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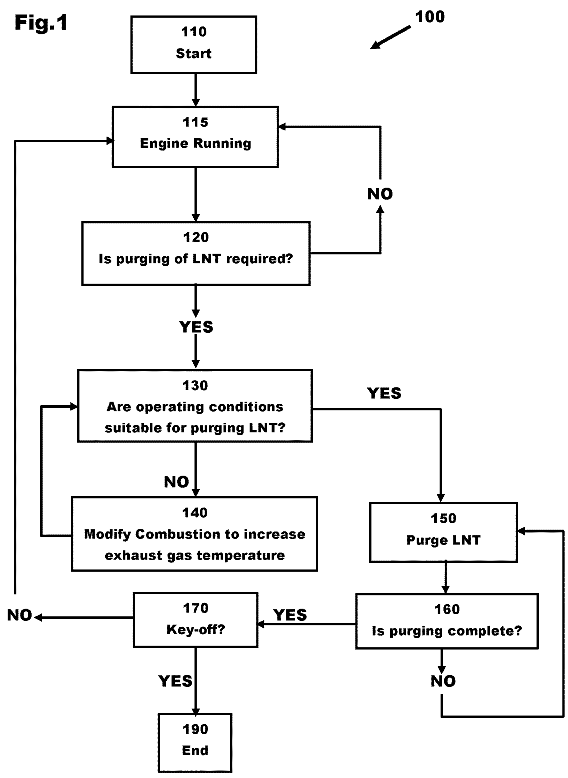
(54) Title of the Invention: **A method of operating an engine**
Abstract Title: **Method of operating a multi-cylinder engine**

(57) Disclosed is a method of operating a multi-cylinder lean burn engine 10 in which when lean NOx trap heating is required some cylinders of the engine 10 are operated rich of stoichiometric in order to increase the reductants and temperature of exhaust gas flowing to a lean NOx trap 16 and the remaining cylinders of the engine 10 are operated lean of stoichiometric to compensate for the rich running cylinders. The method is used to heat the Lean NOx trap 16 for the purpose of regenerating it to remove NOx or SOx. A vehicle having such an engine is also disclosed.

Fig.1



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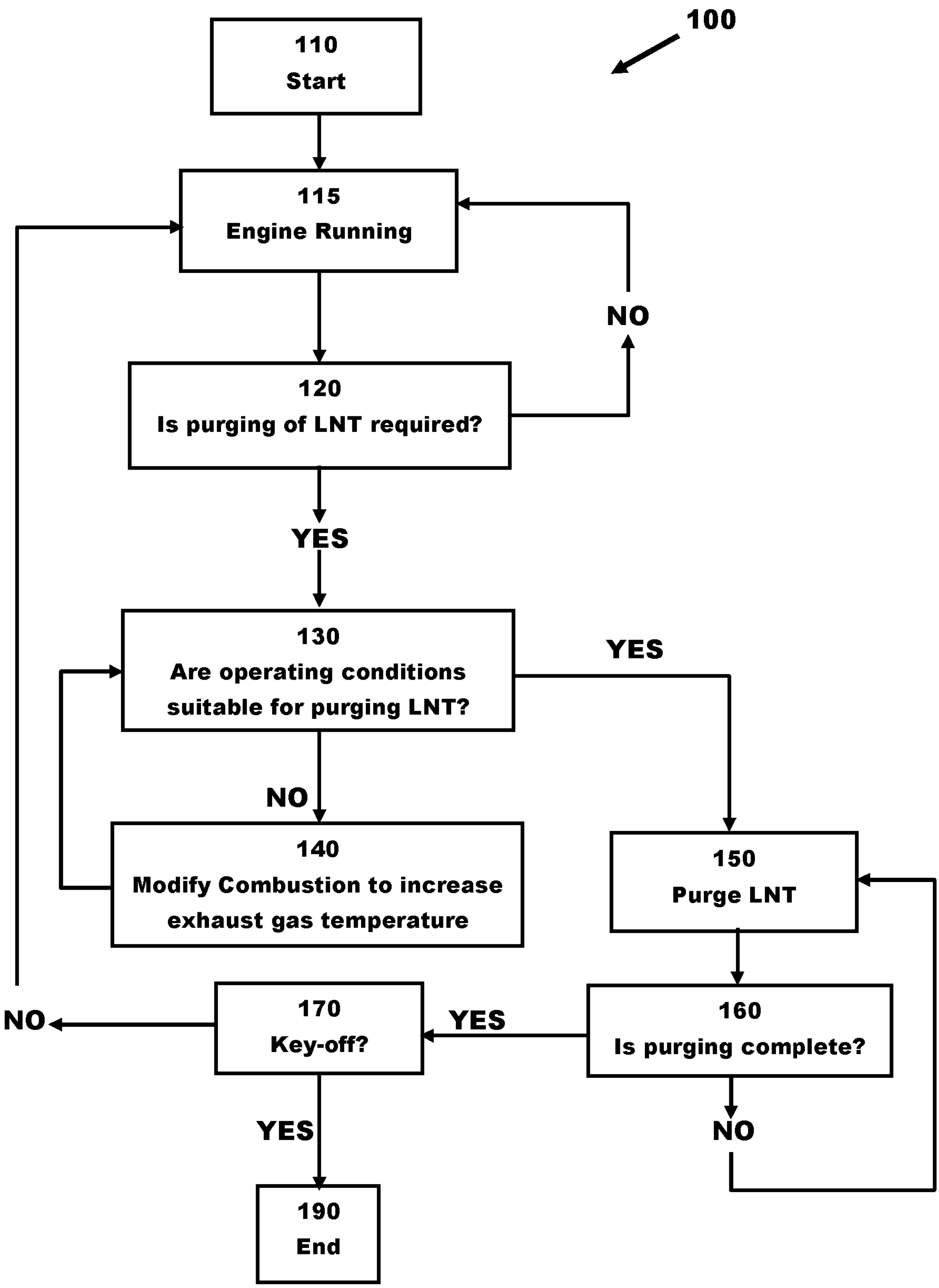
100
110
Start
115
Engine Running
NO
120
Is purging of LNT required?
YES
130
Are operating conditions suitable for purging LNT?
YES
NO
140
Modify Combustion to increase exhaust gas temperature
150
Purge LNT
170
Key-off?
YES
160
Is purging complete?
NO
NO
YES
190
End

Fig.1

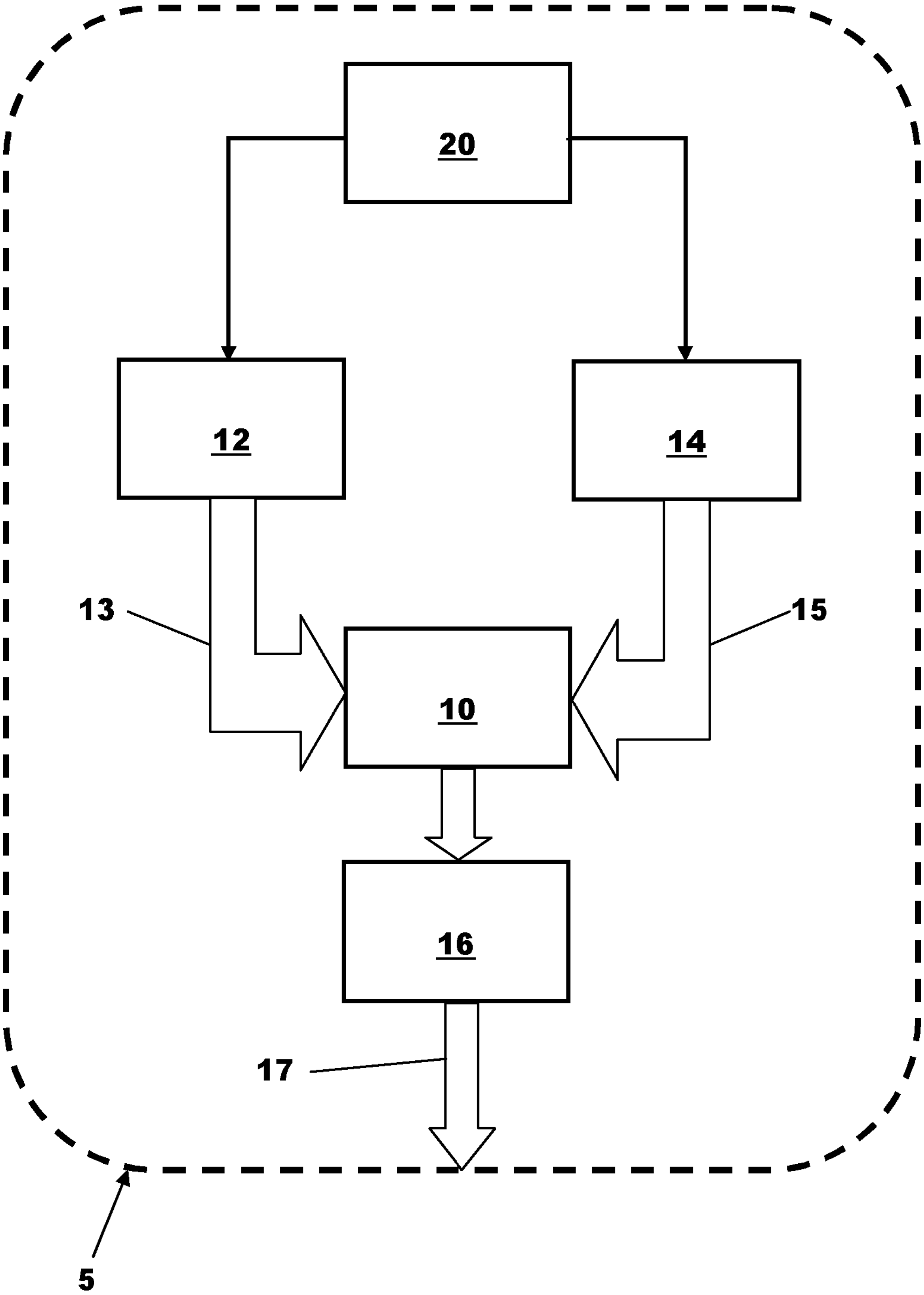

Fig.2

A Method of Operating an Engine

This invention relates to operating an internal combustion engine and in particular to a method of operating an engine in order to facilitate regeneration of a lean NOx trap

In the field of lean-burn internal combustion engines, reduction of NOx, such as NO and NO2, in exhaust gas is a well known problem. It is well known to use a Lean NOx Trap (LNT) in the exhaust system for adsorbing NOx when the engine is run lean and when the amount of NOx stored in the LNT reaches a predefined level to convert the stored NOx into N2 (Nitrogen gas) during a NOx purge regeneration process in which the engine is run rich.

The term 'Lean' as meant herein means an air-fuel ratio above lambda equal to 1. That is to say, above the stoichiometric air-fuel ratio, where the production of HC (hydrocarbons) and CO (carbon oxides) are low and where the production of NOx is high. The term 'Rich' as meant herein means an air-fuel ratio value with a lambda below 1 where the production of HC and CO used as reductants in the regeneration process is high and where the production of NOx and level of O_2 are relatively low.

After completion of the NOx purge regeneration process the engine is run lean again and NOx is again adsorbed in the LNT.

The optimum NOx conversion temperature for a LNT NOx purge is dependent on several factors such as, for example, the composition of the fuel used, the LNT construction in terms of the materials used and the age of the LNT. However, in general terms, the optimum NOx conversion temperature value lies in a temperature region where optimum conversion of NOx into N2 is possible.

The temperature of exhaust gas supplied to a LNT is dependent and is generally increased when the rotational speed of the engine increases, when the load on the engine is increased and in particular when the engine is run rich.

One problem with known LNT NOx purge methods occurs when the engine is being run in a condition where the temperature of the exhaust gas flowing to the LNT is well below the optimum NOx conversion temperature such as can often occur during light duty running such as urban or city driving.

If the temperature of the LNT is below an optimum temperature range of circa 300 to 400°C and the NOx purge regeneration process starts by running the engine rich, then NOx will be released or purged from the LNT but, because the catalyst materials contained within the LNT are not active at such a low temperatures, the released NOx cannot be converted and will result in a sudden large increase in the NOx emissions from the tailpipe. It is therefore desirable to increase the temperature of the exhaust gas flowing to the LNT before starting the NOx purge regeneration process if the temperature of the LNT is below the optimum range if a sudden increase in NOx emissions is to be avoided.

Another factor affecting the performance of an LNT is Sulfur poisoning of the LNT in which active sites within the LNT are poisoned by Sulfur. Sulfur poisoning occurs when the engine is operated with fuel containing Sulfur and an accumulation of the Sulfur contaminant builds up in the LNT and causes a decrease in the amount of NOx the LNT can absorb. In order to remove the Sulfur contaminant the LNT must be regenerated in what is known as a DeSOx purge regeneration (desulphation). In a DeSOx purge regeneration the temperature of the LNT is increased to circa 675°C and the Sulfur contaminant is burned off. One known method for raising the temperature of the LNT from its usual operating temperature to the temperature required for purging it of Sulfur employs the combination of the hot DPF regeneration mode in which no feedgas EGR NOx control is employed and the rich calibration used also for the DeNOx purge. However, this approach to SOx purging regeneration increases NOx emissions during the hot lean phases.

It is therefore desirable to provide a method that can be used to remove Sulfur contaminants from a LNT whilst maintaining feedgas NOx emission control.

It is an object of this invention to provide a method of operating a multi-cylinder lean burn engine to increase the temperature of the exhaust gas entering a lean NOx trap thereby facilitating the regeneration of the lean NOx trap.

According to a first aspect of the invention there is provided a method of operating a multi-cylinder lean burn engine arranged to supply exhaust gas to a lean NOx trap comprising checking whether regeneration of the lean NOx trap is required and whether a current temperature of one of the lean NOx trap and exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, operating the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and operating at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, regenerating the lean NOx trap.

The method may further comprise changing the at least one cylinder of the engine that is operated rich so as to even out temperature differences between the various cylinders of the engine.

The at least one cylinder of the engine that is operated rich may be changed in a sequential manner.

The at least one cylinder of the engine that is operated rich may be changed so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

The number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine may be set so as to produce the required air-fuel ratio of the exhaust gas flowing to the lean NOx trap and to meet a current torque demand for the engine.

The engine may have more than two cylinders, more than one cylinder of the engine may be operated rich and more than one air-fuel ratio may be used for the cylinders of the engine operating rich.

The engine may have more than two cylinders, more than one cylinder of the engine may be operated lean and more than one air-fuel ratio may be used for the cylinders of the engine operating lean.

Operating the engine in the lean NOx trap heating mode may result in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

Regenerating the lean NOx trap may comprise heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

Alternatively, regenerating the lean NOx trap may comprise heating the lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

According to a second aspect of the invention there is provided a motor vehicle having an engine arranged to supply exhaust gas to a lean NOx trap, a fuel injection system to supply fuel to the engine, an air intake system to supply air to the engine and an electronic controller to control the operation of the engine wherein the electronic controller is arranged to check whether regeneration of the lean NOx trap is required and whether a current temperature of one of the Lean NOx trap and exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is arranged to operate the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and operate at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is further arranged to control the operation of the engine to regenerate the lean NOx trap.

The electronic controller may be further arranged to change the at least one cylinder of the engine that is operated rich so as to even out temperature differences between the various cylinders of the engine.

The electronic controller may be arranged to change in a sequential manner the at least one cylinder of the engine that is operated rich.

The electronic controller may be further arranged to change the at least one cylinder of the engine that is operated rich so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

The electronic controller may be arranged to ensure that the number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine may be set so as to produce the required air-fuel ratio for the exhaust gas flowing to the lean NOx trap and may be further arranged to meet a current torque demand for the engine.

The engine may have more than two cylinders, more than one cylinder of the engine may be operated rich by the electronic controller and more than one air-fuel ratio may be used for the cylinders of the engine operating rich.

The engine may have more than two cylinders, more than one cylinder of the engine may be operated lean by the electronic controller and more than one air-fuel ratio may be used for the cylinders of the engine operating lean.

Operating the engine in the lean NOx trap heating mode may result in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

Regenerating the lean NOx trap may comprise heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

Alternatively, regenerating the lean NOx trap may comprise heating the lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

The invention will now be described by way of example with reference to the accompanying drawing of which:-

Fig.1 is a high level flow chart of a method of operating a multi-cylinder lean burn engine in accordance with a first aspect of the invention; and

Fig.2 is a schematic diagram of a motor vehicle having a multi-cylinder lean burn engine in accordance with a second aspect of the invention.

With particular reference to Fig.2 there is shown a motor vehicle 5 having a lean burn engine in the form of a multi-cylinder diesel engine 10.

The engine 10 is supplied with fuel as indicated by the arrow 13 from a fuel injection system 12 and receives a supply of air as indicated by the arrow 15 from an air intake system 14. It will be appreciated that the air intake system could include one or more exhaust gas recirculation circuits and one or more devices to increase the pressure of the air entering the engine 10 such as, for example, a compressor of a supercharger or a compressor of a turbocharger.

An electronic controller 20 is used to control the operation of the engine 10 by controlling the fuel injection system 12 and the air intake system 14 as is well known in the art. It will be appreciated that the electronic controller 20 could be formed from several separate controllers and need not be in the form of a single controller as shown in Fig.2. It will be further appreciated that the electronic controller 20 is arranged to receive inputs from a number of sensors (not shown) in order to control the operation of the engine 10, such as but not limited to, a mass airflow sensor (MAF), an accelerator pedal sensor, one or more exhaust gas NOx sensors, one or more Lambda sensors and one or more temperature sensors including exhaust gas temperature sensors.

Exhaust gas flows out of the engine 10 to a lean NOx trap (LNT) 16 and then out to atmosphere as indicated by the arrow 17. It will be appreciated that other aftertreatment devices could be provided in the exhaust stream from the engine 10 to atmosphere such as, for example, a diesel particulate trap (DPF).

The electronic controller 20 is arranged to operate the engine 10 based upon the inputs it receives from the sensors in several modes of operation including a lean mode of operation, an LNT heating mode of operation and at least one regeneration mode of operation.

In the lean mode of operation the air-fuel ratio of the mixture entering the engine 10 and the resulting exhaust gas (feedgas) supplied to the LNT 16 are both lean of stoichiometric that is to say, the feedgas Lambda is greater than 1. The engine 10 is operated whenever possible in the lean mode of operation because this maximises fuel economy and minimises HC and CO emissions.

In a NOx purge regeneration mode of operation the air-fuel ratio of the feedgas supplied to the LNT 16 is rich of stoichiometric that is to say, Lambda is less than 1.

During the LNT heating mode of operation the air-fuel ratio of the feedgas supplied to the LNT 16 is lean of or close to stoichiometric and the LNT 16 needs to be heated gently so as not to produce a large increase in NOx emissions but the air-fuel ratio of the mixture supplied to individual cylinders of the engine 10 is varied between rich and lean so as to produce the required feedgas Lambda and the required torque output from the engine 10.

That is to say, the electronic controller 20 is arranged to operate a combination of lean and rich combustion regimes on different firing events and across different cylinders.

For example and without limitation, in the case of a four cylinder engine have cylinder numbered 1 to 4, the cylinders 1 and 4 could be operated rich of stoichiometric for two combustion events so as to increase the temperature and reductants of the exhaust gas exiting these cylinders and hence increase the average temperature of the LNT and the exhaust gas flowing to the LNT 16 while the cylinders 2 and 3 are operated lean of stoichiometric for the same combustion events. The cylinders operated rich could then be reversed so that the cylinders 2 and 3 could be operated rich of stoichiometric for two combustion events so as to increase the temperature and reductants of the exhaust gas exiting these cylinders and hence increase the average temperature of the LNT and the exhaust gas flowing to the LNT 16 while the cylinders 1 and 4 are operated lean of stoichiometric for the same combustion events

The net result of the rich and the lean combustion events is that a feedgas composition of the desired Lambda (greater than one) is produced for the LNT 16 while at the same time the temperature of the feedgas and reductants supplied to the LNT 16 is rapidly increased increasing the LNT temperature.

It will be appreciated that in the case of the cylinder or cylinders being operated lean the fuel supply to the respective cylinder or cylinders could be temporarily cut-off resulting in a 100% lean mixture or the amount of fuel could be controlled to produce a mixture close to but lean of stoichiometric depending upon the mixture used for the cylinder or cylinders operated rich and the number of cylinders that are operated rich and lean.

Similarly, in the case of the cylinder or cylinders being operated rich the fuel supply to the respective cylinder or cylinders could be temporarily increased to the smoke limit or the amount of fuel could be controlled to produce a mixture close to but rich of stoichiometric depending upon the mixture used for the cylinder or cylinders operated lean and the number of cylinders that are operated rich an lean.

It will also be appreciated that every cylinder in the engine could be operated with a different Lambda with some being operated rich and some being operated lean.

Irrespective of the combination of rich and lean cylinders and the degree to which a cylinder is operated rich or lean the combined torque output from all cylinders must be matched to meet the current torque demand from a driver of the motor vehicle 5.

With reference to Fig.1 there is shown a method 100 of operating a multi-cylinder lean burn engine such as the engine 10 to increase the temperature of feedgas entering a lean NOx trap such as the LNT 16 thereby facilitating the regeneration of the LNT 16.

In the case of this example the method 100 is applied to a NOx purge regeneration that increases the temperature of feedgas entering the LNT 16 without producing a large increase or spike in NOx emissions. It will be appreciated that the method could be embodied as a programme in an electronic controller such as the electronic controller 20.

The method starts at box 110 which is a ‘key-on’ event and then advances to box 115 where the engine is running.

The method then advances from box 115 to box 120 to check whether regeneration of the LNT 16 is required. It will be appreciated that whether a NOx purge regeneration is required can be determined in many ways such as, for example, by using a model of NOx production from the engine 10, by measuring NOx levels upstream and downstream of the LNT 16 using NOx sensors or in any other suitable manner.

If regeneration of the LNT 16 is not required, then the method returns to box 115 with the engine 10 running. It will be appreciated that, although not shown, the method will end at any time if a Key-off event such as the event indicated in box 170 occurs.

If, when checked in box 120, regeneration of the LNT 16 is required the method advances to box 130. In box 130 it is checked whether the current engine operating conditions are suitable for efficiently regenerating the LNT 16. That is to say, a NOx purge regeneration can be conducted in an efficient manner.

A lean NOx trap is efficiently regenerated when the process of NOx purge regeneration does not release a large amount of NOx from the LNT into the atmosphere.

A number of conditions are required in order to efficiently carry out a NOx purge regeneration of the LNT 16 but the primary conditions so far as this invention is concerned are:-

a/ whether the LNT temperature is sufficiently high that NOx can be liberated from the LNT 16 and the catalyst components of the LNT 16 are lit-up; and

b/ whether the feedgas Lambda can be reduced sufficiently while meeting the current torque demand for the engine 10. That is to say, is the current engine torque demand is high enough to permit rich running of the engine 10.

If both of these conditions are met the method advances to box 150 where conventional regeneration of the LNT 16 commences and then advances to box 160 to check whether the NOx purge regeneration is complete.

If, when checked in box 160, the NOx purge regeneration is considered to be complete, the method advances to box 170 where it is checked whether a ‘key-off’ event has occurred. If a ‘key-off’ event has occurred the method ends in box 190 and, if a ‘key-off’ event has not occurred, the method returns to box 115 with the engine running normally. That is to say, to meet the current torque demand.

Referring back to box 160, if the NOx purge regeneration is not complete the method returns to box 150 and will loop around boxes 150 and 160 until the LNT 16 has been sufficiently purged of NOx or NOx purge regeneration is no longer possible due to, for example, the engine 10 entering an idle state.

Referring back to box 130, if the operating conditions are currently not suitable for NOx purge regeneration of the LNT 16, the method will advance from box 130 to box 140.

A failure of the test in box 130 is primarily due to the current LNT temperature being too low for effective regeneration of the LNT 16 because NOx cannot be released from the LNT 16 and too low to cause light-off of the catalyst materials in the LNT 16.

In box 140 the combustion of the engine 10 is modified to increase the temperature of the feedgas flowing to the LNT 16. This is done by operating at least one cylinder of the engine 10 rich while one or more other cylinders of the engine 10 are operated lean. The use of a rich mixture will result in the temperature and reductants of the exhaust gas exiting that cylinder increasing thereby increasing the resulting temperature of LNT 16.

The combination of rich and lean cylinders known as ‘asymmetric combustion’ is arranged so as to produce a feedgas Lambda greater than 1 and so will not produce any significant release of NOx from the LNT 16.

The number of cylinders operating rich and lean will depend upon a number of factors including the number of cylinders present, the magnitude of heating required, the current demand for torque and the required feedgas Lambda.

It will be appreciated that the cylinders operating rich could be cycled around the engine 10 as to even out the heating of the various cylinders thereby reducing thermal stress build-up in the engine 10.

It is not significant what sequence or cycling of rich and lean operating cylinders is used provided that sufficient LNT heating results, the current engine torque demand is met in an acceptable manner without large torque fluctuations and the required lean or non-rich feedgas lambda is produced.

Referring back to box 140, after the operating conditions have been modified the method returns to check whether the conditions for NOx purge regeneration have now been met and will continue to cycle around the boxes 130 and 140 until the feedgas temperature has increased sufficiently to permit NOx purge regeneration without the production of unacceptably high NOx. That is to say, the feedgas temperature should be sufficiently high to light-up the catalytic materials of the LNT 16 and to facilitate the release of NOx from the LNT 16. It will be appreciated that, instead of using feedgas temperature, an LNT temperature model could be used to provide an estimate of the temperature within the LNT. The temperature within an LNT is normally higher than feedgas temperature due to heating that occurs within the LNT. The LNT temperature can then be used instead of exhaust gas temperature (feedgas temperature) for the test in box 130.

The test in box 130 could include a specific temperature test such as "Is $T > T_{min}$" where T is either the temperature of the feedgas entering the LNT 16 or the temperature within the LNT 16 and T_{min} is the minimum required temperature required for efficient LNT regeneration based upon whether the temperature is feedgas temperature or LNT temperature.

If when returning from box 140 to box 130 the result of the check is that LNT NOx purge regeneration can now be permitted, the method will advance from box 130 to box 150 and the engine 10 is operated rich to produce NOx purge regeneration of the LNT 16.

It will be appreciated that asymmetric combustion could also be used during the regeneration process to either vary the feedgas Lambda between rich and lean or produce a rich feedgas while maintaining torque output, for example, operating at least one cylinder lean while operating other cylinders rich so as to produce the required rich feedgas Lambda and the high temperature required for LNT regeneration.

From box 150 the method advances as before via box 160 to box 170 when regeneration is complete.

In box 170 it is checked whether a ‘key-off’ event has occurred. If a ‘key-off’ event has occurred the method ends in box 190 and, if a ‘key-off’ event has not occurred, the method returns from box 170 to box 115 with the engine running normally. That is to say, to meet the current torque demand.

Therefore in summary, the invention provides a method in which a multi-cylinder lean burn engine is operated in a combination of combustion regimes that combine rich combustion events with lean combustion events that are torque matched, such that the sequence of rich and lean events for the cylinders are continuously variable between 100% lean to 100% rich. For example, a 25% rich event comprises one 10% rich combustion event and three 10% lean combustion events.

By using a net lean mode of operation having a mixture of rich combustion events which supply temperature to the LNT to bring it into its NOx reduction window and lean combustion events that increase the overall feedgas Lambda allows a subsequent rich purge to be more efficient.

It will be appreciated that not only can the number of cylinders that are operated rich or lean be varied but also the degree to which each cylinder is rich or lean. For example, in the case of a three cylinder engine, two cylinders could be operated 10% rich and a single cylinder could be operated 20% lean producing a feedgas Lambda of circa 1.0.

It will also be appreciated that in the case of an engine having a three or more cylinders one or more cylinders could be operated rich, one or more cylinders could be operated lean and one or more cylinders could be operated at stoichiometric.

Although the method 100 is described above with reference to a NOx purge regeneration it will be appreciated that it could be applied with benefit to a DeSOx purge with benefit. In such a case boxes 110 and 115 are as previously described. In box 120 the test is to determine whether the level of Sulfur contamination is such that the purging of Sulfur contaminants is required. One method for estimating the level of Sulfur contamination is disclosed in US Patent 5,832,722 but it will be appreciated that other methods exist for making this determination or estimation and that the invention is not limited to the method disclosed in US Patent 5,832,722.

If DeSOx purge regeneration of the LNT 16 is not required, then the method returns to box 115 with the engine 10 running. It will be appreciated that, although not shown, the method will end at any time if a Key-off event such as the event indicated in box 170 occurs.

If, when checked in box 120, DeSOx purge regeneration of the LNT 16 is required the method advances to box 130. In box 130 it is checked whether the current engine operating conditions are suitable for efficiently regenerating the LNT 16. That is to say, a DeSOx purge regeneration can be conducted in an efficient manner.

A DeSOx purge regeneration can be conducted in an efficient manner when the temperature is sufficiently high that fuel is not wasted trying to release SOx from the LNT in conditions that do not permit its release and combustion.

A couple of conditions are required in order to efficiently carry out a DeSOx purge regeneration of the LNT 16.

These are:-

a/ whether the exhaust gas temperature is sufficiently high that the Sulfur can be liberated from the LNT 16; and

b/ whether the current engine torque demand is high enough to permit rich running of the engine 10.

If both of these conditions are met the method advances to box 150 where DeSOx purge regeneration of the LNT 16 commences.

In the case of this invention DeSOx purging is conducted by operating the engine 10 in an asymmetric combustion mode that produces alternating rich and lean feedgas mixtures for the LNT 16. When the engine is operated to produce a net lean feedgas the level of Oxygen in the feedgas is increased and when the engine 10 is operated to produce a net rich feedgas the amount of Oxygen is reduced but the amount of HC and CO is increased. The combination of these two conditions produces an exothermic reaction in the LNT 16, controls the temperature of the LNT 16 during the lean running and releases the sulfur contaminants from the LNT 16 during the rich running.

For example and without limitation, the feedgas supplied to the LNT 16 could have a Lambda less than one for between 5 and 15 seconds peaking at circa 0.95 and then the feedgas supplied to the LNT 16 could have a Lambda more than one for between 5 and 15 seconds peaking at circa 1.05.

With a conventional DeSOx using such a cyclic switching between rich and lean all of the cylinders are operated either rich or lean to achieve the switching effect however by using asymmetric combustion this is not the case and some cylinders could be operated continuously lean while others cycle between lean and rich or between stoichiometric and rich or vice-versa. It will also be appreciated that, as previously described the cylinders could be operated in a sequence or cyclic manner so as to even out temperature differences between the cylinders.

After box 150 the method advances to box 160 to check whether the DeSOx purge regeneration is complete.

If, when checked in box 160, the DeSOx purge regeneration is considered to be complete, the method advances to box 170 where it is checked whether a 'key-off' event has occurred. If a 'key-off' event has occurred the method ends in box 190 and, if a 'key-off' event has not occurred, the method returns to box 115 with the engine running normally. That is to say, to meet the current torque demand.

Referring back to box 160, if the DeSOx purge regeneration is not complete the method returns to box 150 and will loop around boxes 150 and 160 until the LNT 16 has been sufficiently purged of Sulfur contaminants or a DeSOx purge regeneration is no longer possible due to, for example, the engine 10 entering an idle state.

Referring back to box 130, if the operating conditions are currently not suitable for a DeSOx purge regeneration of the LNT 16, the method will advance from box 130 to box 140.

A failure of the test in box 130 is primarily due to the current exhaust gas and or LNT temperature being too low for effective DeSOx regeneration of the LNT 16 because Sulfur cannot be released from the LNT 16.

In box 140 the combustion of the engine 10 is modified to increase the temperature of the feedgas and reductants flowing to the LNT 16. This is done by operating at least one cylinder of the engine 10 rich while one or more other cylinders of the engine 10 are operated lean. The use of a rich mixture will result in the temperature of the exhaust gas exiting that cylinder increasing thereby increasing the resulting temperature of the feedgas being supplied to the LNT and the exotherm within the LNT 16.

The combination of rich and lean cylinders known as ‘asymmetric combustion’ is arranged so as to produce a feedgas Lambda greater than 1 and so will increase the temperature of the feedgas in a fuel efficient manner.

The number of cylinders operating rich and lean will depend upon a number of factors including the number of cylinders present, the magnitude of heating required, the current demand for torque and the required feedgas Lambda.

As before the cylinders operating rich could be cycled around the engine 10 as to even out the heating of the various cylinders thereby reducing thermal stress build-up in the engine 10 and the sequence or cycling of rich and lean operating cylinders used is not important provided sufficient LNT heating results and the current engine torque demand is met in an acceptable manner without large torque fluctuations.

Referring back to box 140, after the operating conditions have been modified the method returns to check whether the conditions for DeSOx purge regeneration have now been met and will continue to cycle around the boxes 130 and 140 until the feedgas temperature has increased sufficiently to permit DeSOx purge regeneration.

It will be appreciated that, as previously referred to, instead of using feedgas temperature, an LNT temperature model could be used to provide an estimate of the temperature within the LNT. The temperature within an LNT is normally higher than feedgas temperature due to heating that occurs within the LNT. The LNT temperature can then be used instead of exhaust gas temperature (feedgas temperature) for the test in box 130.

If when returning from box 140 to box 130 the result of the check is that DeSOx purge regeneration can now be permitted, the method will advance from box 130 to box 150 and the engine 10 is operated rich and lean to produce DeSOx purge regeneration of the LNT 16 as discussed with reference to box 150.

From box 150 the method advances as before via box 160 to box 170 when regeneration is complete.

In box 170 it is checked whether a 'key-off' event has occurred. If a 'key-off' event has occurred the method ends in box 190 and, if a 'key-off' event has not occurred, the method returns from box 170 to box 115 with the engine running normally. That is to say, to meet the current torque demand.

Therefore in summary by operating the engine in an asymmetric combustion mode heating of the exhaust gas and LNT can be achieved in an efficient manner for the purpose of NOx and Sulfur purging of a lean NOx trap.

In the case of NOx purge regeneration, the temperature can be increased using asymmetric combustion without producing excess NOx during the period when the lean NOx trap is being heated.

In the case of DeSOx purge regeneration, the temperature can be increased using asymmetric combustion and then asymmetric combustion is used to perform a DeSOx regeneration in a fuel efficient manner to provide the required cycling between rich and lean required for removal of Sulfur from the lean NOx trap without loss of feedgas NOx control.

It will be appreciated by those skilled in the art that although the invention has been described by way of example with reference to one or more embodiments it is not limited to the disclosed embodiments and that alternative embodiments could be constructed without departing from the scope of the invention as defined by the appended claims.

Claims

1. A method of operating a multi-cylinder lean burn engine arranged to supply exhaust gas to a lean NOx trap comprising checking whether regeneration of the lean NOx trap is required and whether a current temperature of one of the lean NOx trap and exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, operating the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and operating at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, regenerating the lean NOx trap.

2. A method as claimed in claim 1 wherein the method further comprises changing the at least one cylinder of the engine that is operated rich so as to even out temperature differences between the various cylinders of the engine.

3. A method as claimed in claim 1 or in claim 2 wherein the at least one cylinder of the engine that is operated rich is changed in a sequential manner.

4. A method as claimed in claim 2 or in claim 3 wherein the at least one cylinder of the engine that is operated rich is changed so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

5. A method as claimed in any of claims 1 to 4 wherein the number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine are set so as to produce the required air-fuel ratio of the exhaust gas flowing to the lean NOx trap and to meet a current torque demand for the engine.

6. A method as claimed in any of claims 1 to 5 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated rich and more than one air-fuel ratio is used for the cylinders of the engine operating rich.

7. A method as claimed in any of claims 1 to 5 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated lean and more than one air-fuel ratio is used for the cylinders of the engine operating lean.

8. A method as claimed in any of claims 1 to 7 wherein operating the engine in the lean NOx trap heating mode results in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

9. A method as claimed in any of claims 1 to 8 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

10. A method as claimed in any of claims 1 to 7 wherein regenerating the lean NOx trap comprises heating the

lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

11. A motor vehicle having an engine arranged to supply exhaust gas to a lean NOx trap, a fuel injection system to supply fuel to the engine, an air intake system to supply air to the engine and an electronic controller to control the operation of the engine wherein the electronic controller is arranged to check whether regeneration of the lean NOx trap is required and whether a current temperature of one of the Lean NOx trap and exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is arranged to operate the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and operate at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is further arranged to control the operation of the engine to regenerate the lean NOx trap.

12. A vehicle as claimed in claim 11 wherein the electronic controller is further arranged to change the at least one cylinder of the engine that is operated rich so as to even out temperature differences between the various cylinders of the engine.

13. A vehicle as claimed in claim 11 or in claim 12 wherein the electronic controller is arranged to change in a sequential manner the at least one cylinder of the engine that is operated rich.

14. A vehicle as claimed in claim 12 or in claim 13 wherein the electronic controller is further arranged to change the at least one cylinder of the engine that is operated rich so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

15. A vehicle as claimed in any of claims 11 to 14 wherein the electronic controller is arranged to ensure that the number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine are set so as to produce the required air-fuel ratio for the exhaust gas flowing to the lean NOx trap and is further arranged to meet a current torque demand for the engine.

16. A vehicle as claimed in any of claims 11 to 15 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated rich by the electronic controller and more than one air-fuel ratio is used for the cylinders of the engine operating rich.

17. A vehicle as claimed in any of claims 11 to 15 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated lean by the electronic controller and more than one air-fuel ratio is used for the cylinders of the engine operating lean.

18. A vehicle as claimed in any of claims 11 to 17 wherein operating the engine in the lean NOx trap heating mode results in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

19. A vehicle as claimed in any of claims 11 to 18 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

20. A vehicle as claimed in any of claims 11 to 18 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

21. A method of operating a multi-cylinder lean burn engine arranged to supply exhaust gas to a lean NOx trap substantially as described herein with reference to the accompanying drawing.

22. A motor vehicle having a multi-cylinder lean burn engine substantially as described herein with reference to the accompanying drawing.

Amendments to the claims have been made as follows

Claims

1. A method of operating a multi-cylinder lean burn engine arranged to supply exhaust gas to a lean NOx trap comprising checking whether regeneration of the lean NOx trap is required and whether a current temperature of one of the lean NOx trap and exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, operating the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and at the same time operating at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, regenerating the lean NOx trap wherein the number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine are set so as to produce the required air-fuel ratio of the exhaust gas flowing to the lean NOx trap and to meet a current torque demand for the engine and the at least one cylinder of the engine that is operated rich is changed in a sequential manner so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

2. A method as claimed in claim 1 wherein the engine has more than two cylinders, more than one cylinder of the

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engine is operated rich and more than one air-fuel ratio is used for the cylinders of the engine operating rich.

3. A method as claimed in claim 1 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated lean and more than one air-fuel ratio is used for the cylinders of the engine operating lean.

4. A method as claimed in any of claims 1 to 3 wherein operating the engine in the lean NOx trap heating mode results in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

5. A method as claimed in any of claims 1 to 4 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

6. A method as claimed in any of claims 1 to 4 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

7. A motor vehicle having an engine arranged to supply exhaust gas to a lean NOx trap, a fuel injection system to supply fuel to the engine, an air intake system to supply air to the engine and an electronic controller to control the operation of the engine wherein the electronic controller is arranged to check whether regeneration of the lean NOx trap is required and whether a current temperature of one of the Lean NOx trap and exhaust gas supplied to the

lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap and, if regeneration of the lean NOx trap is required and the current temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is not high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is arranged to operate the engine in a lean NOx trap heating mode in which at least one cylinder of the engine is operated rich of stoichiometric in order to increase the temperature of the lean NOx trap and operating at the same time at least one of the remaining cylinders of the engine lean of stoichiometric and, when the temperature of one of the lean NOx trap and the exhaust gas supplied to the lean NOx trap is high enough to permit efficient regeneration of the lean NOx trap, the electronic controller is further arranged to control the operation of the engine to regenerate the lean NOx trap wherein the electronic controller is further arranged to ensure that the number of cylinders of the engine operated rich and the respective air-fuel ratio of the mixture supplied to the rich cylinders of the engine and the number of cylinders of the engine operated lean and the respective air-fuel ratio of the mixture supplied to the lean cylinders of the engine are set so as to produce the required air-fuel ratio for the exhaust gas flowing to the lean NOx trap and is further arranged to meet a current torque demand for the engine and to change the at least one cylinder of the engine that is operated rich in a sequential manner so that all of the cylinders of the engine are operated rich at some time during the period of time in which the engine is operated in the lean NOx trap heating mode.

8. A vehicle as claimed in claim 7 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated rich by the electronic controller and more than one air-fuel ratio is used for the cylinders of the engine operating rich.

9. A vehicle as claimed in claim 7 wherein the engine has more than two cylinders, more than one cylinder of the engine is operated lean by the electronic controller and more than one air-fuel ratio is used for the cylinders of the engine operating lean.

10. A vehicle as claimed in any of claims 7 to 9 wherein operating the engine in the lean NOx trap heating mode results in an air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap that is not less than one.

11. A vehicle as claimed in any of claims 7 to 10 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient NOx purge regeneration of the lean NOx trap and supplying exhaust gas to the lean NOx trap having an air-fuel ratio less than one.

12. A vehicle as claimed in any of claims 7 to 10 wherein regenerating the lean NOx trap comprises heating the lean NOx trap to a temperature high enough to permit efficient DeSOx purge regeneration of the lean NOx trap and switching the air-fuel Lambda ratio of the exhaust gas flowing to the lean NOx trap between more than one and less than one in a cyclic manner during the DeSOx purge regeneration.

13. A method of operating a multi-cylinder lean burn engine arranged to supply exhaust gas to a lean NOx trap substantially as described herein with reference to the accompanying drawing.

14. A motor vehicle having a multi-cylinder lean burn engine substantially as described herein with reference to the accompanying drawing.

Intellectual Property Office

Application No:	GB1514984.2	**Examiner:**	Mr Alastair Kelly
Claims searched:	1-22	**Date of search:**	22 February 2016

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	1-20	GB2355945 A [FORD] See abstract and figures and note page 2, lines 14-26
X	1-20	US2004/182069 A1 [GORALSKI] See abstract and figures
X	1-20	GB2352650 A [FORD] See abstract and figures
X	1-20	GB2351679 A [FORD] See abstract and figures

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F02D

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

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
F02D	0041/02	01/01/2006
F02D	0041/00	01/01/2006