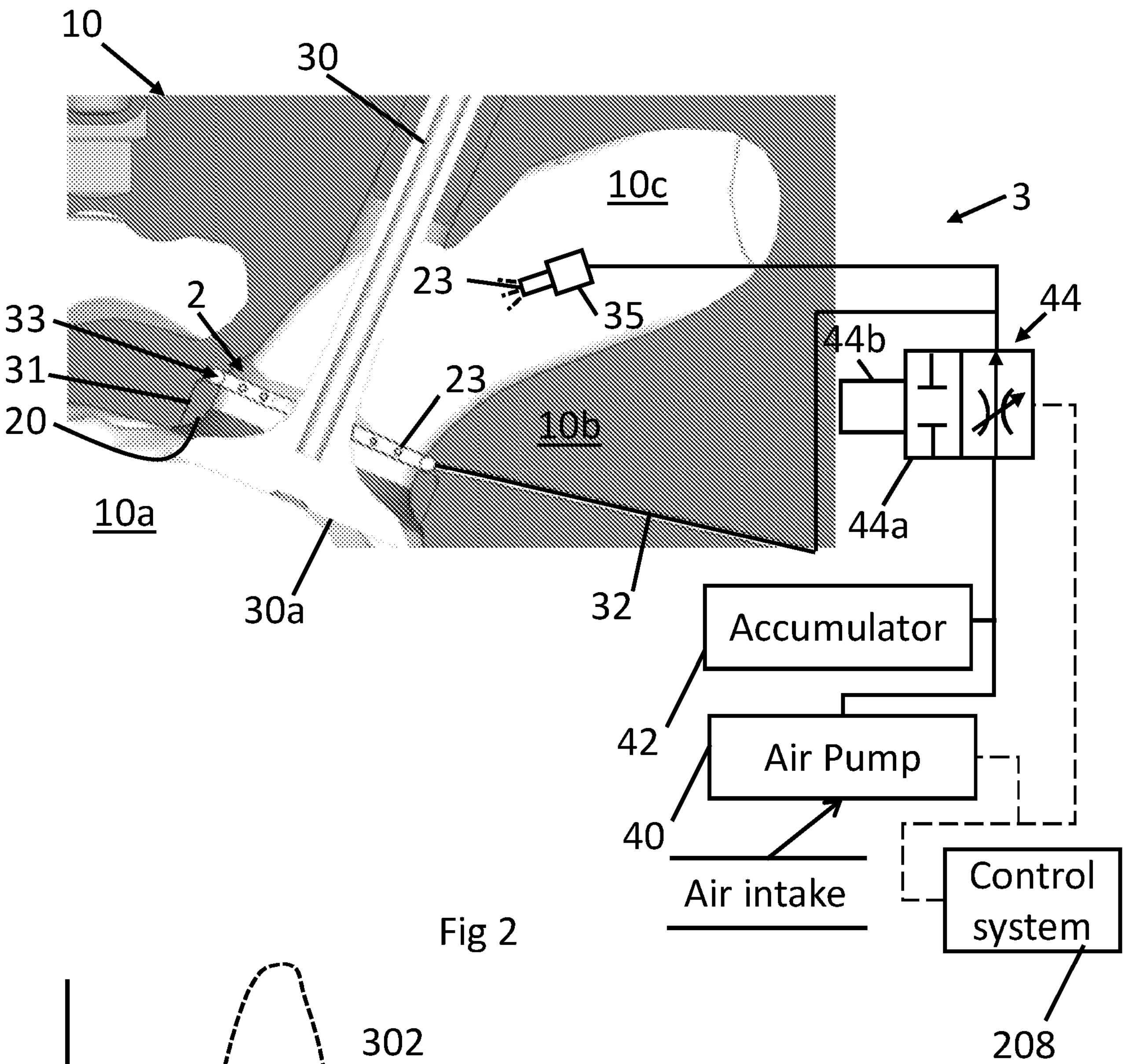

Fig 2

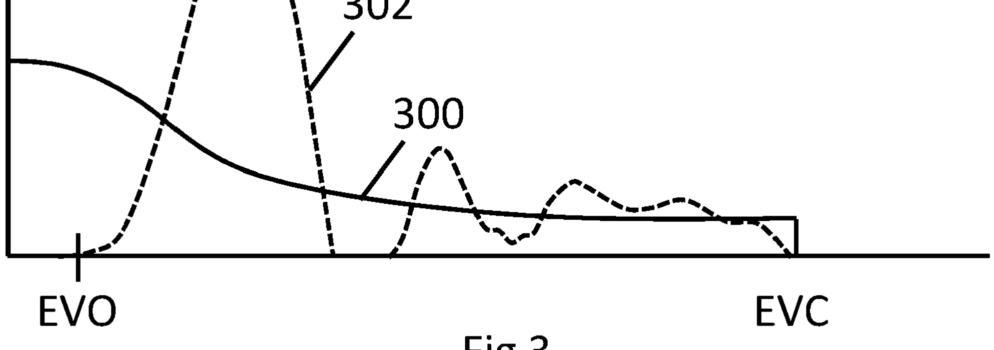

Fig 3

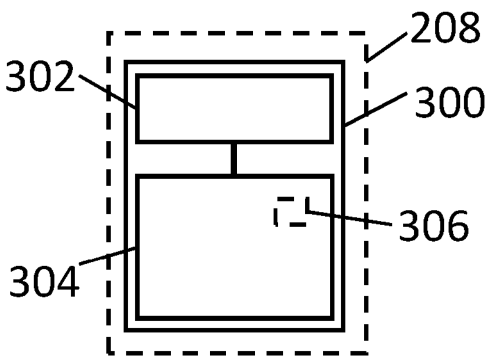

Fig 4A

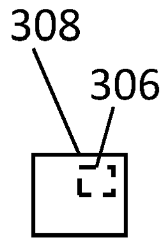

Fig 4B

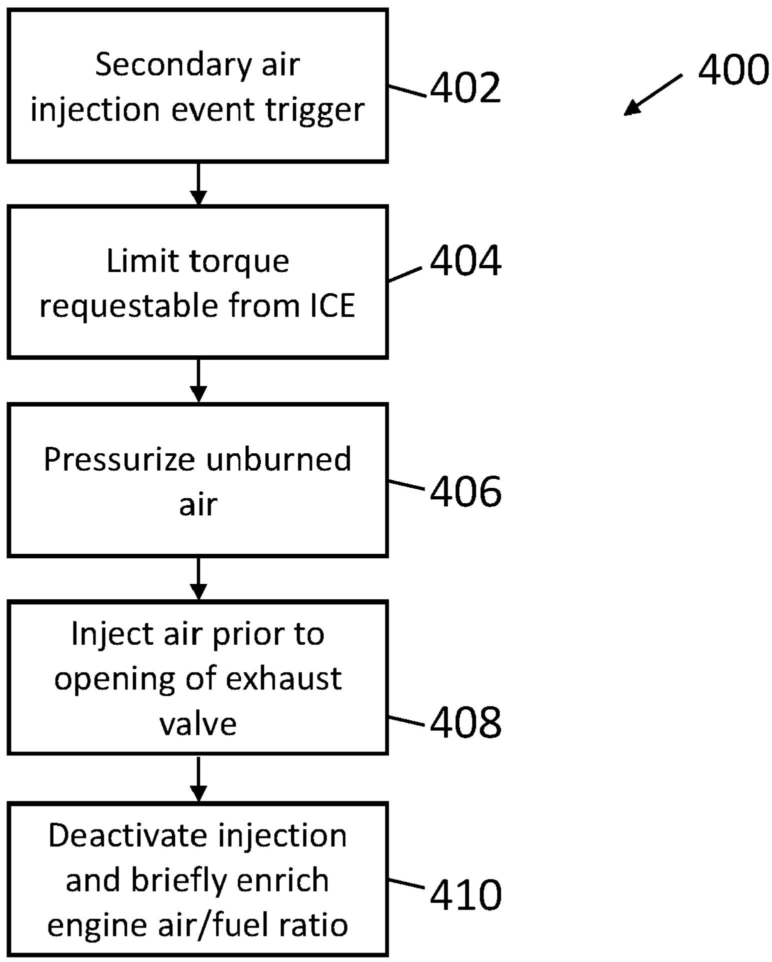

Fig 5

SECONDARY AIR INJECTION SYSTEM AND CONTROL METHOD

TECHNICAL FIELD

The present disclosure relates to a secondary air injection system, a control system and a method. In particular, but not exclusively it relates to a secondary air injection system, a control system and a method for an internal combustion engine of a vehicle.

BACKGROUND

Internal combustion engines comprise various fluid injectors such as fuel injectors, secondary air injectors, water injectors, and exhaust gas recirculation systems.

A secondary air injector is typically placed in an exhaust manifold outside a cylinder head, to inject unburned ambient air into the exhaust gas stream. Atmospheric oxygen in the unburned air promotes oxidization of unburned and partially burned fuel already in the exhaust, and helps to raise the exhaust temperatures for catalyst and particulate filter requirements.

Typically, the unburned air is injected as a continuous stream over a plurality of combustion cycles, until secondary air injection is no longer required.

SUMMARY OF THE INVENTION

It is an aim of the present invention to improve fluid injector technology.

Aspects and embodiments of the invention provide a secondary air injection system, a cylinder head, a control system, a vehicle, a method, and computer software as claimed in the appended claims.

According to an aspect of the invention there is provided a secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises:

an injector valve assembly configured to control an injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas;

wherein the injector valve assembly is configured to commence injecting the unburned air prior to opening of an exhaust valve.

This provides the advantage of enabling improved emissions and/or efficiency. Opening the valve member just before the exhaust valve opens improves mixing during the initial blowdown phase of an exhaust valve opening event. Further, the air is injected very close to a poppet valve into a high energy gas stream.

The injector valve assembly may be configured to inject between approximately 10 crankshaft degrees and approximately 20 crankshaft degrees before opening of the exhaust valve.

The injection may be a time-varying air flow rate of unburned air.

The time-varying air flow rate may comprise an initial peak followed by a decrease. This advantageously follows the profile of exhaust gas flow rate during an exhaust stroke.

The secondary air injection system may comprise a plurality of injector valve assemblies, configured to inject unburned air into different combustion chambers, wherein the injector valve assemblies are configured to inject at different times in dependence on a firing order of the combustion chambers.

The injector valve assembly may comprise a piezo-actuator, which is even faster and provides finer control than a high-speed solenoid.

The secondary air injection system comprises a secondary air pump configured to pressurize the air upstream of the injector valve assembly.

The secondary air injection system may comprise a pressure accumulator configured to store pressurized air upstream of the injector valve assembly.

The secondary air injection system may comprise a body defining the injection port, wherein the body is at least part of an insert configured to be secured to the exhaust port.

The body may comprise a plurality of injection ports, arranged to inject the air into the exhaust gas from different positions around the periphery of the exhaust port. This improves mixing compared with a probe injector.

The insert may further comprise a valve seat to which the body is secured.

According to an aspect of the invention there is provided a cylinder head for an internal combustion engine, wherein the cylinder head comprises:

an exhaust port; and

a feed channel configured to provide the air from the injector valve assembly to the injection port.

The exhaust port may comprise a receiving portion for receiving the injection port, to locate the injection port closer to an upstream end of the exhaust port than to a downstream end of the exhaust port.

According to an aspect of the invention there is provided a control system for controlling a secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises an injector valve assembly configured to control the injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas, wherein the control system comprises one or more controllers, and wherein the control system is configured to:

control the injector valve assembly to commence injecting the unburned air prior to opening of an exhaust valve.

The control system may be configured to advance and/or configured to retard a start timing and/or an end timing of the injection, in dependence on one or more of:

engine speed;

which one or more of a plurality of monitored variables triggered activation of secondary air injection; and

variable exhaust valve timing.

The control system may be configured to activate secondary air injection responsive to an event trigger, wherein satisfaction of the event trigger depends on at least one monitored variable that is associated with a condition of an exhaust gas aftertreatment apparatus.

The at least one monitored variable may comprise one or more of:

ambient temperature;

temperature associated with a powertrain of the vehicle;

a pressure difference across a particulate filter; and

a power mode of the vehicle.

The control system may be configured to limit a torque requestable from the internal combustion engine, while secondary air injection is taking place.

The control system of may be configured to enrich an air/fuel ratio of the internal combustion engine, in dependence on deactivation of secondary air injection.

According to an aspect of the invention there is provided a vehicle comprising the secondary air injection system, or the cylinder head, or the control system.

According to an aspect of the invention there is provided a method of controlling a secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises an injector valve assembly configured to control the injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas, wherein the control system comprises one or more controllers, and wherein the method comprises:

controlling the injector valve assembly to commence injecting the unburned air prior to opening of an exhaust valve.

According to an aspect of the invention there is provided computer software that, when executed, is arranged to perform any one or more of the methods described herein.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination that falls within the scope of the appended claims. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination that falls within the scope of the appended claims, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig 1 illustrates an example of a vehicle;

Fig 2 illustrates an example of a secondary air injection system;

Fig 3 illustrates an example of a time-varying air flow rate of unburned air and of exhaust gas;

Figs 4A, 4B illustrate an example of a control system and of a computer-readable storage medium; and

Fig 5 illustrates an example of a method.

DETAILED DESCRIPTION

Fig 1 illustrates an example of a vehicle 1 in which embodiments of the invention can be implemented. In some, but not necessarily all examples, the vehicle 1 is a passenger vehicle, also referred to as a passenger car or as an automobile. In other examples, embodiments of the invention can be implemented for other applications.

The vehicle 1 comprises an internal combustion engine 10 such as a gasoline or diesel engine, and may optionally comprise other torque sources (not shown). In some examples, the engine 10 has a compression ratio of at least 8:1 and may be turbocharged and/or supercharged. The vehicle 1 also comprises an exhaust gas aftertreatment apparatus 11. The exhaust gas aftertreatment apparatus 11 may comprise a catalytic converter and/or a particulate filter.

As shown in Fig 2, the internal combustion engine 10 comprises a secondary air injection system 3 for injecting unburned air into an exhaust port 10c.

In accordance with aspects of the present disclosure, the feed of unburned air is pulsating and timed to coincide with the exhaust gas pulsations. This is controlled by a control system 208 and a fast-switching injector actuator.

Fig 2 illustrates various elements of the secondary air injection system 3 according to an example implementation.

Firstly, the secondary air injection system comprises hardware for obtaining the unburned air, such as channels or conduits from an air intake of an aspiration system of the vehicle 1, or from outside the vehicle 1.

Fig 2 illustrates a secondary air pump 40 configured to pressurize the unburned air. The pressure should be higher than that in the exhaust port 10c, to push air into the exhaust port 10c. The specific pressure depends on implementation.

In some, but not necessarily all examples, the secondary air obtaining means 34 further comprises a pressure accumulator 42, configured to store air that has been pressurized by the secondary air pump 40. The secondary air injection system 3 may either comprise a high-pressure secondary air pump 40 without a pressure accumulator 42, or a low-pressure secondary air pump 40 with a pressure accumulator 42.

The secondary air injection system of Fig 2 then comprises an injector valve assembly 44, configured to control the flow of unburned air to coincide with exhaust gas pulsations.

The illustrated injector valve assembly 44 comprises a valve member 44a, wherein the valve member 44a comprises at least a closed position that blocks flow therethrough, and an open position that allows flow therethrough.

Fig 2 shows a two-way, two-position valve member 44a. However, the specific number of ports and positions of the valve member 44a may vary depending on the implementation. Extra flow control valves and check valves may be provided but are not necessary to show in Fig 2.

The injector valve assembly 44 further comprises an injection valve actuator 44b configured to connect to a control system 208 and to move the valve member 44a between its closed and open positions to coincide with exhaust gas pulsations.

The valve member 44a is moved to the open position to commence air injection at the required opening time, which in this case is just prior to opening of the exhaust valve 30. Opening the valve member 44a just before the exhaust valve 30 opens improves mixing during the initial blowdown phase of an exhaust valve opening event, which lasts for 40-50 crankshaft degrees from exhaust valve opening.

The exhaust valve opening time corresponds to a crankshaft position between 360 degrees and 540 degrees within a four-stroke combustion cycle. The secondary air injection may commence at least 10 crankshaft degrees before the exhaust valve opening time. Secondary air injection may optionally commence no earlier than 20 crankshaft degrees before the exhaust valve opening time, because injecting air too early before exhaust valve opening is not as effective.

In an example implementation, the exhaust valve 30 normally opens at 45 degrees before bottom dead centre, so secondary air injection starts at approximately 55 degrees before bottom dead centre or earlier.

The valve member 44a is held open for the required duration, then is moved back to the closed position at a required closing time. The required closing time may be at the same time as an exhaust valve closing time, or shortly before or after the exhaust valve closing time. The required duration of air injection may therefore be 180 degrees, or some other value from the nearby range 150-210 degrees. Therefore, the injection cycle ceases prior to the next top dead centre event.

The opening time and the closing time of the injection valve actuator 44b may be controlled by electrical pulses that are synchronized to a timing signal from a crankshaft position sensor or a signal from an exhaust valve position sensor such as a camshaft position sensor.

The injection valve actuator 44b may be capable of completing a single injection cycle (fully closed to fully open to fully closed) in approximately no more than 270 crankshaft degrees, at a typical engine speed of less than 2000rpm. The exhaust valve opening duration is a fixed or variable value between 150 and 270 crankshaft degrees. If air continues to be injected after the exhaust valve closing time, excessive unburned oxygen would remain in the exhaust system.

Suitably fast injection valve actuators include high-speed solenoids or piezo-actuators. A high-speed solenoid has a greater force and/or a shorter stroke than a standard solenoid.

In some examples, the injector valve assembly 44 is controllable to one or more intermediate phases or positions between fully open and fully closed, to provide a time-varying air flow rate over a single injection cycle.

Fig 3 is a graph illustrating the approximate time-variation of injected unburned air flow rate 300. The y-axis is flow rate and the x-axis is time. The graph extends over a single secondary air injection cycle, taking place over a portion of one combustion cycle. The dashed line 302 shows the flow rate of exhaust gas in the exhaust port. As shown by the initial peak in the curve 300 in Fig 3, the injected air flow rate is higher in the first half of the exhaust valve opening period, and lower in the second half of the exhaust valve opening period. This ensures that the flow rate of unburned air coincides with the similarly variable flow rate of exhaust gas, which starts high and later reduces. As shown in Fig 3, exhaust valve opening (EVO) occurs shortly after the secondary air injection cycle begins. The injection cycle stops at around the time of exhaust valve closing (EVC).

The exhaust gas plot 302 Fig 3 shows a zero-crossing point where flow reversal occurs. In some examples, the unburned air injection profile 300 may take on a more complex shape similar to 302, including for example a reduction or zero point of unburned air injection rate to coincide with the exhaust gas flow reversal, followed by a subsequent increase.

In order to control a time-varying air flow rate, the injector valve assembly 44 may have multiple controllable phases, such as: opening; stay open; closing. Some valve members can settle into partially-open positions. A piezo-actuator with a needle injector provides fine control over time-varying flow rates.

The secondary air injection system 3 of Fig 2 then comprises one or more injection ports 23 configured to inject the air into an exhaust port 10c of the internal combustion engine 10, to mix with an exhaust stream.

As illustrated, the injection ports 23 are as far upstream the exhaust path as practicable, within the exhaust port 10c inside the cylinder head 10b. At this location, the exhaust gas temperature is high enough to support self-ignition of the unburned air, whereas outside the cylinder head 10b the gas temperature falls rapidly, resulting in less complete ignition. This location also maximises the mixing length upstream of the exhaust gas aftertreatment apparatus 11, which is useful because the high pressure (>3bar) and velocity (>700m/s) of exhaust gases makes homogeneous mixing difficult to achieve in the limited space available. However, the unburned air should not be injected directly into the combustion chamber 10a during an exhaust stroke, as this would result in high temperatures and would generate high levels of nitrogen oxides.

As illustrated in Fig 2, the injection ports 23 may be provided by a suitable body such as a probe injector 35 or a wall injector 2, or both as shown. Wall injectors comprise apertures on the wall of the exhaust port 10c, whereas a probe injector 35 is inserted into the exhaust gas stream, away from the walls.

The probe injector 35 in Fig 2 has been inserted into the gas stream of the exhaust port 10c, to inject in a generally retrograde direction. The probe injector 35 does not mix as effectively as a wall injector 2, because the probe injector 35 only injects at one location, whereas wall injectors 2 can comprise a plurality of distributed injection ports 23 to inject at multiple locations around the periphery of the exhaust port 10c.

As shown in Fig 2, the wall injector 2 may be an annular insert comprising the injection ports 23, obviating the need to drill multiple holes into the cylinder head 10b. The centre hole of the annulus allows exhaust gases to flow therethrough. The insert therefore forms part of the wall of the exhaust port 10c. The injection ports 23 face into the centre hole. The injection ports 23 may be circular holes as illustrated, or may be grooves in a surface of the insert that abuts another surface such as the cylinder head 10b. Fig 2 shows a plurality of injection ports 23 spaced around the periphery of the exhaust port 10c, facing into the central aperture. This arrangement of ports 23 enables more complete mixing

The annular insert may be integrated with a valve seat 20, for example attached to a valve seat 20. The valve seat 20 is a component that forms a seal with the back of a valve head 30a of an exhaust poppet valve 30. This ensures that injection is as close as possible to an upstream end of the exhaust port 10c than to a downstream end of the exhaust port 10c, to improve mixing. This location makes use of a favourable venturi effect behind the exhaust valve head. This location is also readily accessible during manufacture: the cylinder head 10b may be cast with a receiving portion 31 (e.g. shelf) for receiving the annular insert and the valve seat 20. The insert can be press-fit into the receiving portion 31 before attachment of the cylinder head 10b to an engine block.

In order to enable the air to reach the wall injector 2, a feed channel 32 may extend through the cylinder head 10b. The feed channel 32 is a passage/gallery, such as a drilling in the cylinder head 10b, that carries the air from outside the cylinder head 10b to the wall injector 2. The feed channel 32 extends laterally, avoiding the hot exhaust valve bridge of the engine 10.

If multiple wall injection ports 23 are provided in a given wall injector 2, the feed channel may fluidly couple with a manifold 33 for distributing the air to the plurality of injection ports 23. The manifold 33 may be a hollow volume within the insert as shown in Fig 2, or may be an enclosed volume between the insert and the cylinder head 10b.

For a probe injector 35, the valve member 44a and injection valve actuator 44b may be integrated with the injection port(s) 23 in a single injector valve assembly 44 (probe body). For wall injection, the valve member 44a and injection valve actuator 44b may be provided outside the cylinder head 10b, upstream of the feed channel, due to packaging constraints. Therefore, for wall injection the injector valve assembly 44 may not comprise the injection ports.

Fig 2 just shows one combustion chamber 10a and one exhaust port 10c. If the engine 10 comprises a plurality of exhaust ports and combustion chambers, a separate injector valve assembly 44 may be provided for each exhaust port 10c. The injector valve assemblies would inject at different times to coincide with the different exhaust valve opening times. The specific timing of each injector valve assembly 44 depends on the firing order of the combustion chambers, and the type of combustion cycle employed (e.g. four-stroke).

The actuatable components of the secondary air injection system 3 can be managed by any suitable control system 208, in an open loop manner, or a closed loop manner using a sensor (e.g. lambda sensor). Fig 4A illustrates how the control system 208 may be implemented. The control system 208 of Fig 4A illustrates a controller 300. In other examples, the control system 208 may comprise a plurality of controllers on-board and/or off-board the vehicle 1.

The controller 300 of Fig 4A includes at least one processor 302; and at least one memory device 304 electrically coupled to the electronic processor 302 and having instructions 306 (e.g. a computer program) stored therein, the at least one memory device 304 and the instructions 306 configured to, with the at least one processor 302, cause any one or more of the methods described herein to be performed. The processor 302 may have an electrical input/output I/O or electrical input for receiving information and interacting with external components.

In some examples, the control system 208 is configured to vary the opening degree and/or start timing and/or end timing and/or duration of secondary air injection events within the engine time domain, by controlling the electrical pulses accordingly. In some examples, if the engine speed becomes too high for the injectors, the control system 208 could select a different strategy, e.g. air injection from 540 crankshaft degrees to 600 degrees, during the exhaust stroke. This strategy ends before the exhaust valve closes. Missing the final 20-30% of the time during which the exhaust valve is open is unlikely to have a significant emissions consequences. In some examples, the injection could be synchronized with variable exhaust valve timing, e.g. exhaust cam phase changes.

In some examples, the control system 208 is operable to perform the illustrated secondary air injection method 400 of Fig 5. In some examples, the air injection may last for a few seconds, e.g. up to approximately half a minute or less.

Block 402 of the method 400 comprises determining a secondary air injection event trigger, wherein satisfaction of the event trigger depends on at least one monitored variable that is associated with a condition of an exhaust gas aftertreatment apparatus 11. Examples of the variable include temperature, pressure, and/or a vehicle power mode, as described below.

Secondary air injection may be triggered if the monitored temperature of an exhaust gas aftertreatment apparatus 11 is too low for a catalytic reaction. The temperature can be measured directly using data from an exhaust system temperature sensor (e.g. catalyst temperature sensor). Additionally or alternatively, the temperature can be measured indirectly using data from an ambient temperature sensor, an engine fluid temperature sensor or the like. In an example, an ambient temperature below a threshold requires secondary air injection, the threshold being a suitable value between approximately 0 Celsius and approximately 30 Celsius. Secondary air injection is more important as temperatures get colder.

Secondary air injection may be triggered if the monitored pressure loss across an exhaust gas aftertreatment apparatus 11 is too high due to particulate (e.g. soot) accumulation. The pressure loss can be measured by comparing pressure data from a pair of pressure sensors, one of which is upstream of a catalyst-carrying substrate of the exhaust gas aftertreatment apparatus 11, and the other of which is downstream of the substrate of the apparatus 11.

Another example of a variable indicative of the temperature of the exhaust gas aftertreatment apparatus 11 is a power mode of the vehicle 1, so that secondary air injection can be performed at the beginning of a drive cycle when the exhaust gas aftertreatment apparatus 11 is cold. Optionally, secondary air injection may not be performed at the beginning of a drive cycle if the temperature/pressure is acceptable.

First, power modes are explained, using the example of starting a parked vehicle. The vehicle 1 starts in a 'Key Out' (standby) power mode in which the vehicle 1 is not in a travelable state, e.g. parked, and most functions are disabled.

The vehicle 1 then receives a 'wake-up' message, for example by detecting proximity of a keyless entry device, by receiving a user (e.g. driver) signal transmitted from an entry device, and/or by counting down a user preset wakeup timer. The vehicle 1 then transitions to one or more intermediate power modes, in which the vehicle 1 is still not in a travelable state but a plurality of auxiliary features of the vehicle 1 are activated.

In an intermediate 'Accessory' power mode, entertainment and telematics features may be activated. The vehicle 1 may have a further intermediate 'Ignition On' power mode, in which most functions are available but the engine 10 is not running. Some vehicles can enter the Ignition On mode when a physical key is turned to an intermediate position in an ignition barrel. If the vehicle 1 has keyless start, the transition could be prompted by other events such as detection of vehicle occupancy (e.g. door/seat sensing).

When a final transition condition is satisfied, the vehicle 1 starts the engine 10 and enters a travelable 'Running' power mode in which the engine 10 is running. In the travelable power mode, the engine 10 is active and torque is requestable by the driver, e.g. via an accelerator pedal, for moving the vehicle 1. The final transition condition could be caused by turning the key to a start position, or by user actuation of a 'start' control or other user action. In some vehicles, the user needs to depress a brake pedal.

One approach for secondary air injection is to automatically activate the engine 10 at an earlier power mode than usual so that secondary air injection can be completed before the driver wishes to depart. The engine 10 may be activated for secondary air injection based on a transition to an intermediate power mode. The engine 10 could run at an elevated idle that enables the process to complete in a short period of time. During this time, torque is not requestable by the driver. If the driver progresses to the travelable power mode before secondary air injection has completed, the secondary air injection may continue without interruption until complete.

A problem with the above approach is that the driver may have activated the intermediate power mode for reasons other than to start a journey. A better approach would be to first allow a driver-initiated transition to the travelable power mode. To reduce initial emissions prior to catalyst light-off, block 404 of the method 400 sets a limiter that limits the maximum engine torque and/or engine speed requestable by the driver. The requestable engine torque may be limited to zero, or to a threshold nonzero value that allows the vehicle 1 to drive normally but with reduced acceleration. The driver may be automatically informed of this limit via a suitable visual/audible cue.

In some examples, the vehicle 1 may be capable of triggering secondary air injection during a drive cycle. An event trigger such as catalyst light-out (extinction of reaction) can be checked based on temperature, pressure, and/or emissions detection (e.g. lambda). Particulate congestion (e.g. soot) can be checked based on pressure loss, time/mileage, etc. If secondary air injection is triggered during a drive cycle, maximum torque may be limited to a lesser extent than the vehicle start-up scenario. The torque is limited while still enabling the vehicle 1 to be driven at a reasonable pace.

Blocks 406 to 408 then perform secondary air injection. At block 406, the unburned air is pressurized by the secondary air pump 40. At block 408, the injector valve assembly 44 is opened to inject air in the manner described earlier.

In some examples, the time for which secondary air injection is required depends on which event trigger started secondary air injection: vehicle startup or during a drive cycle. Secondary air may be injected for a different duration during vehicle startup than during a drive cycle. In a light-out event during a drive cycle, the engine may run richer for a period of time to further assist with light-off. The flow rate of secondary air injection may similarly be controlled differently depending on which event trigger started secondary air injection.

At block 410, a completion condition is satisfied, so secondary air injection is deactivated (e.g. stop pumping and close injector valve assembly 44). The completion condition could be satisfied when catalyst light-off/soot removal is achieved, as detected using the above-described variables (pressure/temperature), or as indicated based on calibration and/or a timer and/or indicative sensed variables such as emissions sensing (e.g. lambda).

When secondary air injection is deactivated, the engine 10 may be run slightly rich for a short time (e.g. <1 second), to burn off any excess oxygen that may have accumulated. Afterwards, the optional torque limit may be removed.

Without secondary air injection, catalyst light-off could take upwards of 100 seconds and may require inefficient engine fuelling/ignition timing. This would result in high drive-cycle average emissions. With the present approach, the catalyst light-off time is considerably shortened, resulting in a substantial saving in drive-cycle average emissions. The system of Fig 2 can achieve catalyst light-off in around 8-10 seconds. Some strategies could limit requestable torque for longer (e.g. 20-30 seconds) until the temperature is optimum, e.g. after secondary air deactivation.

For purposes of this disclosure, it is to be understood that the controller(s) described herein can each comprise a control unit or computational device having one or more electronic processors. A vehicle and/or a system thereof may comprise a single control unit or electronic controller or alternatively different functions of the controller(s) may be embodied in, or hosted in, different control units or controllers. A set of instructions could be provided which, when executed, cause said controller(s) or control unit(s) to implement the control techniques described herein (including the described method(s)). The set of instructions may be embedded in one or more electronic processors, or alternatively, the set of instructions could be provided as software to be executed by one or more electronic processor(s). For example, a first controller may be implemented in software run on one or more electronic processors, and one or more other controllers may also be implemented in software run on one or more electronic processors, optionally the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present disclosure is not intended to be limited to any particular arrangement. In any event, the set of instructions described above may be embedded in a computer-readable storage medium (e.g., a non-transitory computer-readable storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM and EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.

It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

The blocks illustrated in Fig 5 may represent steps in a method and/or sections of code in the computer program 306. The illustration of a particular order to the blocks does not necessarily imply that there is a required or preferred order for the blocks and the order and arrangement of the block may be varied. Furthermore, it may be possible for some steps to be omitted.

The present disclosure refers to the stem of the poppet valve being behind the head of the poppet valve. This would be understood as the stem being downstream of the head, wherein the stem extends through the exhaust port towards a poppet valve actuator. It would further be understood that as the stem is behind the head, the combustion chamber can be referred to as being in front of the head.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as claimed.

Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant reserves the right to claim protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises:

an injector valve assembly configured to control an injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas;

wherein the injector valve assembly is configured to commence injecting the unburned air prior to opening of an exhaust valve.

2. The secondary air injection system of claim 1, wherein the injector valve assembly is configured to inject between approximately 10 crankshaft degrees and approximately 20 crankshaft degrees before opening of the exhaust valve.

3. The secondary air injection system of claim 1 or 2, wherein the injection is a time-varying air flow rate of unburned air.

4. The secondary air injection system of claim 3, wherein the time-varying air flow rate comprises an initial peak followed by a decrease.

5. The secondary air injection system of any preceding claim, comprising a plurality of injector valve assemblies, configured to inject unburned air into different combustion chambers, wherein the injector valve assemblies are configured to inject at different times in dependence on a firing order of the combustion chambers.

6. The secondary air injection system of any preceding claim, wherein the injector valve assembly comprises a piezo-actuator.

7. The secondary air injection system of any preceding claim, comprising a secondary air pump configured to pressurize the air upstream of the injector valve assembly.

8. The secondary air injection system of any preceding claim, comprising a pressure accumulator configured to store pressurized air upstream of the injector valve assembly.

9. The secondary air injection system of any preceding claim, comprising a body defining the injection port, wherein the body is at least part of an insert configured to be secured to the exhaust port.

10. The secondary air injection system of claim 9, wherein the body comprises a plurality of injection ports, arranged to inject the air into the exhaust gas from different positions around the periphery of the exhaust port.

11. The secondary air injection system of claim 9 or 10, wherein the insert further comprises a valve seat to which the body is secured.

12. A cylinder head for an internal combustion engine, wherein the cylinder head comprises:

an exhaust port; and

a feed channel configured to provide the air from the injector valve assembly of any preceding claim to the injection port.

13. The cylinder head of claim 12, wherein the exhaust port comprises a receiving portion for receiving the injection port, to locate the injection port closer to an upstream end of the exhaust port than to a downstream end of the exhaust port.

14. A control system for controlling a secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises an injector valve assembly configured to control the injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas, wherein the control system comprises one or more controllers, and wherein the control system is configured to:

control the injector valve assembly to commence injecting the unburned air prior to opening of an exhaust valve.

15. The control system of claim 14, configured to advance and/or configured to retard a start timing and/or an end timing of the injection, in dependence on one or more of:

engine speed;

which one or more of a plurality of monitored variables triggered activation of secondary air injection; and

variable exhaust valve timing.

16. The control system of claim 14 or 15, configured to activate secondary air injection responsive to an event trigger, wherein satisfaction of the event trigger depends on at least one monitored variable that is associated with a condition of an exhaust gas aftertreatment apparatus.

17. The control system of claim 16, wherein the at least one monitored variable comprises one or more of:

ambient temperature;

temperature associated with a powertrain of the vehicle;

a pressure difference across a particulate filter; and

a power mode of the vehicle.

18. The control system of any one of claims 14 to 17, configured to limit a torque requestable from the internal combustion engine, while secondary air injection is taking place.

19. The control system of any one of claims 14 to 18, configured to enrich an air/fuel ratio of the internal combustion engine, in dependence on deactivation of secondary air injection.

20. A vehicle comprising the secondary air injection system of any one of claims 1 to 11, or the cylinder head of claim 12 or 13, or the control system of any one of claims 13 to 19.

21. A method of controlling a secondary air injection system for an internal combustion engine, wherein the secondary air injection system comprises an injector valve assembly configured to control the injection of unburned air via an injection port into an exhaust port of the internal combustion engine, to mix with exhaust gas, wherein the method comprises:

controlling the injector valve assembly to commence injecting the unburned air prior to opening of an exhaust valve.

22. Computer software that, when executed, is arranged to perform a method according to claim 21.

Intellectual Property Office

Application No:	GB2010563.1	**Examiner:**	Mr Gareth Bond
Claims searched:	1 to 22	**Date of search:**	22 December 2020

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 7-14, 20, 21	US3641767 A (Kraus et al) See figures 1 and 2, column 2 lines 62 to 65, and column 2 line 74 to column 3 line 2. Disclosing air injection into exhaust valve port 4 that leads the start of the exhaust port opening.
X	1-3, 5, 7-14, 20, 21	US2007/240404 A1 (Pekrul et al) See figure 8 and paragraphs 38, 52, 68 and 69. Disclosing a cam 170 actuated secondary air valve 176 that is open when the exhaust port 16 valve is closed. An exhaust port location is disclosed in paragraph 52.
X	1, 5, 7, 12, 14, 20-22	US2013/199497 A1 (Sharma et al) See figures 1 and 4, and paragraphs 40 to 43. disclosing that the exhaust valve opens during the exhaust stroke, and that air injection occurs substantially during the exhaust stroke.
X	1 at least	US5419125 A1 (Fukae et al) see figure 4 and column 7 lines 18 to 34. Disclosing an air reservoir 20 that supplies compressed air continuously to all the exhaust ports.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

F01N

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, Patent Fulltext

Intellectual Property Office

International Classification:

Subclass	Subgroup	Valid From
F01N	0003/34	01/01/2006
F01L	0003/16	01/01/2006
F01L	0003/22	01/01/2006