A motor vehicle diesel engine (10) has an exhaust system (16) having a diesel particulate filter (18) that traps particulate matter in engine exhaust gases passing through the exhaust system. A control system (22) processes certain data to control engine and diesel particulate filter operation. In response to driver release of the accelerator, the engine decelerates toward idling at a lower low idle speed that has been predetermined appropriate for low idling when the diesel particulate filter is not being regenerated but inappropriate when the diesel particulate filter is being regenerated because of the potential for causing on-going regeneration to become uncontrolled. When the diesel particulate filter is being regenerated, a higher low idle speed sufficiently higher than the lower low idle speed is substituted as the low idle speed set-point essentially eliminating the potential for continuation of on-going diesel particulate filter regeneration becoming uncontrolled as the engine idles.
FIG. 3

no protection needed:
prot = 0;
timer = 0;

(soot_load>min_soot_prot) -> ready_to_protect

protection_off:
prot = 0;
timer = 0;

(engine_state==idle) & (DPF_in_T>min_T_prot)

(protection_on:
prot = 1;
timer = 1+)

(soot_load<min_soot_prot) -> no protection needed:
prot = 0;
timer = 0;

(engine_state==load) or (timer>=max_time) or (DPF_in_T>min_T_prot)

[Diagram]
protection_off:
prot = 0;
timer = 0;

protection_on:
prot = 1;
timer = 1+

(engine_state = load)
(DPF_in_T > min_T_prot) & (soot_hys
(soot_load < min_soott_prot - soot_hys)
(timer > max_time) & ([timer > min_time])
CONTROLLING ENGINE OPERATION DURING DIESEL PARTICULATE FILTER REGENERATION TO AVOID RUNAWAY FIELD OF THE INVENTION

[0001] This invention relates generally to emission control systems of internal combustion engines, more particularly diesel engines that have certain exhaust gas treatment devices for treating exhaust gases passing through their exhaust systems. The invention more especially also relates to a system and method for controlling engine operation in ways that avoid on-going controlled regeneration of a diesel particulate filter (DPF) from becoming uncontrolled when the engine is decelerated to low idle speed.

BACKGROUND OF THE INVENTION

[0002] A known system for treating exhaust gas passing through an exhaust system of a diesel engine comprises a diesel oxidation catalyst (DOC) associated with a diesel particulate filter (DPF). The combination of these two exhaust gas treatment devices promotes chemical reactions in exhaust gas and traps diesel particulate matter (DPM) as exhaust flows through the exhaust system from the engine, thereby preventing significant amounts of pollutants such as hydrocarbons, carbon monoxide, soot, SOF, and ash, from entering the atmosphere.

[0003] Certain DPF’s use a a catalyzed ceramic substrate for trapping certain constituents in DPM. Such a substrate possesses certain significant advantages over competing materials, including cost, material properties, and commercial availability. In its present form however, this substrate is somewhat less durable against thermally induced shocks and stresses than other competing DPF substrate materials.

[0004] Manufacturers of large vehicles powered by diesel engines are confronted by both government and consumer demands that on occasion ostensibly conflict. On one hand, certain government regulations mandate compliance with certain tailpipe emission standards that can be met only at added cost to consumers. On the other hand, consumers seek to purchase new vehicles that are cost-efficient.

[0005] A DPF having a catalyzed ceramic substrate can satisfy both requirements provided that its useful life is long enough to cover an applicable warranty time span.

[0006] It has been discovered that premature aging of a catalyzed ceramic substrate, leading to early failure of a DPF, may be an impediment to a manufacturer’s ability to bring the benefits of catalyzed ceramic substrate technology to the marketplace. A premature failure of a DPF that uses a catalyzed ceramic substrate may result in a warranty claim that must be satisfied by the manufacturer. The potential for large warranty costs due to DPF failure may be intolerable to a manufacturer, and therefore the manufacturer may adopt a different but initially more expensive alternative.

[0007] Consequently, it is seen desirable to develop a solution for mitigating potential early failure of a DPF that uses catalyzed ceramic substrate technology so that the benefit of a cost-effective DPF may inure to consumers while the manufacturer can secure compliance with applicable governmental regulations without unreasonable warranty cost risk.

SUMMARY OF THE INVENTION

[0008] Accordingly, a system and method that can provide such a solution should enjoy commercial acceptance.

[0009] The present invention is directed toward such a system and method.

[0010] During controlled regeneration, conditions that cause uncontrolled (runaway) regeneration may arise in various ways. Prior to the present invention, a protection strategy was incorporated in an engine control system to guard against unintended runaway regeneration. The present invention results from a discovery that “drop-to-idle” events occurring in a diesel-powered motor vehicle during a controlled regeneration of a DPF having a catalyzed ceramic substrate while the engine is in operation can also lead to potentially damaging uncontrolled, or runaway, regeneration.

[0011] For example, when a truck stops at a stop light and engine speed drops to low idle speed, the exhaust gas flow through the exhaust system, including the DPF, will significantly decrease and the concentration of oxygen inside the DPF will increase. Because the regeneration that is in progress has already elevated substrate temperature to that required for burning off trapped soot, the combination of decreasing flow rate and increasing oxygen concentration can start a self-propagating (uncontrolled) reaction that elevates the substrate temperature even higher.

[0012] Such a high temperature shock increases stresses in the internal materials. Even a single drop-to-idle event can create a shock that cracks a substrate. Repeated shocks have a cumulative effect that can eventually lead to even more cracking of the material and resulting DPF failure, because a DPF will progressively lose soot trapping effectiveness as cracks propagate. DPF failure within an applicable warranty period imposes a warranty cost on the manufacturer.

[0013] Known regeneration control strategies do address issues of DPF temperature and soot loading, but insofar as the inventor is aware they do not address the possibility of runaway regeneration caused by a drop-to-idle event that takes place during a controlled regeneration.

[0014] The present invention provides a more robust strategy because it includes a change-in-engine-operation protection feature that addresses the issue of potential runaway regeneration due to occurrence of a drop-to-idle event while a controlled regeneration is under way.

[0015] An aftertreatment strategy that provides a software solution for avoiding runaway regeneration as a consequence of a drop-to-idle event is especially advantageous because the need for additional hardware, except for possibly the necessary computing capability to incorporate a small amount of additional software, is obviated.

[0016] Briefly, the invention involves allowing the aftertreatment control strategy to override basic engine operation set-points in favor of other set-points specifically calibrated to protect the DPF when a drop-to-idle event occurs while a controlled regeneration is in process. Detection of a drop-to-idle event changes the set-points for certain parameters in the control strategy affecting engine operation. The engine’s idle speed will be increased to that of a special predefined set-point for the purpose of increasing airflow through the
DPF. Other parameters whose set-points may be changed include: main fuel injection timing, EGR valve position, turbocharger (EVRT) vane position, intake throttle position, post-injection fuel quantity, and post-injection fuel timing.

[0017] The pertinent exhaust temperatures and engine information are detected using existing sensors. If regeneration-level exhaust temperatures are present and no more than a fairly small quantity of soot has been burned off as a controlled regeneration is proceeding, the inventive strategy will activate a "ready-to-protect" mode by setting an appropriate flag. While that flag is set, detection of a drop-to-idle event, such as a command to run the engine at low idle speed, will cause special set-points to be substituted for the ones that would otherwise be used during the controlled regeneration. Use of the special set-points will continue during what is now a "protect" mode.

[0018] The protect mode will continue until the inlet and/or outlet DPF temperatures are below a safe threshold, or until a maximum time limit is reached. The driver will be able to operate the vehicle normally during this protection mode.

[0019] One generic aspect of the present invention relates to a method for controlling operation of a diesel engine during controlled regeneration of a diesel particulate filter in an engine exhaust system. The method comprises processing certain data related to engine and diesel particulate filter operation, and when the processing discloses the engine being commanded to idle at a low idle speed that has been predetermined appropriate for low idling in the absence of diesel particulate filter regeneration but inappropriate for low idling in the presence of controlled diesel particulate filter regeneration because of the potential for causing on-going regeneration of the diesel particulate filter to become uncontrolled, commanding the engine to idle at a lower low idle speed that is high enough to essentially eliminate the potential for diesel particulate filter regeneration becoming uncontrolled as the engine idles.

[0020] Another generic aspect relates to an engine that uses the method just described.

[0021] A further aspect relates to a motor vehicle comprising a diesel engine for accelerating the vehicle when a driver operates an accelerator, an exhaust system having a diesel particulate filter that traps particulate matter in engine exhaust gases passing through the exhaust system and that at times is regenerated, and a control system comprising a processor for processing certain data to control engine and diesel particulate filter operation.

[0022] In response to release of the accelerator the control system causes the engine to idle at a lower low idle speed that has been predetermined appropriate for low idling when the diesel particulate filter is not being regenerated but inappropriate when the diesel particulate filter is being regenerated because of the potential for causing on-going regeneration to become uncontrolled, and when the diesel particulate filter is being regenerated, to idle at a higher low idle speed sufficiently higher than the lower low idle speed to essentially eliminate the potential for continued diesel particulate filter regeneration becoming uncontrolled as the engine idles.

[0023] The foregoing, along with further features and advantages of the invention, will be seen in the following disclosure of a presently preferred embodiment of the invention depicting the best mode contemplated at this time for carrying out the invention. This specification includes drawings, now briefly described as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. 1 is a basic schematic diagram of portions of a diesel engine relevant to the present invention.

[0025] FIG. 2 is a general software strategy diagram embodying the present invention.

[0026] FIG. 3 is a first embodiment showing more detail of the strategy of FIG. 2.

[0027] FIG. 4 is a second embodiment showing more detail of the strategy of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0028] FIG. 1 shows a diesel engine 10 having an intake system 12 leading to an engine block 14 containing cylinders into which diesel fuel is injected by a fueling system and from which an exhaust system 16 conveys exhaust gases. Exhaust system 16 contains one or more exhaust after-treatment devices one of which is a diesel particulate filter (DPF) 18 having a catalyzed ceramic substrate for trapping diesel particulates.

[0029] When engine 10 is operating to propel a motor vehicle, such as a large truck, exhaust gas exits the engine combustion chambers to enter exhaust system 16 and pass through DPF 18 before eventually passing into the surrounding atmosphere.

[0030] Various sensors are associated with the after-treatment devices. One of them that is relevant to the specific embodiments discussed here is a DPF inlet temperature sensor 20 disposed to measure temperature at the inlet of DPF 18.

[0031] The inventive method is implemented in an engine control system 22 that processes various data from various sources, including sensor 20, to control certain aspects of engine operation, typically by repeated execution of programmed algorithms as the engine operates.

[0032] One such algorithm 24 in FIG. 2 is a part of the basic strategy for controlled regeneration of DPF 18. That basic strategy initiates controlled regeneration when prevailing conditions for controlled regeneration are suitable, provided that the DPF evidences a need for regeneration. Regeneration can be initiated and continued when the vehicle is being driven, as explained in certain prior patent filings on behalf of the assignee.

[0033] A portion of algorithm 24 includes the ability to initiate a protection mode for the DPF. Before the present invention, such protection did not take into account protection against a drop-to-idle event while the DPF was being regenerated.

[0034] If the vehicle is decelerated while a controlled regeneration is underway, the changing prevailing conditions due to that deceleration may not be appropriate for continuing regeneration. As discussed above, engine speed will drop to low idle speed when the vehicle stops and the engine continues to run at low idle, such as when stopping
at a stop light. As a result, exhaust gas flow through the exhaust system, including the DPF, will significantly decrease and the concentration of oxygen inside the DPF will increase. Because internal DPF temperature is already at or above that needed for burning off trapped soot, the combination of decreasing flow rate and increasing oxygen concentration can cause runway regeneration, and repeated regeneration runways can prematurely age the particulate trapping media, a catalyzed ceramic in this case.

[0035] When a vehicle begins to decelerate as a result of the driver releasing the accelerator pedal, control system 22 issues what can be called a drop-to-idle request. Such a request commands the engine to run at a defined low idle speed. That low idle speed is a programmed parameter that can be considered a data set-point in the control system representing the speed at which the engine should idle when engine load is essentially zero. Continued idling at that low idle speed set-point can however cause an on-going DPF regeneration to become uncontrollable.

[0036] The present invention provides a solution for avoiding runway regeneration in that situation by overriding basic engine operation set-points in favor of other set-points specifically calibrated to protect the DPF. When a drop-to-idle command is detected, the invention will trigger substitution of those other set-points into the control strategy.

[0037] As a consequence, the substituted set-points will be processed by the control strategy on the basis of a higher low idle speed, which has been substituted for the predefined low idle speed that is deemed suitable when regeneration is not occurring. The increased low idle speed will increase airflow through DPF 18.

[0038] Other parameters may also be overridden by substituted set-points. They include: main fuel injection timing, EGR valve position, turbocharger (EVRT) vane position, intake throttle position, post-injection fuel quantity, and post-injection fuel timing.

[0039] A first embodiment of the invention is disclosed in FIG. 3 with reference to a state chart 26. When no protection is needed (reference numeral 28), the state of a parameter “prot” is “0”, and a timer “timer” is reset at “0” and is not running. Processing performed by a processor in control system 22 processes the data value of a parameter “soot_load” that indicates the amount of soot trapped in DPF 18. The data value for “soot_load” is obtained in any suitably appropriate way.

[0040] As long as the data value for “soot_load” is less than or equal to the data value for a parameter “min_soott_prot”, “prot” remains a “0”. When the data value for “soot_load” exceeds the data value for “min_soott_prot”, the control system is placed in a “ready-to-protect” mode (reference numeral 30), indicated by the setting of a flag in the processor. In this mode, a drop-to-idle event will trigger the “protect mode” provided that one other condition is satisfied.

[0041] That other condition involves the temperature of exhaust gas entering the DPF inlet, with the condition being satisfied by the data value for a parameter “DPF_in_T” being greater than a minimum temperature “min_T_prot”. Hence, with both DPF soot load exceeding a minimum load defined by “min_soott_prot” and with DPF inlet temperature exceeding a minimum temperature “min_T_prot”, a drop-to-idle event will trigger the “protect mode”, causing “prot” to become a “1” and the timer “timer” to begin running (reference numeral 32).

[0042] With “prot” set to “1”, substitute set-point parameters, one of which is for low idle speed, replace corresponding parameters in the control strategy. The driver will still be able to operate the vehicle normally during this protection mode.

[0043] Protection remains on but will go off when one or more of the following occur: a) timer “timer” times out after a defined maximum amount of time, b) the processing of data from sensor 20 indicates temperature of exhaust gas entering DPF 18 to be less than min_T_prot after timer “timer” has timed for a defined minimum amount of time “min_time”, and c) the engine is commanded to accelerate from low idle, i.e. come under load.

[0044] State chart 30 is implemented in the control system processor by an algorithm forming drop-to-idle protection strategy 34 in FIG. 2. When “prot” is set to “1”, an OR logic function 36 triggers use of the substitute set-points (reference numeral 38). A flag 40 is also set to indicate that the protect state is in effect. By using the OR function 36, the protect state can be activated either by the existing strategy that does not include drop-to-idle protection or by the new drop-to-idle protection strategy.

[0045] FIG. 4 discloses a modified state chart 30 that differs from chart 30 in that some hysteresis in soot load is accounted for when switching the protection mode in and out.

[0046] While a presently preferred embodiment of the invention has been illustrated and described, and is intended to promote use of a catalyzed ceramic as a substrate material in the DPF, it should be appreciated that principles of the invention apply to all embodiments falling within the scope of the following claims. An example of such a catalyzed ceramic is sold under the tradename Coming DuraTrap® RC.

What is claimed is:

1. A method for controlling operation of a diesel engine during controlled regeneration of a diesel particulate filter in an engine exhaust system, the method comprising:
   - processing certain data related to engine and diesel particulate filter operation, and when the processing discloses the engine being commanded to idle at a low idle speed that has been predetermined appropriate for low idling in the absence of diesel particulate filter regeneration but inappropriate for low idling in the presence of controlled diesel particulate filter regeneration because of the potential for causing on-going regeneration of the diesel particulate filter to become uncontrollable, commanding the engine to idle at a higher low idle speed that is high enough to essentially eliminate the potential for diesel particulate filter regeneration becoming uncontrollable as the engine idles.

2. A method as set forth in claim 1 comprising processing data indicative of soot load in the diesel particulate filter and conditioning the step of commanding the engine to idle at a higher low idle speed upon the processing disclosing that the indicated soot load in the diesel particulate filter exceeds a defined soot load.
3. A method as set forth in claim 2 comprising processing data indicating temperature of exhaust gas entering the diesel particulate filter and conditioning the step of commanding the engine to idle at a higher low idle speed upon
the processing disclosing that indicated exhaust gas temperature entering the diesel particulate filter exceeds a defined temperature.

4. A method as set forth in claim 1 comprising processing data indicating temperature of exhaust gas entering the diesel particulate filter and conditioning the step of commanding the engine to idle at a higher low idle speed upon
the processing disclosing that indicated exhaust gas temperature entering the diesel particulate filter exceeds a defined temperature.

5. A method as set forth in claim 1 comprising starting a timer upon occurrence of the step of commanding the engine to idle at a higher low idle speed, and thereafter commanding
the engine to idle at a low idle speed that has been predetermined appropriate for low idling in the absence of diesel particulate filter regeneration but inappropriate for low idling in the presence of controlled diesel particulate filter regeneration upon occurrence of one or more of a) the timer timing out after a defined maximum amount of time, b) the processing of data indicating temperature of exhaust gas entering the diesel particulate filter disclosing a temperature less than a defined temperature after the timer has timed for a defined minimum amount of time, and c) the engine being commanded to accelerate from low idle.

6. A method as set forth in claim 1 comprising conditioning the step of commanding the engine to idle at a higher low idle speed upon a flag, that is selectively set and reset by the
processing step, being set.

7. A method as set forth in claim 6 wherein the conditioning step comprises processing data indicative of soot load in the diesel particulate filter, setting the flag upon the
processing disclosing indicated soot load in the diesel particulate filter exceeding a defined soot load, and resetting the flag upon the processing ceasing to disclose indicated soot load in the diesel particulate filter exceeding the defined soot load.

8. A diesel engine comprising:

an exhaust system having a diesel particulate filter that
traps particulate matter in engine exhaust gases passing
through the exhaust system and that at times is regenerated;
and

a control system comprising a processor for processing certain data to control engine and diesel particulate filter operation, and that in response to a command for
the engine to run at low idle speed causes the engine to
idle at a lower low idle speed that has been predetermined appropriate for low idling when the diesel particulate filter is not being regenerated but inappropriate when the diesel particulate filter is being regenerated because of the potential for causing on-going regeneration to become uncontrolled, and when the diesel particulate filter is being regenerated, to idle at a higher low idle speed sufficiently higher than the lower low idle speed to essentially eliminate the potential for continued diesel particulate filter regeneration becoming uncontrolled as the engine idles.

9. An engine as set forth in claim 8 wherein the processor is arranged to process data indicative of soot load in the
diesel particulate filter and to condition the step of com-
mmanding the engine to idle at a higher low idle speed upon
processing data disclosing that the indicated soot load in the
diesel particulate filter exceeds a defined soot load.

10. An engine as set forth in claim 9 wherein the processor
is arranged to process data indicating temperature of exhaust
gas entering the diesel particulate filter and to condition
commanding the engine to idle at a higher low idle speed
upon indicated exhaust gas temperature entering the diesel
particulate filter exceeding a defined temperature.

11. An engine as set forth in claim 8 wherein the processor
is arranged to process data indicating temperature of exhaust
gas entering the diesel particulate filter and to condition
commanding the engine to idle at a higher low idle speed
upon indicated exhaust gas temperature entering the diesel
particulate filter exceeding a defined temperature.

12. An engine as set forth in claim 8 wherein the processor
is arranged to start a timer upon commanding the engine to
idle at a higher low idle speed, and thereafter to command
the engine to idle at a lower low idle speed upon occurrence of one or more of a) the timer timing out after a defined maximum amount of time, b) the processing of data indicating temperature of exhaust gas entering the diesel particulate filter disclosing a temperature less than a defined temperature after the timer has timed for a defined minimum amount of time, and c) the engine is commanded to accelerate from low idle speed.

13. An engine as set forth in claim 8 wherein the processor
is arranged to condition the step of commanding the engine to
idle at a higher low idle speed upon a flag, that is selectively set and reset, being set.

14. An engine as set forth in claim 13 wherein the processor
is arranged to process data indicative of soot load in the
diesel particulate filter, to condition setting the flag
upon the indicated soot load in the diesel particulate filter exceeding a defined soot load, and to condition resetting the flag upon the indicated soot load in the diesel particulate filter ceasing to exceed the defined soot load.

15. An engine as set forth in claim 8 wherein the diesel
particulate filter comprises a catalyzed ceramic substrate.

16. A motor vehicle comprising:

a diesel engine for accelerating the vehicle when a driver
operates an accelerator;

an exhaust system having a diesel particulate filter that
traps particulate matter in engine exhaust gases passing
through the exhaust system and that at times is regenerated;
and

a control system comprising a processor for processing certain data to control engine and diesel particulate filter operation, and that in response to release of the accelerator causes the engine to idle at a lower low idle speed that has been predetermined appropriate for low idling when the diesel particulate filter is not being regenerated but inappropriate when the diesel particulate filter is being regenerated because of the potential for causing on-going regeneration to become uncontrolled, and when the diesel particulate filter is being regenerated, to idle at a higher low idle speed sufficiently higher than the lower low idle speed to essentially eliminate the potential for continued diesel particulate filter regeneration becoming uncontrolled as the engine idles.

17. A motor vehicle as set forth in claim 16 wherein the processor is arranged to process data indicative of soot load
in the diesel particulate filter and to condition the step of
commanding the engine to idle at a higher low idle speed
upon processing data disclosing that the indicated soot load
in the diesel particulate filter exceeds a defined soot load.

18. A motor vehicle as set forth in claim 17 wherein the
processor is arranged to process data indicating temperature
of exhaust gas entering the diesel particulate filter and to
condition commanding the engine to idle at a higher low idle
speed upon indicated exhaust gas temperature entering the
diesel particulate filter exceeding a defined temperature.

19. A motor vehicle as set forth in claim 16 wherein the
processor is arranged to process data indicating temperature
of exhaust gas entering the diesel particulate filter and to
condition commanding the engine to idle at a higher low idle
speed upon indicated exhaust gas temperature entering the
diesel particulate filter exceeding a defined temperature.

20. A motor vehicle as set forth in claim 16 wherein the
processor is arranged to start a timer upon commanding the
engine to idle at a higher low idle speed, and thereafter to
command the engine to idle at a lower low idle speed upon
occurrence of one or more of a) the timer timing out after a
defined maximum amount of time, b) the processing of data
indicating temperature of exhaust gas entering the diesel
particulate filter disclosing a temperature less than a defined
temperature after the timer has timed for a defined minimum
amount of time, and c) the accelerator is again operated to
accelerate the vehicle.

21. A motor vehicle as set forth in claim 16 wherein the
processor is arranged to condition the step of commanding
the engine to idle at a higher low idle speed upon a flag, that
is selectively set and reset, being set.

22. A motor vehicle as set forth in claim 21 wherein the
processor is arranged to process data indicative of soot load
in the diesel particulate filter, to condition setting the flag
upon the indicated soot load in the diesel particulate filter
exceeding a defined soot load, and to condition resetting the
flag upon the indicated soot load in the diesel particulate
filter ceasing to exceed the defined soot load.

23. A motor vehicle as set forth in claim 16 wherein the
diesel particulate filter comprises a catalyzed ceramic sub-
strate.

* * * * *