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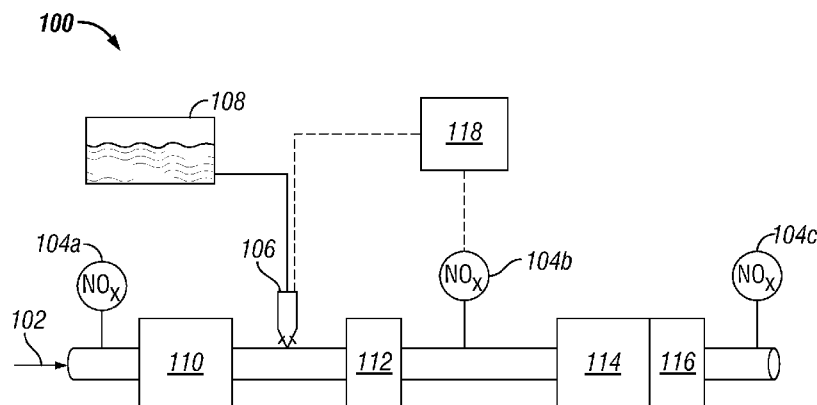
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(54) Title: CONTROL TECHNIQUES FOR AN SCR AFTERTREATMENT SYSTEM

**FIG. 1**(57) Abstract: A method includes providing: a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst, and a NO_x sensor coupled to the exhaust gas stream at a position downstream of at least a first portion of the SCR catalyst. The method includes operating an extremum seeking controller to determine a first reagent injection amount corresponding to a pre-determined slope of $\delta\text{NO}_x/\delta\text{ANR}$, the $\delta\text{NO}_x/\delta\text{ANR}$ determined according to the NO_x sensor, providing a reagent injection command in response to the first reagent injection amount, and injecting an amount of the reagent in response to the reagent injection command.

CONTROL TECHNIQUES FOR AN SCR AFTERTREATMENT SYSTEM

RELATED APPLICATIONS

This application is related to, and claims the benefit of, US Provisional Application 61/481,939, entitled CONTROL TECHNIQUES FOR AN SCR AFTERTREATMENT SYSTEM, which is incorporated herein by reference in the entirety for all purposes.

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BACKGROUND

The technical field generally relates to control of selective catalytic reduction (SCR) aftertreatment systems for internal combustion engines. SCR systems present several control challenges for internal combustion engine applications, including for mobile applications. SCR systems include a reduction catalyst and a reducing agent, such as urea or ammonia.

An injector provides the reducing agent to the exhaust stream at a position upstream of the SCR catalyst, and the reducing agent enters the gas phase of the exhaust stream as ammonia. A delay sometimes occurs between the introduction of the reducing agent and the availability of the reductant product, for example injected particles of the reducing agent may need to evaporate into the exhaust stream, hydrolyze from urea to ammonia, and/or thoroughly mix into the exhaust stream for general availability across the SCR catalyst. Additionally, the SCR catalyst may include some ammonia storage capacity. Storage capacity can complicate the controls process, for example by creating additional controls targets (e.g. a storage target), by releasing ammonia unexpectedly (e.g. when a system condition causes a decrease in storage capacity), and/or by adsorbing some of the injected ammonia in an early part of the catalyst thereby reducing the availability of ammonia at a rear portion of the catalyst during catalyst filling operating periods.

The challenges presented by presently available SCR systems are exacerbated by the transient nature of mobile applications. The engine load

and speed profile varies during operations in a manner that is determined by an operator and generally not known in advance to the SCR control system. Additionally, available feedback systems suffer from several drawbacks. For example, the concentration of ammonia is difficult to determine in real time.

- 5 Commercially reasonable ammonia sensors often suffer from cross-sensitivity with NO_x, complicating the determination of the amount of ammonia present. Further, ammonia is generally an undesirable constituent of the final exhaust emissions, and further emitted ammonia represents ineffectively utilized reductant that increases operating costs. Therefore it is desirable to operate at
- 10 a very low or zero ammonia concentration at the SCR catalyst outlet. Ammonia levels at the SCR outlet in many applications are below the reliable level of commercially reasonable sensor detection, especially in aging or marginal ammonia sensors.

SUMMARY

One embodiment is a unique method for controlling an SCR aftertreatment system. Other embodiments include unique methods, systems, and apparatus to minimize a NO_x sensor output, to operate an SCR aftertreatment system at an operating point offset from the minimum point, and/or to control an SCR aftertreatment system at a δ -NO_x/ δ ANR value. This summary is provided to introduce a selection of concepts that are further described below in the illustrative embodiments. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a system for operating an SCR catalyst to reduce NO_x emissions of an engine.

Fig. 2 is a schematic diagram of a control loop for operating an SCR catalyst to reduce NO_x emissions of an engine.

Fig. 3 is an illustration of a NO_x concentration response to an ammonia-to- NO_x ratio in an exhaust gas stream.

Fig. 4 is a second illustration of a NO_x concentration response to an ammonia-to- NO_x ratio in an exhaust gas stream.

Fig. 5 is an illustration of reductant injection and a NO_x -ANR slope plotted over time.

Fig. 6 is a second illustration of reductant injection and a NO_x -ANR slope plotted over time.

Fig. 7 is a schematic diagram of a processing subsystem for operating an SCR catalyst.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will
5 nevertheless be understood that no limitation of the scope of the invention is thereby intended, any alterations and further modifications in the illustrated embodiments, and any further applications of the principles of the invention as illustrated therein as would normally occur to one skilled in the art to which the invention relates are contemplated herein.

10 Referencing Fig. 1, a system 100 includes an exhaust flow 102 from an internal combustion engine, the exhaust flow 102 including an amount of NO_x . The system 100 includes a first NO_x sensor 104a that is an optional NO_x sensor to provide an estimate of engine-out NO_x . The engine-out NO_x may alternatively be determined by a model or a sensor positioned at a different
15 location in the system. The system 100 includes an upstream aftertreatment component 110, that may be an oxidation catalyst, a particulate filter, or both. In certain embodiments, the upstream NO_x sensor 104a is positioned without any oxidation catalyst between the sensor 104a and a first SCR catalyst 112.

The system 100 includes a reductant injector 106 fluidly coupled to a
20 reductant injector source 108. The reductant injector 106 injects urea, NH_3 , or other NH_3 producing constituent. The system 100 includes the first SCR catalyst 112 and the second SCR catalyst 114, with a second NO_x sensor 104b positioned therebetween. In the illustrated example, the first SCR catalyst 112 is smaller than the second SCR catalyst 114, providing for most of the SCR
25 based NO_x reduction capacity of the system 100 to be downstream of the second NO_x sensor 104b. The ratio of the first SCR catalyst 112 to the second SCR catalyst 114 is selectable to any value, including at least values from 1:9 to 9:1, and 1:4 to 4:1, although values outside these ranges are also contemplated herein. The only requirement in the sizes of the catalyst ranges
30 are, during periods wherein an operating slope 304 (reference Fig. 3 and the

referencing description) is being determined, the first SCR catalyst 112 includes sufficient catalyst material to reduce a statistically significant amount of NO_x to N₂ compared to the precision of the sensor 104b. In certain embodiments, the second SCR catalyst 114 is sufficiently sized to reduce a statistically significant amount of NO_x to N₂ compared to the precision of the sensor 104b or the sensor 104c, although typically the second SCR catalyst 114 will include half or more of the total SCR catalyst mass.

The system 100 further includes an optional NH₃ oxidation (AMOX) catalyst 116, provided to oxidize at least a portion of the slipping NH₃ from the second SCR catalyst 114 during at least some operating conditions. The AMOX 116 may be presented as a discrete catalytic element, in the same or a different housing from the second SCR catalyst 114, and may be included as a washcoat on a portion (specifically a rear portion) of the second SCR catalyst 114. The first SCR catalyst 112 and the second SCR catalyst 114 may be located in the same or a different housing. Additional SCR catalyst elements may be present, and are schematically included with the second SCR catalyst 114 herein.

The system 100 further includes a controller 118. The controller 118 may form a portion of a processing subsystem, and may include functional elements in software and/or hardware. The controller 118 may be a single device or more than one distributed devices. The controller 118 may have modules structured to functionally execute any operations of any method or procedure described herein.

An exemplary method includes providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst. The method includes providing a NO_x sensor coupled to the exhaust gas stream at a position downstream of a first portion of the SCR catalyst and upstream of a second portion of the SCR catalyst. The NO_x sensor may be provided at a mid-bed location between the

first and second SCR catalysts. The mid-bed location is a location between two SCR catalyst elements, or a position within a single SCR catalyst element that includes some of the SCR catalyst mass upstream and some of the SCR catalyst mass downstream. The first and second SCR catalysts may be within
5 the same housing or be provided within separate housings.

The method includes operating an extremum seeking algorithm to determine a first reagent injection amount corresponding to a minimum apparent NO_x measurement from the NO_x sensor. Referencing Fig. 2, an exemplary extremum seeking algorithm is illustrated, with a perturbation (or
10 dithering) operation 202 that perturbs an inlet command parameter (e.g. the reductant injection rate), adds the perturbation term to a current estimate of the optimal parameter (x) to generate an input command 206, and measures the resulting output 208 after the system 204 operates on the input 206. The utilization of the integrator 210 attenuates high frequency dynamics from the
15 output 208. In certain embodiments, a low-pass filter or other high frequency attenuation may be utilized. The exemplary extremum controller 200 in Fig. 2 is illustrative and non-limiting, and any extremum seeking controller, or other algorithm that provides a convergence of the NO_x measurement from the NO_x sensor to a minimum value is contemplated herein.

20 The method includes providing a reagent injection command in response to the first reagent injection amount. The provided reagent injection command may be the first reagent injection amount that is found to minimize the NO_x measurement. Alternatively, the reagent injection command may be a command having an ANR value that is offset (e.g. higher or lower) than the
25 ANR value associated with the first reagent injection amount. Alternatively or additionally, the reagent injection command may be a command having an ANR value that is a multiple of the ANR value associated with the first reagent injection amount.

For example, referencing Fig. 3, illustrative data 300 including an
30 operating curve 302 of the ANR versus the NO_x measurement of the NO_x

sensor is shown for a particular set of conditions. The curve 302 includes a minimum NO_x measurement 306, illustrated in the example at an ANR value of greater than 1, in the region of 1.15. One of skill in the art will recognize that any change in the system conditions, including a temperature of the SCR catalyst, an amount of NO_x being emitted by the engine, an amount of NH_3 presently stored on the SCR catalyst, an exhaust flow rate through the SCR catalyst, or other factors, will change the operating curve 302 and the point of the minimum 306 on the curve. At the point 306 where the minimum occurs, a slope 304 of $\delta\text{-NO}_x/\delta\text{-ANR}$ is shown and is zero. Exemplary operations include determining the minimum 306 at the present operating conditions utilizing an extremum seeking controller, and injecting reductant at the ANR of the minimum 306, injecting at an offset ANR from the minimum (e.g. 1.2 rather than 1.15, or 1.05 rather than 1.15), and/or injecting at a multiple ANR of the minimum 306 ANR (e.g. between 0.95x and 1.25x the minimum 306).

The method includes injecting an amount of the reagent in response to the reagent injection command.

In certain embodiments, the method includes dithering (or perturbing) an input term of the controller. The dithering may be performed continuously or periodically. For example, where the dithering is performed continuously, the controller continuously perturbs the input term (e.g. the reductant injection rate), and checks for the minimum 306 on the operating curve 302, or for operation at a predetermined slope 304 value of the operating curve 302. Where the dithering is performed periodically, the minimum 306 or predetermined slope 304 value along the operating curve 302 is determined for the present operating conditions, and the reductant injection rate determined thereby is utilized for a period of time before perturbation is resumed to check the operating point again. The period of time may be related to a period of time during which catalyst degradation may occur, the period of time may be determined to expire in response to a catalyst NH_3 storage level change (e.g. the catalyst has emptied or filled with NH_3 since the perturbation check),

and/or the period of time may be determined to expire in response to operating condition changes that have changed or introduced the risk of changing the operating curve 302. The dithering of the input term may be performed using an oscillating or varying function of any type, including utilizing an oscillating trigonometric function.

In certain embodiments, the amplitude of the dithering is limited, for example based upon an amount of reagent that would be required to react with all of the engine emitted NO_x . An exemplary dithering amplitude includes dithering with an amplitude of less than 25% of a stoichiometric reagent amount, and/or dithering with an amplitude of less than 10% of a stoichiometric reagent amount. In certain embodiments, the method includes continuously dithering the input term utilizing a differentiable function. In certain embodiments, the operations of the extremum controller are not suspended for invasive testing.

In certain embodiments, the second portion of the SCR catalyst includes a majority of the SCR catalyst. The majority of the SCR catalyst can include at least three-fourths of the SCR catalyst, although a smaller fraction of the SCR catalyst may be provided in the second portion. The utilization of a smaller amount of catalyst in the first portion of the SCR catalyst provides for a more responsive control system, and for a more accurate determination of the minimum 306 operating point or of the slope 304. The utilization of a larger amount of catalyst in the first portion of the SCR catalyst provides for feedback control on a greater portion of the SCR catalyst, and is therefore more robust to disturbances such as uneven degradation of the first and second portions of the SCR catalyst, or uneven NO_x reduction performance of the first and second SCR catalysts. One of skill in the art contemplating a particular system and having the benefit of the disclosures herein can determine appropriate fractions for the first portion and second portion of the SCR catalyst.

In certain embodiments, the first reagent injection amount corresponds to a first ANR, and the method includes providing the reagent injection command by determining a second ANR that is offset from the first ANR and providing the reagent injection command to achieve the second ANR. The second ANR may be lower or higher than the first ANR. The exemplary method further includes determining the second ANR by determining an ANR lower than the first ANR that still provides an apparent NO_x measurement that is lower than a threshold apparent NO_x measurement. The threshold apparent NO_x measurement may be an emissions limit or other selected NO_x limit.

An exemplary method includes providing the second ANR that is lower than the first ANR, where an increasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR (i.e. operating slope 304 on Fig. 3) that is below a first threshold value and that decreasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is above a second threshold value. Another exemplary method includes providing the second ANR that is lower than the first ANR, where an increasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is above a first threshold value and that decreasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is below a second threshold value. Another exemplary embodiment includes providing the second ANR that is lower than the first ANR, where a δ -apparent NO_x/ δ -ANR at the second ANR is within a third threshold value of a target δ -apparent NO_x/ δ -ANR (i.e. the slope 304 at the second ANR is within the third threshold value of a target slope 304).

Another exemplary method includes providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst. The method further includes providing a NO_x sensor coupled to the exhaust gas stream at a position downstream of at least a first portion of the SCR catalyst, and

operating an extremum seeking controller to determine a first reagent injection amount corresponding to a predetermined slope of $\delta\text{NO}_x/\delta\text{ANR}$, the $\delta\text{NO}_x/\delta\text{ANR}$ determined according to the NO_x sensor. The extremum seeking controller may be a slope seeking controller, and/or the extremum seeking controller may be a controller seeking a minimum of an error value, where the error value is determined as a difference between the predetermined slope of $\delta\text{NO}_x/\delta\text{ANR}$ and a presently observed slope 304 of a current operating point.

The method further includes providing a reagent injection command in response to the first reagent injection amount, and injecting an amount of the reagent in response to the reagent injection command.

Referencing Fig. 4, illustrative data 400 is shown with an operating curve 402, an operating point 406, and a slope 404 at the operating point 406. Where the slope 404 is the predetermined slope, the system in Fig. 4 is operating at the designed operating point. Referencing Fig. 5, a controller dithers the reductant injection rate versus time on curve 502. The actual mid-bed NO_x observed is shown on the curve 504, which will be dampened somewhat from the reductant injection rate curve 502 due to system dynamics. The curve 504 will also be slightly phase-shifted behind curve 502, but this effect is not illustrated to simplify the example. A slope 506 of zero is illustrated in Fig. 5, showing that the curve 504 is operating in pseudo-steady state at small positive slope value. The data in Fig. 5 is consistent with a system operating on curve 402 (see Fig. 4) near the operating point 406, with some movement back and forth on the curve 402 due to the control dithering, and to the right of the minimum.

Referencing Fig. 6, a system response is illustrated where external disturbances are introduced. The data 600 in Fig. 6 is illustrative and demonstrates the control response, but the type and magnitude of the disturbances are not indicative of any particular effect. After a brief period of dithering on the curve 602 and dampened oscillation on curve 604, the slope of the $\delta\text{NO}_x/\delta\text{ANR}$ drops, for example due to a change in the operating curve 402

due to a temperature, NH_3 storage, flow rate, or other system change. A rapid increase in the engine-out NO_x amount would also introduce a rapid reduction in the ANR which could introduce the drop in the $\delta\text{NO}_x/\delta\text{ANR}$. The controller responds on curve 602 with an increase in reductant injection rate. The control response is less oscillatory during the change in the example, due to the feedforward NO_x control algorithm inducing a rapid change in the reductant injection amount (e.g. in response to a rapid engine-out NO_x increase). As the curve 604 returns to the predetermined slope value, the oscillatory character of the control curve 602 returns. The control curves in Figs. 5 and 6 are shown to be oscillating throughout the illustrated time segment, but the oscillation may be periodic, continuous, intermittent, or performed in response to certain triggering criteria as otherwise explained herein.

An example system includes a processing subsystem having a controller 118 structured to functionally execute certain operations to control an SCR aftertreatment system. The controller 118 form a portion of a processing subsystem, and may include functional elements in software and/or hardware. The controller 118 may be a single device or more than one distributed devices. The controller 118 may have modules structured to functionally execute any operations of any method or procedure described herein.

In certain embodiments, the controller 118 includes one or more modules structured to functionally execute the operations of the controller 118. Referencing Fig. 7, an example processing subsystem 700 includes a controller 118 having a NO_x determination module 702, a dithering module 704, and a reagent targeting module 706. The description herein including modules emphasizes the structural independence of the aspects of the controller, and illustrates one grouping of operations and responsibilities of the controller. Other groupings that execute similar overall operations are understood within the scope of the present application. Modules may be implemented in

hardware and/or software on computer readable medium, and modules may be distributed across various hardware or software components.

Certain operations described herein include operations to interpret one or more parameters. Interpreting, as utilized herein, includes receiving values by any method known in the art, including at least receiving values from a datalink or network communication, receiving an electronic signal (e.g. a voltage, frequency, current, or PWM signal) indicative of the value, receiving a software parameter indicative of the value, reading the value from a memory location on a computer readable medium, receiving the value as a run-time parameter by any means known in the art, and/or by receiving a value by which the interpreted parameter can be calculated, and/or by referencing a default value that is interpreted to be the parameter value.

The controller 118 may be a part of a system including a selective catalytic reduction (SCR) portion and a NO_x sensor operationally coupled to an internal combustion engine exhaust at a position downstream of the SCR portion. The SCR portion includes any fraction of an SCR catalyst amount in the system, including the full SCR catalyst amount. In certain embodiments, the SCR portion is an upstream fraction of at least two SCR portions, and may be provided in a separate housing or the same housing as a downstream portion. Additionally or alternatively, the SCR portion and a downstream SCR portion may be physically part of the same catalyst substrate, with the NO_x sensor provided at a mid-location in the catalyst substrate. The NO_x sensor providing a NO_x measurement, which may be an output value of the NO_x sensor, a measurement of NO_x in the exhaust stream, and/or an apparent measurement of NO_x, for example combined with any apparent NO_x due to cross-sensitivity to and presence of ammonia in the exhaust stream at the NO_x sensor.

The controller 118 includes a NO_x determination module 702 that interprets the NO_x measurement. The controller 118 further includes a dithering module 704 that provides a dithering value which includes a reagent

target adjustment. The dithering value is a value that varies a reagent injection amount 712, including a value that is dithered and converted elsewhere in the system to adjust a command for a reagent injector. The dithering of the reagent injection amount 712 determines a minimum NO_x operating point in terms of ANR (e.g. reference Fig. 3 and the referencing description), determines an ANR value or range of values that provide a NO_x amount that is lower than a threshold NO_x amount (e.g. through determination of specific operating points on a curve 302), and/or determines one or more slope values of $\delta\text{NO}_x/\delta\text{ANR}$. The determination of one or more slope values $\delta\text{NO}_x/\delta\text{ANR}$ can be utilized to provide a robust minimum NO_x ANR (e.g. near a value or range of values where $\delta\text{NO}_x/\delta\text{ANR}$ is close to zero) and/or to determine an ANR value or range of ANR values that provide an acceptably low slope value $\delta\text{NO}_x/\delta\text{ANR}$. The slope value $\delta\text{NO}_x/\delta\text{ANR}$ may be an instantaneous slope or approximation thereof (e.g. by determining a fit equation for a curve 302 and using a derivative equation) and/or by determining averaged slope value over a range of ANR values.

The operations of the dithering module 704 may be continuous and/or periodic – for example occurring continuously during all engine operating periods, operating continuously during certain engine operating periods, and/or occurring at certain intervals (e.g. once per trip, once per day, once per hour, etc.)

The controller 118 further includes a reagent targeting module 706 that determines a reagent injection amount 712 in response to the reagent target adjustment and the NO_x measurement 708. Example and non-limiting reagent target adjustments include an ANR target 718, an ANR offset 720, an ANR corresponding to a target $\delta\text{NO}_x/\delta\text{ANR}$ value 716, and/or an ANR corresponding to a NO_x minimum value 714. The reagent injection amount 712 is additionally or alternatively adjusted by the dithering amount 710 during operations of the dithering module 704.

The system further includes a reagent injector responsive to the reagent injection amount 712. The reagent injector response to the reagent injection amount 712 may be any type of response understood in the art. Example and non-limiting responses of the reagent injector include targeting the reagent injection amount 712 as an injection amount, progressing toward injecting the reagent injection amount 712 (e.g. through a feedforward and/or feedback controller), and/or providing the reagent injection amount 712 into a controller accepting other competing or limiting values for injection (e.g. ammonia slip limits, SCR catalyst storage limits, current conversion efficiency limits, etc.).

As is evident from the figures and text presented above, a variety of embodiments according to the present disclosure are contemplated.

An example set of embodiments is a method including providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst, providing a NO_x sensor coupled to the exhaust gas stream at a position downstream of a first portion of the SCR catalyst and upstream of a second portion of the SCR catalyst, and operating an extremum seeking algorithm to determine a first reagent injection amount corresponding to a minimum apparent NO_x measurement from the NO_x sensor. The method further includes providing a reagent injection command in response to the first reagent injection amount, and injecting an amount of the reagent in response to the reagent injection command.

In certain further embodiments, the method additionally or alternatively includes the operating the extremum seeking algorithm including dithering an injected reagent amount, where the dithering may include scaling a feedback term by a dithering value and biasing the injected reagent amount by the dithering value. The dithering may be performed continuously, for example by utilizing an oscillating trigonometric function and/or by utilizing a differentiable function. In certain embodiments, the

method includes periodically and/or intermittently performing the dithering. In certain embodiments, the dithering includes an amplitude of up to 25% of a stoichiometric reagent amount, or an amplitude of up to 10% of the stoichiometric reagent amount. An example methods includes operating the
5 extremum controller without pauses for invasive testing.

In certain embodiments, the second portion of the SCR catalyst includes a majority of the SCR catalyst, and may further include at least three-fourths of the SCR catalyst. In certain embodiments, the first reagent injection amount corresponds to a first ammonia to NO_x ratio (ANR), where providing
10 the reagent injection command in response to the first reagent injection amount includes determining a second ANR that is offset from the first ANR, and providing the reagent injection command to achieve the second ANR. Additional or alternative embodiment include one or more of: the second ANR is lower than the first ANR by an offset amount; the determining the second
15 ANR includes determining an ANR lower than the first ANR that provides an apparent NO_x measurement that is lower than a threshold apparent NO_x measurement; and/or the second ANR being an ANR lower than the first ANR such that: an increasing ANR from the second ANR has a δ -apparent NO_x / δ -ANR that is below a first threshold value and that decreasing ANR from the
20 second ANR has a δ -apparent NO_x / δ -ANR that is above a second threshold value; an increasing ANR from the second ANR has a δ -apparent NO_x / δ -ANR that is above a first threshold value and that decreasing ANR from the second ANR has a δ -apparent NO_x / δ -ANR that is below a second threshold value; and/or a δ -apparent NO_x / δ -ANR at the second ANR is within a third threshold
25 value of a target δ -apparent NO_x / δ -ANR.

Another example set of embodiments is a method including providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst,
30 providing a NO_x sensor coupled to the exhaust gas stream at a position

downstream of at least a first portion of the SCR catalyst, operating an extremum seeking controller to determine a first reagent injection amount corresponding to a predetermined slope of $\delta\text{NO}_x/\delta\text{ANR}$, the $\delta\text{NO}_x/\delta\text{ANR}$ determined according to the NO_x sensor, providing a reagent injection
5 command in response to the first reagent injection amount, and injecting an amount of the reagent in response to the reagent injection command.

In certain additional or alternative embodiments, the method includes the operating the extremum seeking algorithm including dithering the reagent injection command to confirm the current slope of $\delta\text{NO}_x/\delta t$, the predetermined
10 slope of $\delta\text{NO}_x/\delta t$ occurring at a reagent injection command greater than an ANR of 1, and/or the predetermined slope of $\delta\text{NO}_x/\delta t$ being a positive non-zero value.

An example set of embodiments is a system including a selective catalytic reduction (SCR) portion and a NO_x sensor operationally coupled to an
15 internal combustion engine exhaust at a position downstream of the SCR portion, the NO_x sensor providing a NO_x measurement, a controller having a NO_x determination module that interprets the NO_x measurement, a dithering module that provides a dithering value including a reagent target adjustment, and a reagent targeting module that determines a reagent injection amount in
20 response to the reagent target adjustment and the NO_x measurement. The system includes a reagent injector responsive to the reagent injection amount.

In certain additional or alternative embodiments, the system includes the dithering module operating periodically, the reagent targeting module further targeting a reagent injection amount corresponding to a minimum
25 value of the NO_x measurement, and/or the SCR portion including a first SCR portion, where the system further includes a second SCR portion downstream of the NO_x sensor, and where the second SCR portion is larger than the SCR portion.

While the invention has been illustrated and described in detail in the
30 drawings and foregoing description, the same is to be considered as illustrative

and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described. Those skilled in the art will appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, 5 all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

In reading the claims, it is intended that when words such as “a,” “an,” “at least one,” or “at least one portion” are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the 10 claim. When the language “at least a portion” and/or “a portion” is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

WHAT IS CLAIMED IS:

1. A method, comprising:
 - providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst;
 - providing a NO_x sensor coupled to the exhaust gas stream at a position downstream of a first portion of the SCR catalyst and upstream of a second portion of the SCR catalyst;
 - operating an extremum seeking algorithm to determine a first reagent injection amount corresponding to a minimum apparent NO_x measurement from the NO_x sensor;
 - providing a reagent injection command in response to the first reagent injection amount; and
 - injecting an amount of the reagent in response to the reagent injection command.
2. The method of claim 1, wherein the operating the extremum seeking algorithm comprises dithering an injected reagent amount.
3. The method of claim 2, wherein the dithering comprises scaling a feedback term by a dithering value and biasing the injected reagent amount by the dithering value.
4. The method of claim 2, further comprising continuously performing the dithering.
5. The method of claim 4, wherein the continuously performing the dithering comprises utilizing an oscillating trigonometric function.
6. The method of claim 2, further comprising periodically performing the dithering.
7. The method of claim 2 wherein the dithering comprises an amplitude of less than 25% of a stoichiometric reagent amount.

8. The method of claim 2, wherein the dithering comprises an amplitude of less than 10% of a stoichiometric reagent amount.
9. The method of claim 4, wherein the continuously performing the dithering comprises utilizing a differentiable function.
10. The method of claim 1, wherein the operations of the extremum controller are not suspended for invasive testing.
11. The method of claim 1, wherein the second portion of the SCR catalyst comprises a majority of the SCR catalyst.
12. The method of claim 11, wherein the second portion of the SCR catalyst further comprises at least three-fourths of the SCR catalyst.
13. The method of claim 1, wherein the first reagent injection amount corresponds to a first ammonia to NO_x ratio (ANR), wherein providing the reagent injection command in response to the first reagent injection amount comprises determining a second ANR that is offset from the first ANR, and providing the reagent injection command to achieve the second ANR.
14. The method of claim 13, wherein the second ANR is lower than the first ANR by an offset amount.
15. The method of claim 13, wherein determining the second ANR comprises determining an ANR lower than the first ANR that provides an apparent NO_x measurement that is lower than a threshold apparent NO_x measurement.
16. The method of claim 13, wherein the second ANR comprises an ANR lower than the first ANR such that one of:
 - an increasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is below a first threshold value and that decreasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is above a second threshold value;
 - an increasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is above a first threshold value and that decreasing ANR from the second ANR has a δ -apparent NO_x/ δ -ANR that is below a second threshold value; and

a δ -apparent $\text{NO}_x/\delta\text{-ANR}$ at the second ANR is within a third threshold value of a target δ -apparent $\text{NO}_x/\delta\text{-ANR}$.

17. A method, comprising:

providing a selective catalytic reduction (SCR) catalyst disposed in an exhaust gas stream of an internal combustion engine, and a reagent injector operationally coupled to the exhaust gas stream at a position upstream of the SCR catalyst;

providing a NO_x sensor coupled to the exhaust gas stream at a position downstream of at least a first portion of the SCR catalyst;

operating an extremum seeking controller to determine a first reagent injection amount corresponding to a predetermined slope of $\delta\text{NO}_x/\delta\text{ANR}$, the $\delta\text{NO}_x/\delta\text{ANR}$ determined according to the NO_x sensor;

providing a reagent injection command in response to the first reagent injection amount; and

injecting an amount of the reagent in response to the reagent injection command.

18. The method of claim 17, wherein the operating the extremum seeking algorithm comprises dithering the reagent injection command to confirm the current slope of $\delta\text{NO}_x/\delta t$.

19. The method of claim 17, wherein the predetermined slope of $\delta\text{NO}_x/\delta t$ occurs at a reagent injection command greater than an ANR of 1.

20. The method of claim 17, wherein the predetermined slope of $\delta\text{NO}_x/\delta t$ is a positive non-zero value.

21. A system, comprising:

a selective catalytic reduction (SCR) portion and a NO_x sensor operationally coupled to an internal combustion engine exhaust at a position downstream of the SCR portion, the NO_x sensor providing a NO_x measurement;

a controller, the controller comprising:

a NO_x determination module structured to interpret the NO_x measurement;

a dithering module structured to provide a dithering value comprising a reagent target adjustment;

a reagent targeting module structured to determine a reagent injection amount in response to the reagent target adjustment and the NO_x measurement; and

a reagent injector responsive to the reagent injection amount.

22. The system of claim 21, wherein the dithering module operates periodically.

23. The system of claim 21, wherein the reagent targeting module is further structured to target a reagent injection amount corresponding to a minimum value of the NO_x measurement.

24. The system of claim 21, the SCR portion comprising a first SCR portion, the system further comprising a second SCR portion downstream of the NO_x sensor, wherein the second SCR portion is larger than the SCR portion.

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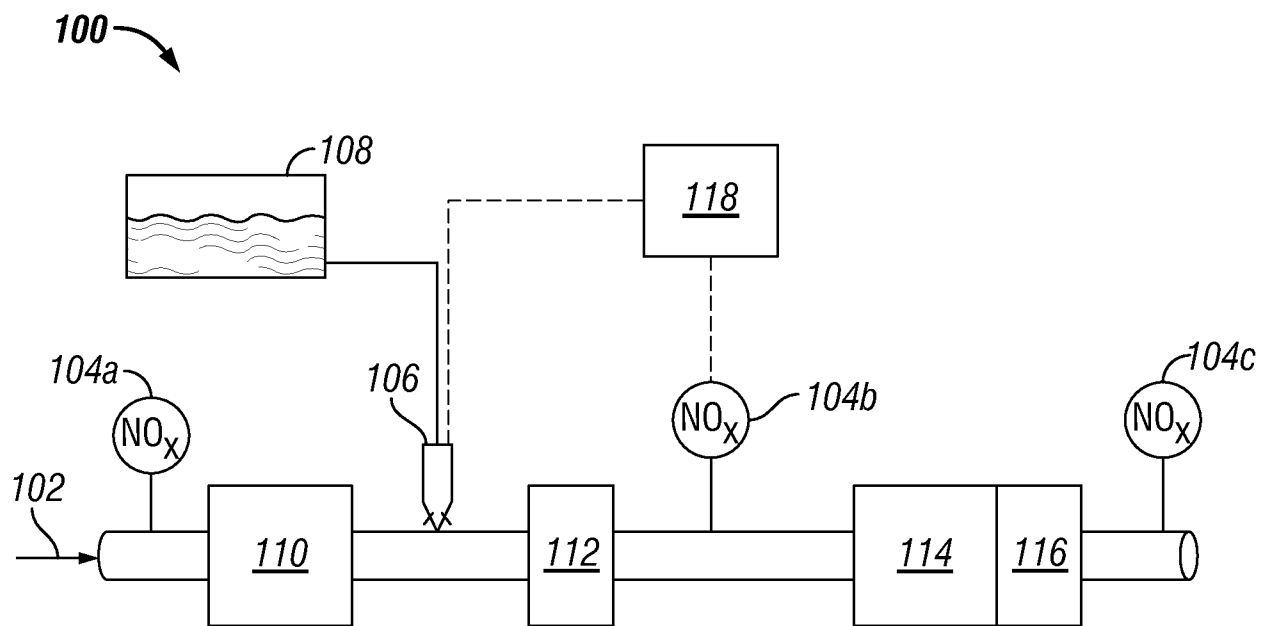


FIG. 1

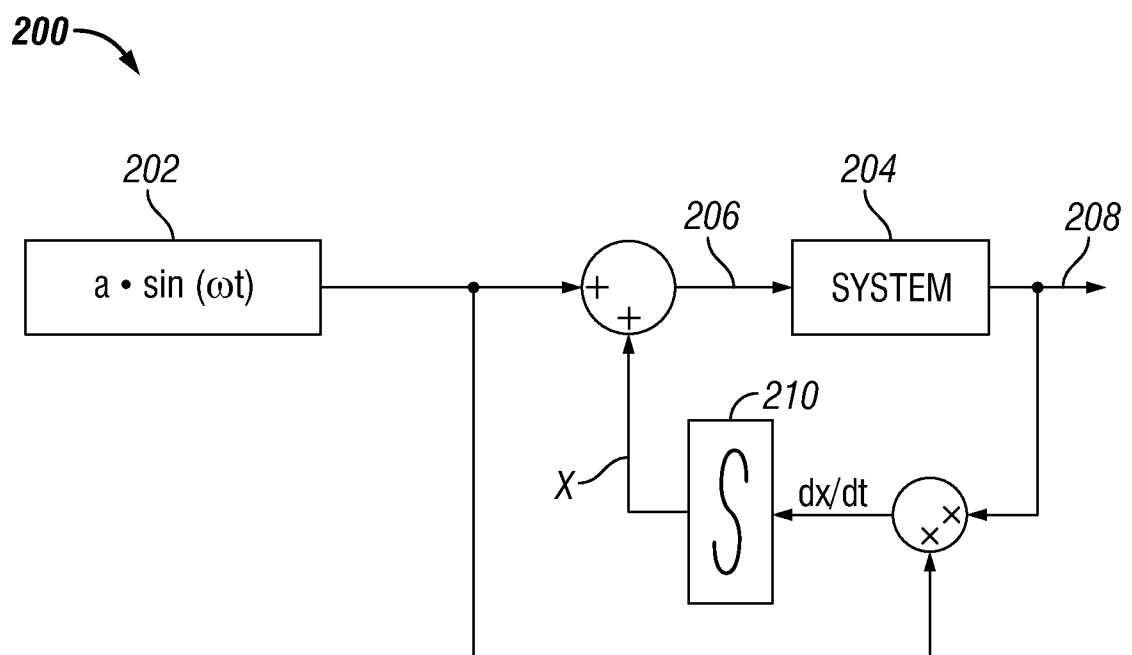


FIG. 2

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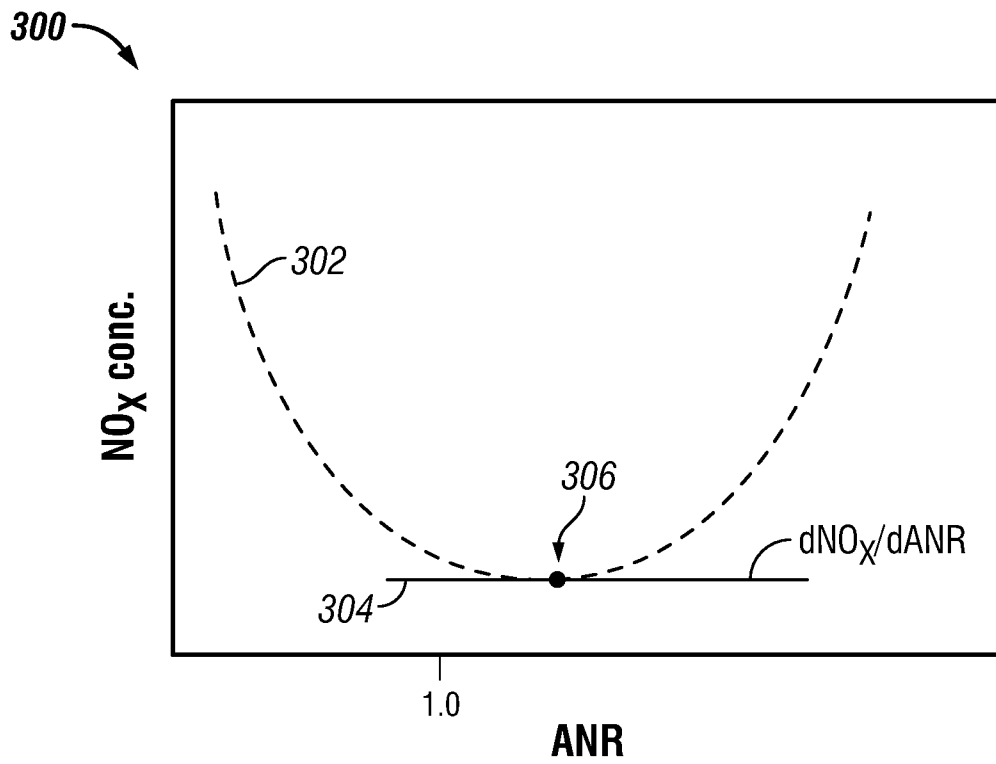


FIG. 3

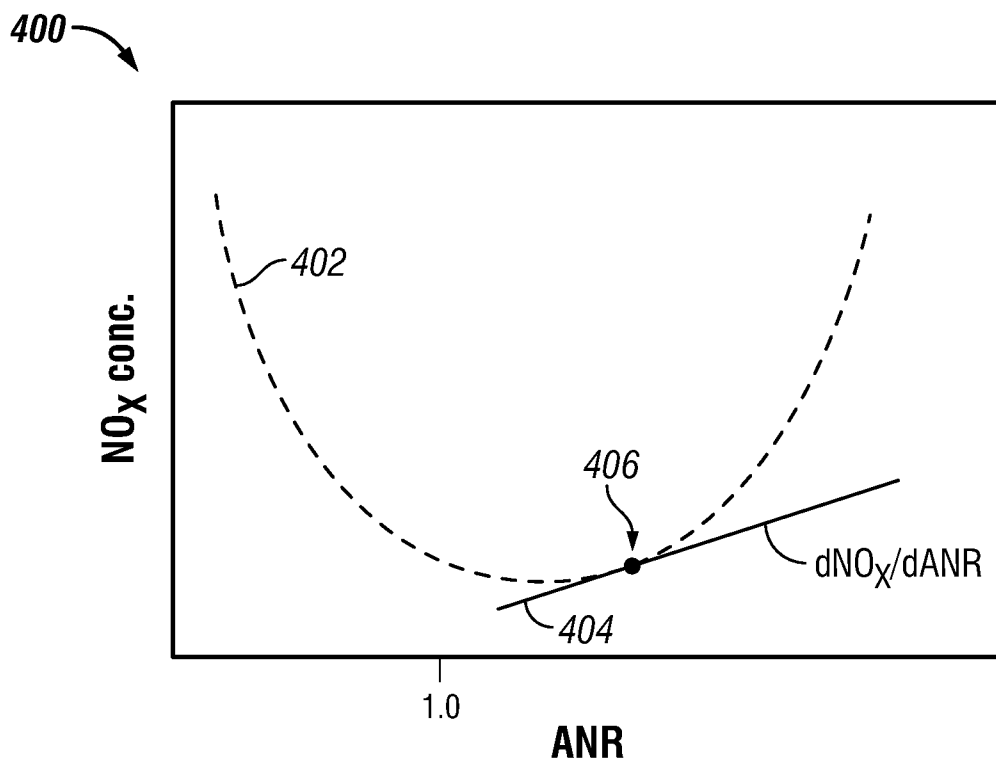
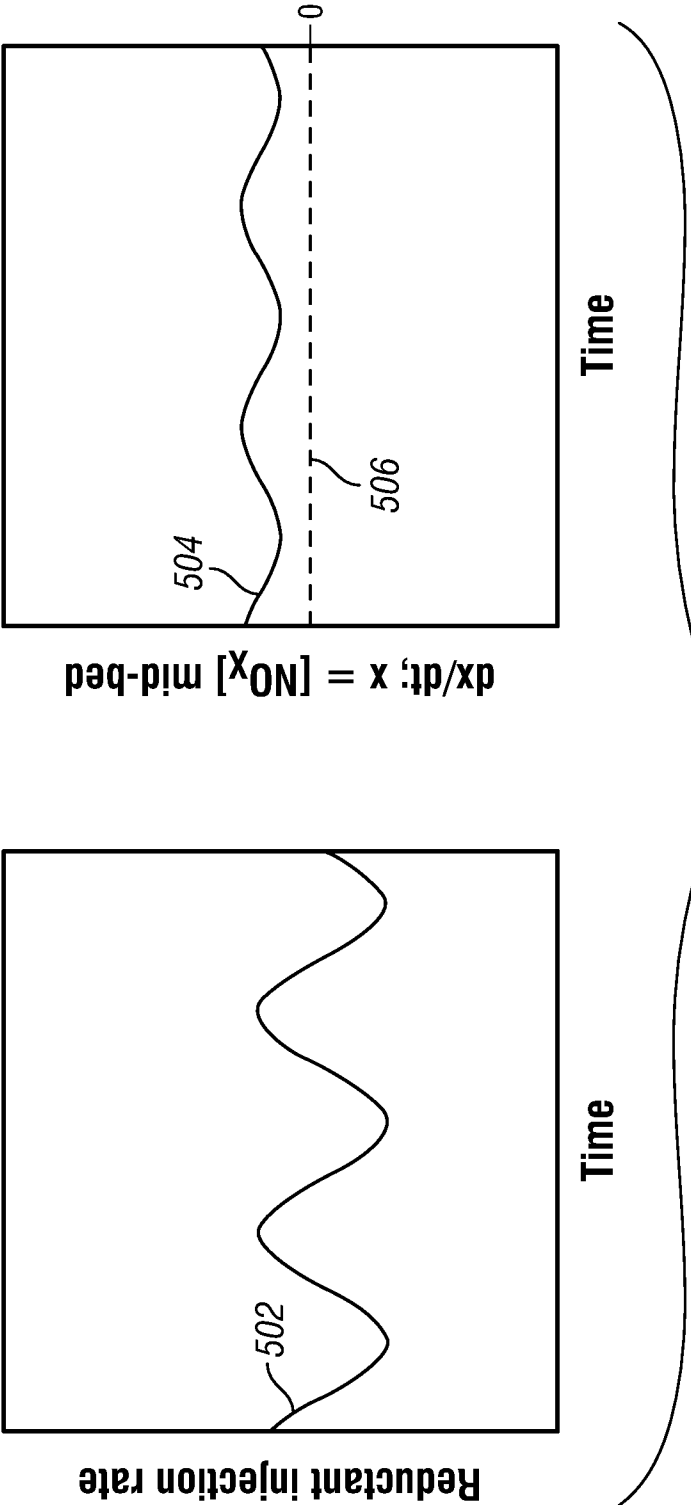
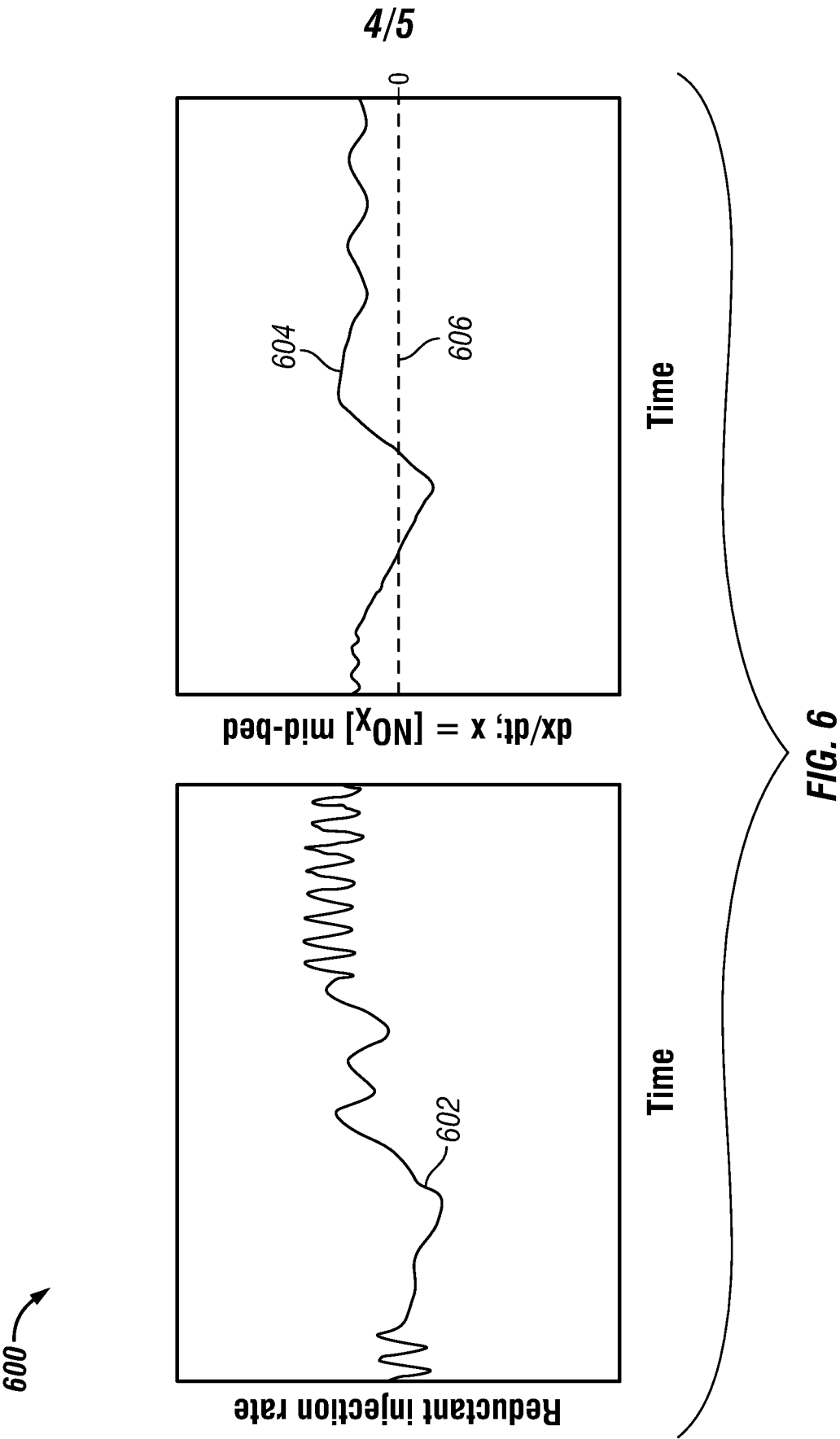


FIG. 4

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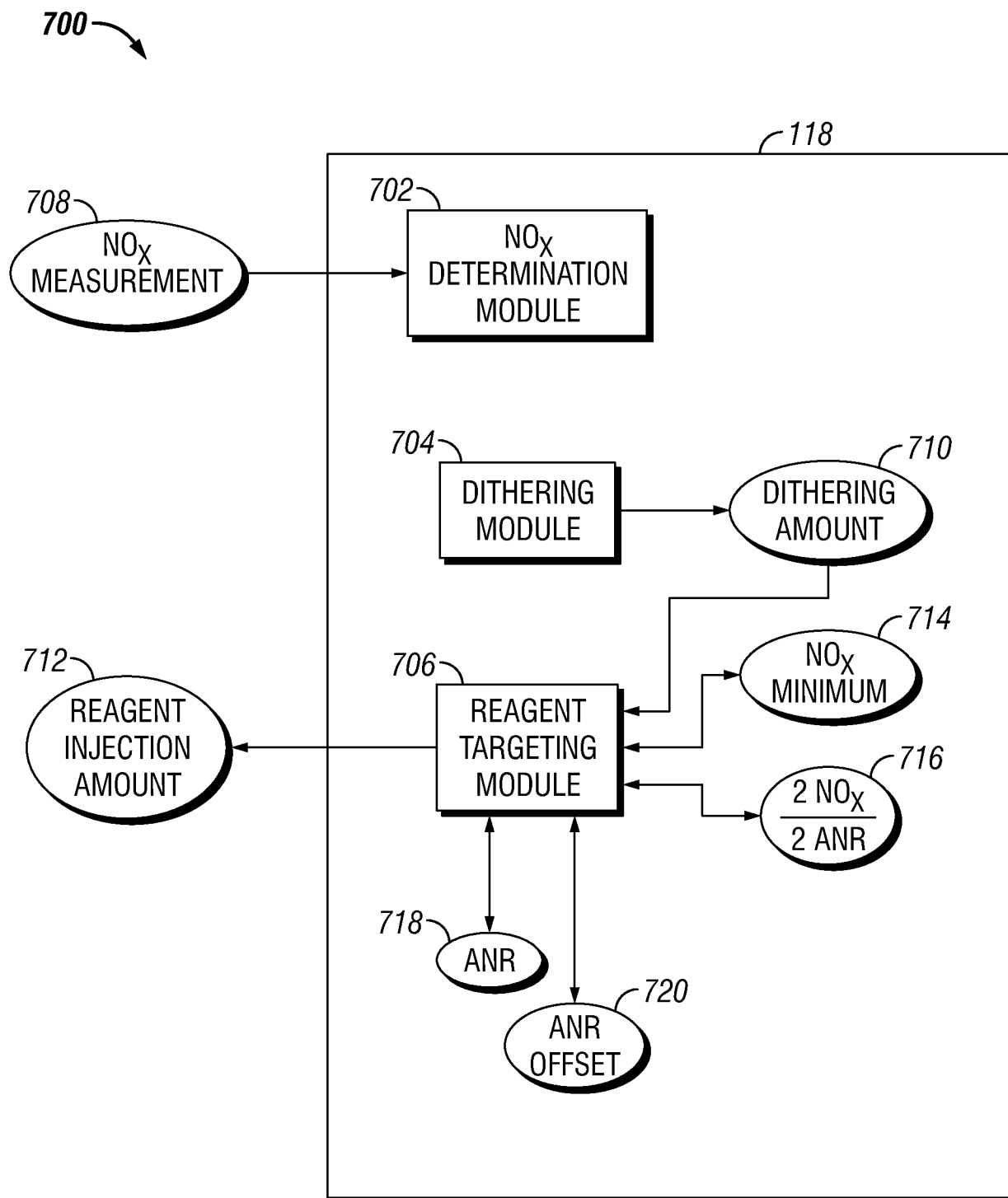


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/036392

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01N 11/00 (2012.01)

USPC - 60/276

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - F01N 3/035, 9/00, 11/00 (2012.01)

USPC - 60/274, 276, 297

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MicroPatent, Freepatentsonline, Google, Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/0024393 A1 (CHI et al.) 04 February 2010 (04.02.2010) entire document	21-23
Y		1-20, 24
Y	SCHMITT. Selective Catalytic Reduction: Testing, Numeric Modeling, and Control Strategies. <Accessed: http://digitool.library.colostate.edu//exlibris/dtl/d3_1/apache_media/L2V4bGlicmlzL2R0bC9kM18xL2FwYWNoZV9tZWRRpYS84Mjk4Ng==.pdf online on 07 Jul 2012, Presented on 04 March 2010>	1-20, 24
Y	US 2010/0139257 A1 (DRISCOLL et al.) 10 June 2010 (10.06.2010) entire document	13-16
Y	US 2009/0185954 A1 (QI et al.) 23 July 2009 (23.07.2009) entire document	17-20
A	SCR COMMITTEE. SELECTIVE CATALYTIC REDUCTION (SCR) CONTROL OF NOx EMISSIONS. Institute for Clean Air (White Paper, 1997) pg. 1-34	1-24

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

03 July 2012

Date of mailing of the international search report

17 JUL 2012

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