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UK CL (Edition W):
G3N N288A
G3R RBE72 RB27

Documents Cited:

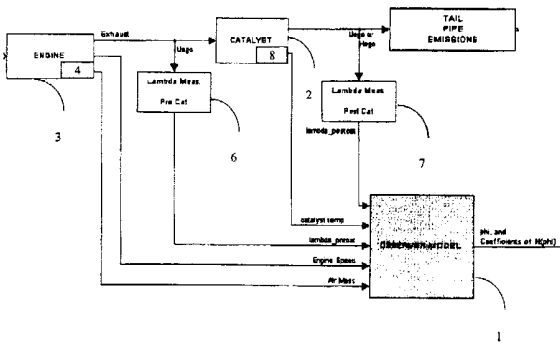
EP 1253309 A1	US 5842339 A
US 5771688 A	US 5609023 A
US 5528899 A	

Field of Search:
UK CL (Edition V) **G3N, G3R**
INT CL⁷ **F01N, F02D**
Other: **Online: WPI, EPODOC, JAPIO**

Abstract Title: Open loop air-fuel ratio controller

An open loop controller, for controlling the air-fuel ratio demanded by a fuel controller, comprises a detector, a catalyst model 1, a comparator and demand adjusting means. The detector is located downstream of a catalyst 2, and detects rich breakthroughs. The catalyst model 1 has an estimator for estimating a stored oxygen level in the catalyst 2. The comparator compares an estimated stored oxygen level with a number of predetermined thresholds. The demand adjusting means adjusts an air-fuel ratio demand in response to signals received from the comparator and the detector. The open loop controller may also include a model adjusting means for adjusting the model 1 in response to signals received from the comparator and the detector. A universal exhaust gas oxygen (UEGO) or a heated exhaust gas oxygen (HEGO) sensor 7 may be used to monitor the air-fuel ratio downstream of the catalyst 2. A sensor 8 may be used to measure the temperature of the catalyst 2.

Fig. 1



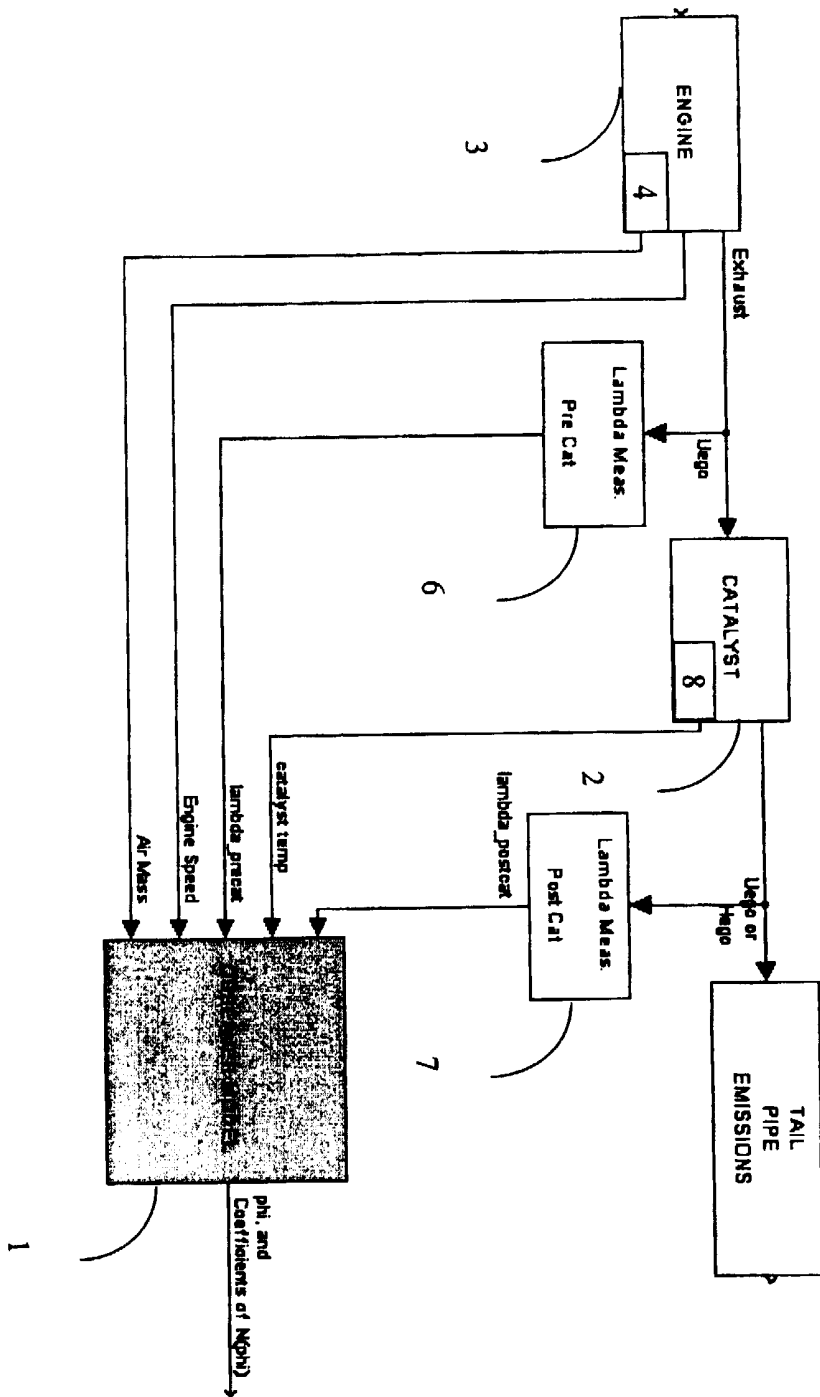


Fig. 1

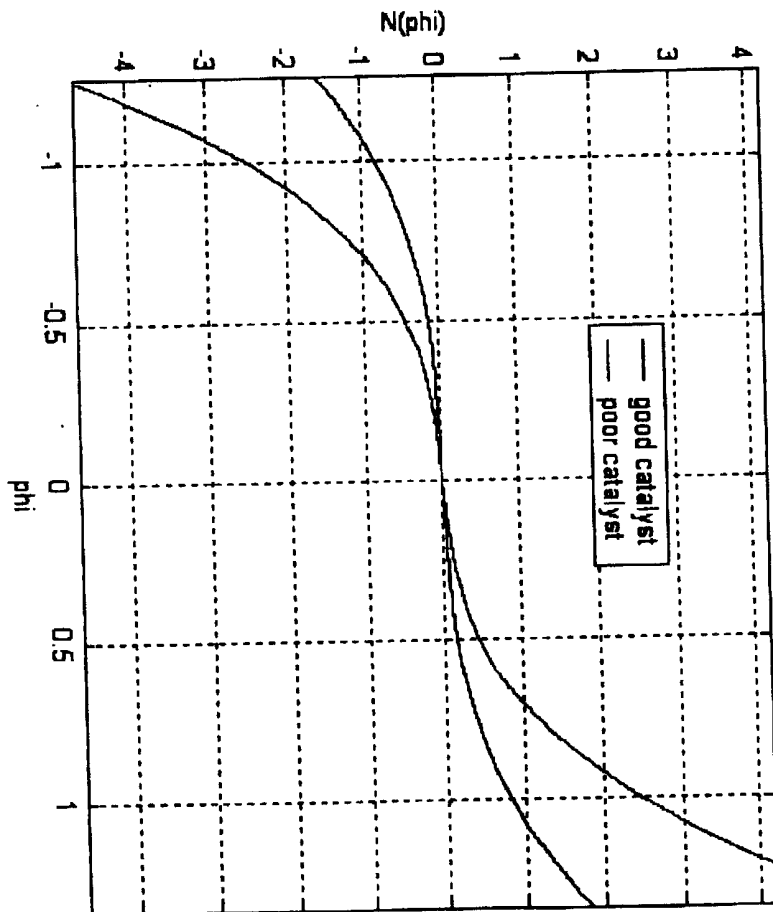


Fig. 2

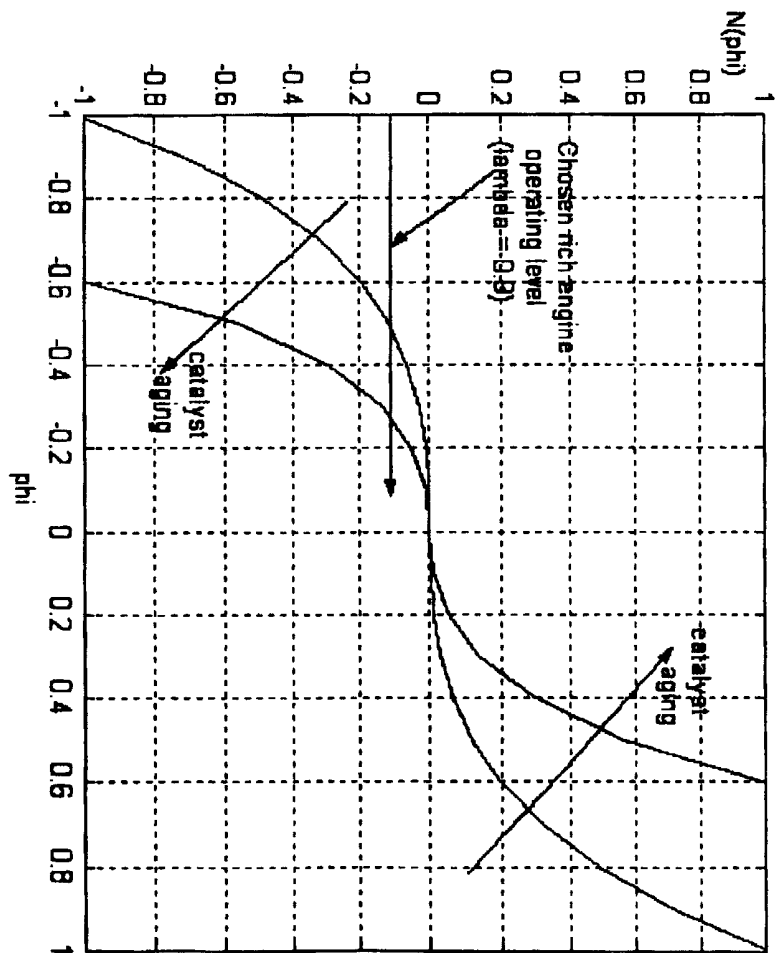
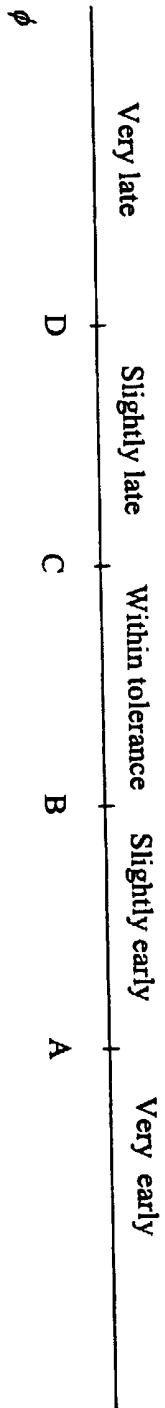
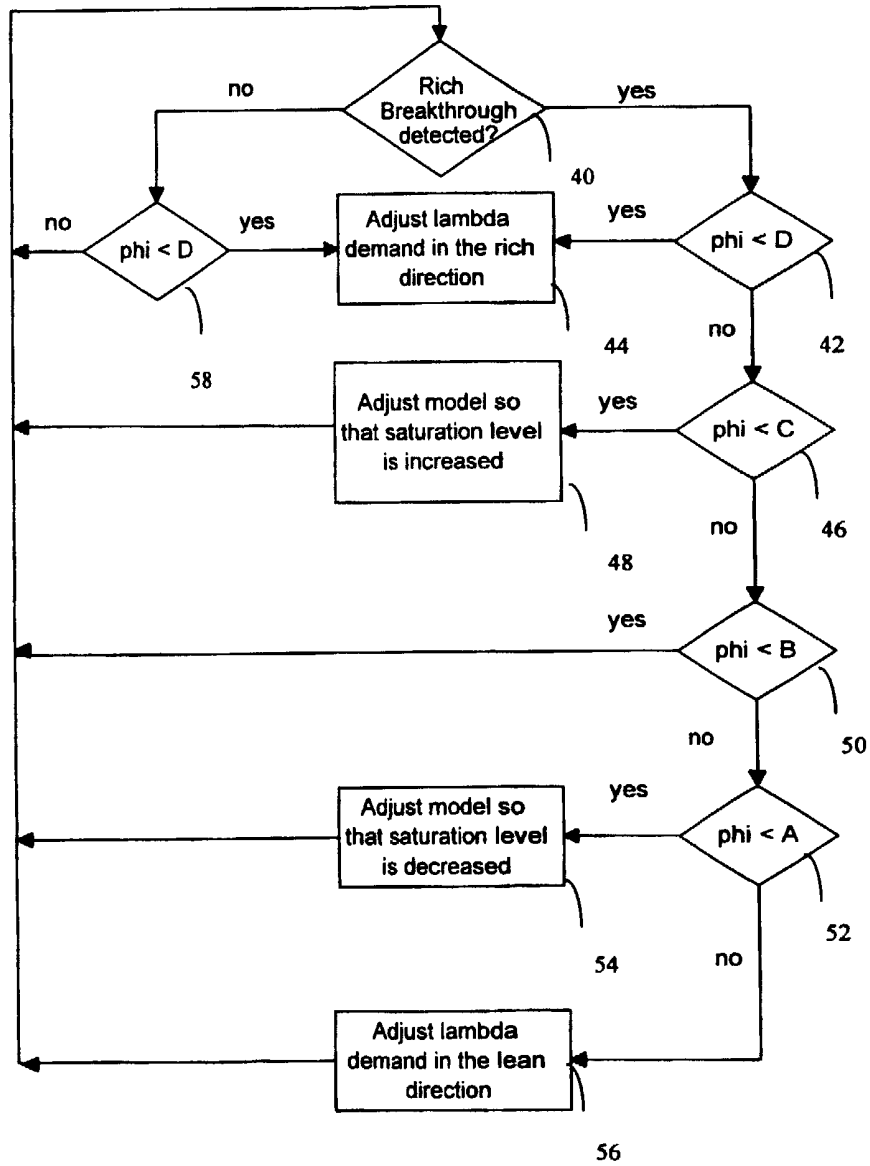


Fig.3

Value of ϕ when rich break through occurs





OPEN LOOP FUEL CONTROLLER

This invention relates to a method and apparatus for controlling the air-fuel ratio demanded by a fuel controller
5 in order to maintain optimum performance of a catalytic converter where there is no feed back between the achieved air fuel ratio and the desired air fuel ratio.

Three way catalytic converters are used to reduce exhaust
10 emission of nitrous oxides (NO_x) hydrocarbon (HC) and carbon monoxide (CO). In a steady state of operation the performance of the catalyst in removing these pollutants is at an optimum level when the air fuel ratio of the exhaust gas is within a narrow range, close to the stoichiometric air-fuel ratio.

15

Conventionally, a fuel controller is used to control the air fuel ratio demand from an engine based on feedback from an air fuel ratio sensor upstream of a catalytic converter in the exhaust passage or from two air fuel ratio sensors, one
20 upstream of the catalytic converter, and one downstream of the catalytic converter. Operation based on such feedback is known as 'closed-loop' operation.

However, when it is desired to operate the engine away from
25 the stoichiometric, as the air fuel sensors are insensitive to changes in the air fuel ratio other than around the stoichiometric air fuel ratio, there is no feed back correction relating to the air-fuel ratio actually achieved. Such operation is known as 'open-loop' operation.

30

For example, after throttle opening it may be desirable to operate on the rich side of a stoichiometric air fuel ratio

in order to provide extra torque. Another example is after deceleration fuel shut off it may be desirable to operate on the rich side of a stoichiometric air fuel ratio in order to regenerate the catalyst.

5

The problem therefore is that when an engine is operating away from stoichiometric it is in open loop operation and any error between the requested air fuel ratio and the achieved air fuel ratio is not corrected.

10

The object of this invention is to provide a method and apparatus for correcting air fuel ratio errors when in open-loop operation when the engine is operating with a substantially different air fuel ratio to that which is stoichiometric.

15

According to the present invention there is provided an open loop air fuel ratio controller comprising a detector arranged down stream of a catalyst for detecting rich breakthrough; a catalyst model having an estimator for estimating a stored oxygen level in the catalyst; a comparator for comparing an estimated stored oxygen level with a plurality of predetermined thresholds; demand adjusting means for adjusting an air fuel ratio demand in dependence upon a received signal from said comparator and upon a received signal from said detector.

20

25

This provide means for adjusting the air fuel ratio by using the estimated stored oxygen level as well as an indication of whether rich breakthrough has yet occurred.

30

It is an advantage of the controller further comprises model

(
adjusting means for adjusting the model in dependence upon a
received signal from said comparator and upon a received
signal from said detector so that the model may also be
adjusted, for example if characteristics of the catalyst
5 change due to ageing.

If the comparator is arranged to compare an estimated stored
oxygen level with a plurality of thresholds when the detector
10 detects rich breakthrough then different actions may be taken
in dependence upon the estimated stored oxygen level falling
within various ranges when rich breakthrough is detected.

Preferably either the model is adjusted or the air fuel ratio
15 demand is adjusted in particular circumstances, but not both.
Therefore preferably the controller is arranged such that
when the model adjusting means adjusts the model the demand
adjusting means does not adjust the air fuel ratio demand.
Furthermore, the controller is arranged such that when the
20 demand adjusting means adjusts the air fuel ratio demand the
model adjusting means does not adjust the model.

In a preferred embodiment the model adjusting means is
arranged to adjust the model to reduce or increase a maximum
25 oxygen storage value and the detector is a heated exhaust gas
oxygen sensor.

According to another aspect of the invention there is also
provided a method of open loop fuel control comprising the
30 steps of detecting rich breakthrough downstream of a
catalyst; estimating an oxygen storage level in the catalyst;
comparing the estimated oxygen storage level with a plurality

of predetermined thresholds; and adjusting the air fuel ratio demand in dependence upon the results of said comparing step and said detecting step.

- 5 It is an advantage if the method further comprises the step of adjusting the model in dependence upon the results of said comparing step and said detecting step.

Preferably, if the estimated oxygen storage level is less
10 than a first predetermined threshold then the air fuel ratio demand is adjusted in a rich direction.

In a preferred embodiment there is a range of values within which the estimated oxygen storage level is expected to fall
15 when a rich breakthrough is detected, and therefore not action is taken. Accordingly in this embodiment the model adjusting step and the air fuel ratio demand adjusting step are not performed if a rich breakthrough is detected and if the estimated oxygen level is greater than a second
20 predetermined threshold and less than a third predetermined threshold.

Preferably adjusting the air fuel ratio demand comprises the sub step of determining whether the estimated oxygen storage
25 level is greater than a fourth predetermined threshold when a rich breakthrough is detected, if so then the air fuel ratio demand is adjusted in a lean direction.

Preferably the model adjusting step is arranged to adjust the
30 model such that a maximum value for the oxygen storage level is increased if a rich breakthrough is detected and if the estimated oxygen level is between the first predetermined

threshold and the second predetermined threshold.

It follows that, preferably the model adjusting step is also arranged to adjust the model such that a maximum value for the oxygen storage level is decreased if a rich breakthrough is detected and if the estimated oxygen level between the third predetermined threshold and the fourth predetermined threshold.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which

Figure 1 is a block diagram illustrating use of a catalyst observer model;
Figure 2 is a graph showing the difference in operation between a new catalyst, and one which has deteriorated;
Figure 3 is a graph showing how catalyst characteristics change with age of the catalyst;
Figure 4 illustrates a range of estimated oxygen storage values with predetermined thresholds indicated therein;
and
Figure 5 is a flow chart showing the method steps carried out in an open loop fuel controller of the present invention.

Referring now to Figure 1, a model 1 of a catalyst 2 will be described. An air flow sensor 4 mounted in an intake pipe of an engine 3 is used to measure air mass flow induced by the engine 3. In other embodiments of the invention the air mass flow may be estimated from other parameters, for example

manifold pressure, engine speed and air temperature.

Exhaust gases from the engine 3 are fed to the catalyst 2 mounted in an exhaust pipe. A sensor 7 measures the air fuel ratio downstream of the catalyst 2. The sensor 7 may be a Universal Exhaust Gas Oxygen (UEGO) sensor or may be a Heated Exhaust Gas Oxygen (HEGO) sensor. A HEGO sensor senses whether the air-fuel ratio is rich or lean of stoichiometric, whereas a UEGO sensor provides a measurement of the air fuel ratio. A sensor 8 measures the temperature of the catalyst 2. The catalyst 2 does not perform well at low temperatures so the model 1 has the measured catalyst temperature as an input, and does not operate until the temperature of the catalyst reaches a minimum temperature. In other embodiments the catalyst temperature may be estimated using a catalyst model.

The observer model 1 operates as will now be described, although the invention is not limited to use of this particular model, and simpler or more complex catalyst models could be utilised.

Oxygen storage of the catalyst is represented by an oxygen storage variable ϕ which is equal to zero when the catalyst is in a neutral state, is negative if the catalyst is depleted of oxygen and is positive if the catalyst is oxygen rich. It is possible to measure the air fuel ratio upstream of the catalyst 2 by use of a UEGO. However, use of a UEGO is costly, and even a UEGO has a limited range around stoichiometric within which the air fuel ratio measurement is accurate. Therefore the model used assumes that the

precatalyst air fuel ratio λ_{precat} is equal to the air fuel ratio demanded by a control system (not shown). Therefore the model 1 has as an input an air fuel ratio demand which is received from the control system.

5

The rate of change of the oxygen storage variable ϕ is estimated according to the following equation.

$$d\phi/dt = (\Delta\lambda_{\text{precat}} - N(\phi) S_{\text{wv}}) * \text{oxygen_mass}/\lambda_{\text{precat}}$$

10

$\Delta\lambda_{\text{precat}}$ is equal to $\lambda_{\text{precat}} - 1$, therefore $\Delta\lambda_{\text{precat}}$ is negative if the air fuel ratio is rich of stoichiometric, and $\Delta\lambda_{\text{precat}}$ is positive if the air fuel ratio is lean of stoichiometric. The air mass flow measured at the sensor 4 is multiplied by a constant value 0.21 which is equal to the fraction of air by mass which is oxygen, this fraction is denoted oxygen_mass in the above equation.

15

$N(\phi) = \sum a_i \phi^i$ and represents the resistance to oxygen storage of the catalyst for a particular value of ϕ as illustrated in Figure 2.

20

S_{wv} is equal to 0 when $\Delta\lambda_{\text{precat}}$ is negative i.e. the air fuel ratio is rich of stoichiometric and ϕ is greater than 0 i.e. there is excess oxygen stored in the catalyst.

25

It will be understood that when a rich air fuel ratio is supplied to the engine 3, and when there is excess oxygen stored in the catalyst 2, then the engine 3 emits gaseous components which can be oxidised by the catalyst 2, and in this case S_{wv} is equal to 0 so that

30

$$d\phi/dt = \Delta\lambda_{\text{precat}} * \text{oxygen_mass}/\lambda_{\text{precat}}$$

However, when a lean air fuel ratio is supplied to the engine
5 3 or when the catalyst 2 is depleted of oxygen then S_{wv} is
equal to 1 so that

$$d\phi/dt = (\Delta\lambda_{\text{precat}} - N(\phi)) * \text{oxygen_mass}/\lambda_{\text{precat}}$$

10 so in this case $d\phi/dt$ is reduced by an amount equal to
 $N(\phi) * \text{oxygen_mass}/\lambda_{\text{precat}}$ when compared to the previous case.

$$\text{Est}(\lambda_{\text{postcat}}) = N(\phi) S_{wv} + 1$$

15 λ_{postcat} is the downstream air fuel ratio divided by the
stoichiometric air fuel ratio. ϕ is calculated by integrating
the above differential equation, and then $N(\phi)$ is calculated.
When $S_{wv} = 0$ then $\text{Est}(\lambda_{\text{postcat}}) = 1$, otherwise $\text{Est}(\lambda_{\text{postcat}}) =$
 $N(\phi) + 1$.

20

$\text{Est}(\lambda_{\text{postcat}})$ and the measured λ_{postcat} may be compared if the
sensor 7 is a UEGO, and the difference between them may be
used to update the coefficients a_i of the oxygen storage
characteristic curve $N(\phi)$ and the ϕ value itself so that the
25 model 1 more accurately represents the performance of the
catalyst 2. The coefficients a_i may be updated using a Kalman
filter, a description of which may be found in "Applied
Optimal Estimation", Gelb, the MIT press 1974. If the sensor
7 is a HEGO then it is only possible to determine whether
30 λ_{postcat} is rich or lean of stoichiometric, and hence it is

only possible to decide whether to increase or reduce the maximum level of ϕ , which may be regarded as the oxygen saturation level.

- 5 Figure 2 illustrates the differing $N(\phi)$ curves for a good catalyst compared with a deteriorated catalyst.

After the engine has been operating at a particular air fuel ratio for some time, then the oxygen stored in the catalyst
10 will stabilise at a value which depends upon the operating air-fuel ratio, thus $d\phi/dt = 0$ and

$$\Delta\lambda_{\text{precat}} = \Delta\lambda_{\text{postcat}}$$

Figure 3 illustrates an example oxygen storage characteristic
15 curve showing the oxygen storage value when $\Delta\lambda_{\text{precat}} = \Delta\lambda_{\text{postcat}} = 0.1$ and when $\Delta\lambda_{\text{precat}} = \Delta\lambda_{\text{postcat}} = -0.1$. Figure 3 illustrates how an oxygen storage characteristic curve may change for a deteriorated catalyst. The difference in the steady state oxygen storage value is illustrated for $\Delta\lambda_{\text{precat}} = \Delta\lambda_{\text{postcat}} = -$
20 0.1 for two examples of oxygen storage characteristic curves. Hence it will be appreciated that if fuel control is implemented using air fuel ratio thresholds measured at the sensor 7, then as the catalyst deteriorates, the fuel control scheme will allow breakthrough of NO_x when the catalyst
25 resists absorption of any more oxygen, and breakthrough of HC and CO when the catalyst is depleted of oxygen.

It is known to update a catalyst model by detecting unexpected breakthroughs. In particular the model parameters
30 are adjusted such that the maximum level of oxygen storage is adjusted to accommodate aging properties of the catalyst.

However, unexpected breakthrough may also occur when λ_{precat} does not accurately reflect lambda-demand. As explained earlier, use of a wide ranging precatalyst UEGO is not practical so adjusting the lambda demand using feedback is not possible. This invention addresses the problem of open loop fuel control together with updating of a catalyst model as the catalyst characteristics change.

10 The catalyst characteristics are only likely to change slowly over time, therefore any difference between $\text{Est}(\lambda_{\text{postcat}})$ and the measured λ_{postcat} due to catalyst ageing is likely to be within a small range. In this invention it is assumed that differences within a small range are due to catalyst aging and that larger differences are due to errors in the open loop control (i.e. due to differences between lambda-demand and λ_{precat}). The difference between $\text{Est}(\lambda_{\text{postcat}})$ and the measured λ_{postcat} is estimated by monitoring ϕ as predicted by the model 1 and detecting rich breakthrough using the sensor 7.

If the catalyst is in a neutral state then we expect ϕ to be equal to 0. If ϕ is less than 0 then we expect rich breakthrough to occur and if ϕ is greater than 0 then we do not expect rich breakthrough to occur (although lean breakthrough might then occur resulting in NO_x emissions)

However, to allow for some tolerance a range may be defined, within which is it expected that ϕ will fall when rich breakthrough occurs. Figure 4 illustrates a range of ϕ values with

predetermined thresholds A, B, C and D indicated therein.

When rich breakthrough is detected the current value of ϕ estimated by the model 1 is used to determine what if any
5 action is to be taken. A first predetermined threshold D is defined, and if ϕ falls below this threshold then rich breakthrough is considered to have occurred very late and the open loop fuel control is adjusted accordingly. A second
10 predetermined threshold C is defined and if ϕ is between the first predetermined threshold D and the second predetermined threshold C then rich breakthrough is considered to have occurred late enough for the model to need to be updated. A
third predetermined threshold B is defined and if ϕ falls
15 between the second predetermined threshold C and the third predetermined threshold B when rich breakthrough occurs then this is considered to be within normal limits. Finally a
fourth predetermined threshold A is defined and if ϕ is
20 between the third predetermined threshold B and the fourth predetermined threshold A then rich break through is considered to have occurred early enough for the model to
need to be updated. If ϕ is greater than the fourth
predetermined threshold A then it is considered that rich
breakthrough has occurred very early and the open loop fuel
control is adjusted accordingly. $D \leq C \leq B \leq A$, and Figure
25 4 indicates the conclusion made when ϕ falls within the ranges shown. It will be appreciated that $C \leq 0 \leq B$ so that rich breakthrough is expected to occur close to $\phi = 0$. Also
it is with noting that one or more thresholds may be equal to
one another, so for example the tolerance range C-B could be
30 set to be equal to 0. Finally it is worth noting that if no
rich break through is detected and ϕ is less than the first

predetermined threshold D then rich breakthrough is considered to have occurred very late and the open loop fuel control is adjusted accordingly.

5 Figure 5 illustrates the steps taken by an open loop fuel controller according to one embodiment of the present invention.

10 If rich breakthrough is detected at the sensor 7 at step 40, then ϕ is compared to the first predetermined threshold D at step 42. If ϕ is less than D then rich breakthrough has occurred very much later than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In
15 this case at step 44 the lambda demand is adjusted to become richer. If ϕ is not less than D at step 42 then ϕ is compared to the second predetermined threshold C at step 46. If ϕ is less than C it is assumed that the error is due to a change in the catalyst characteristics and the catalyst model is
20 adjusted so that the saturation level is increased at step 48.

If ϕ is not less than C at step 46 then ϕ is compared to the third predetermined threshold B at step 50. If ϕ is less than
25 B it is considered that rich break trough has occurred within expected range of ϕ and no action is taken. However, if ϕ is not less than B at step 50 then ϕ is compared to the first predetermined threshold A at step 52.

30 If ϕ is less than A it is assumed that the error is due to a

change in the catalyst characteristics and the catalyst model is adjusted so that the saturation level is decreased at step 54.

5 If ϕ is not less than A then rich breakthrough has occurred very much earlier than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In this case at step 56 the lambda demand is adjusted to become
10 leaner.

Lambda demand may be adjusted by means of a data table, which is updated according to the value of ϕ at step 56 or 44 as appropriate, and which is added to the lambda demand as
15 determined by a conventional open loop fuel controller.

If rich breakthrough is not detected at step 40, then at step 58 ϕ is compared to the first predetermined threshold D. If ϕ is less than D then rich breakthrough has occurred very much
20 later than the model 1 predicts. Therefore it is assumed that the error is due to a difference between the lambda demand and the achieved lambda (i.e. λ_{precat}). In this case at step 44 the lambda demand is adjusted to become richer.

25 It is intended that the foregoing detailed description be regarded as illustrative rather than limiting and that it be understood that it is the following claims, which are intended to define the scope of the invention.

CLAIMS

1. An open loop air fuel ratio controller comprising
a detector arranged down stream of a catalyst for
5 detecting rich breakthrough;
a catalyst model having an estimator for estimating a
stored oxygen level in the catalyst;
a comparator for comparing an estimated stored oxygen
level with a plurality of predetermined thresholds;
10 demand adjusting means for adjusting an air fuel ratio
demand in dependence upon a received signal from said
comparator and upon a received signal from said
detector.
- 15 2. An open loop air fuel ratio controller according to
claim 1, further comprising
model adjusting means for adjusting the model in
dependence upon a received signal from said comparator
and upon a received signal from said detector.
20
3. An open loop air fuel ratio controller according to
claim 1 or claim 2, in which the comparator is arranged to
compare an estimated stored oxygen level with a plurality of
25 thresholds when the detector detects rich breakthrough.
4. An open loop air fuel ratio controller according to
claim 3, in which the controller is arranged such that when
the model adjusting means adjusts the model the demand
30 adjusting means does not adjust the air fuel ratio demand.
5. An open loop air fuel ratio controller according to

claim 4, in which the controller is arranged such that when the demand adjusting means adjusts the air fuel ratio demand the model adjusting means does not adjust the model.

5 6. An open loop air fuel ratio controller according to any one of the preceding claims in which the model adjusting means is arranged to adjust the model to reduce or increase a maximum oxygen storage value.

10 7. An open loop air fuel ratio controller according to any one of the preceding claims in which the detector is a heated exhaust gas oxygen sensor.

8. A method of open loop fuel control comprising the steps
15 of

detecting rich breakthrough downstream of a catalyst;
estimating an oxygen storage level in the catalyst;
comparing the estimated oxygen storage level with a
plurality of predetermined thresholds; and
20 adjusting the air fuel ratio demand in dependence upon
the results of said comparing step and said detecting step.

9. A method of open loop fuel control according to claim 8,
further comprising the step of
25 adjusting the model in dependence upon the results of
said comparing step and said detecting step.

10. A method according to claim 8 or claim 9, in which
adjusting the air fuel ratio demand comprises the sub step of
30 if the estimated oxygen storage level is less than
a first predetermined threshold then the air fuel ratio
demand is adjusted in a rich direction.

11. A method according to any one of claim 8 to 10, in which the model adjusting step and the air fuel ratio demand
5 adjusting step are not performed if a rich breakthrough is detected and if the estimated oxygen level is greater than a second predetermined threshold and less than a third predetermined threshold.

10 12. A method according to any one of claim 8 to 11, in which adjusting the air fuel ratio demand comprises the sub step of
if a rich breakthrough is detected and the
estimated oxygen storage level is greater than a fourth
predetermined threshold then the air fuel ratio demand is
15 adjusted in a lean direction.

13. A method according to any one of claims 8 to 12, in which the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level
20 is increased if a rich breakthrough is detected and if the estimated oxygen level is greater than the first predetermined threshold and less than the second predetermined threshold.

25 14. A method according to any one of claims 8 to 12, in which the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level is decreased if a rich breakthrough is detected and if the
estimated oxygen level is greater than the third
30 predetermined threshold and less than the fourth predetermined threshold.

15. A method according to any one of claims 11 to 14 wherein
the first predetermined threshold is less than or equal to
the second predetermined threshold and the second
predetermined threshold is less than or equal to the third
5 predetermined threshold.

16. A method according to any one of claims 12 to 14 wherein
the first predetermined threshold is less than or equal to
the second predetermined threshold and the second
10 predetermined threshold is less than or equal to the third
predetermined threshold and the third predetermined threshold
is less than or equal to the fourth predetermined threshold.

17. An air fuel ratio controller substantially as herein
15 described, with reference to the accompanying drawings.

18. A method of open loop fuel control substantially as
herein described with reference to the accompanying drawings.

20

25

Amendments to the claims have been filed as follows

CLAIMS

1. An open loop air fuel ratio controller comprising
a detector arranged down stream of a catalyst for
5 detecting rich breakthrough;
a catalyst model having an estimator for estimating a
stored oxygen level in the catalyst;
a comparator for comparing an estimated stored oxygen
level with a plurality of predetermined thresholds;
10 demand adjusting means for adjusting an air fuel ratio
demand in dependence, upon a received signal from said
comparator and upon a received signal from said
detector.
- 15 2. An open loop air fuel ratio controller according to
claim 1, in which the comparator is arranged to compare an
estimated stored oxygen level with a plurality of thresholds
when the detector detects rich breakthrough.
- 20 3. An open loop air fuel ratio controller according to
claim 1 or claim 2, further comprising
model adjusting means for adjusting the model in
dependence upon a received signal from said comparator
and upon a received signal from said detector.
- 25 4. An open loop air fuel ratio controller according to
claim 3, in which the controller is arranged such that when
the model adjusting means adjusts the model the demand
adjusting means does not adjust the air fuel ratio demand.
- 30 5. An open loop air fuel ratio controller according to
claim 4, in which the controller is arranged such that when

the demand adjusting means adjusts the air fuel ratio demand
the model adjusting means does not adjust the model.

6. An open loop air fuel ratio controller according to any
5 one of claims 3 to 5, in which the model adjusting means is
arranged to adjust the model to reduce or increase a maximum
oxygen storage value.

7. An open loop air fuel ratio controller according to any
10 one of the preceding claims in which the detector is a heated
exhaust gas oxygen sensor.

8. A method of open loop fuel control comprising the steps
of
15 detecting rich breakthrough downstream of a catalyst;
estimating an oxygen storage level in the catalyst;
comparing the estimated oxygen storage level with a
plurality of predetermined thresholds; and
adjusting the air fuel ratio demand in dependence upon
20 the results of said comparing step and said detecting step.

9. A method according to claim 8, in which adjusting the
air fuel ratio demand comprises the sub step of adjusting the
air fuel ratio demand in a rich direction if the estimated
25 oxygen storage level is less than a first predetermined
threshold.

10. A method of open loop fuel control according to claim 8
or claim 9, further comprising the step of
30 adjusting the model in dependence upon the results of
said comparing step and said detecting step.

11. A method according to claim 10, in which the model adjusting step and the air fuel ratio demand adjusting step
5 are not performed if a rich breakthrough is detected and the estimated oxygen level is greater than a second predetermined threshold and the estimated oxygen level is less than a third predetermined threshold.
- 10 12. A method according to claim 11, in which the first predetermined threshold is less than the second predetermined threshold and the second predetermined threshold is less than the third predetermined threshold.
- 15 13. A method according to claim 11, in which adjusting the air fuel ratio demand comprises the sub step of adjusting the air fuel ratio demand in a lean direction if a rich breakthrough is detected and the estimated oxygen storage
level is greater than a fourth predetermined threshold.
- 20 14. A method according to claim 13, in which the first predetermined threshold is less than the second predetermined threshold and the second predetermined threshold is less than the third predetermined threshold and the third predetermined
25 threshold is less than the fourth predetermined threshold.
15. A method according to any one of claims 10 to 14, in which the model adjusting step is arranged to adjust the model such that a maximum value for the oxygen storage level
30 is increased if a rich breakthrough is detected and the estimated oxygen level is greater than the first predetermined threshold and the estimated oxygen level is

less than the second predetermined threshold.

16. A method according to any one of claims 10 to 15, in which the model adjusting step is arranged to adjust the
5 model such that a maximum value for the oxygen storage level is decreased if a rich breakthrough is detected and the estimated oxygen level is greater than the third predetermined threshold and the estimated oxygen level is less than the fourth predetermined threshold.

10

17. An air fuel ratio controller substantially as herein described, with reference to the accompanying drawings.

18. A method of open loop fuel control substantially as
15 herein described with reference to the accompanying drawings.

20



INVESTOR IN PEOPLE

Application No: GB 0217422.5
Claims searched: 1-18

22

Examiner: Philip Ord
Date of search: 28 January 2003

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	
A,E	-	EP 1 253 309 A1	NISSAN See abstract noting references to estimation of stored oxygen levels and comparisons with predetermined thresholds.
A	-	US 5,842,339	MOTOROLA See column 2 line 61- column 3 line 15, noting references to detecting rich breakthrough and to calculating amounts of oxygen absorbed by a catalyst for use in control systems.
A	-	US 5,771,688	NIPPONDENSO See abstract noting reference to a CPU performing open loop control when the air-fuel ratio is outside the operating range of air-fuel sensors.
A	-	US 5,609,023	HONDA See abstract noting references to estimating amounts of oxygen stored in a catalyst and to controlling air-fuel ratio.
A	-	US 5,528,899	NIPPONDENSO See abstract noting references to open loop control and to controlling air-fuel ratio based on a downstream sensor when the air-fuel ratio is outside a preselected range.

Categories:

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



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Application No: GB 0217422.5
Claims searched: 1-18

23

Examiner: Philip Ord
Date of search: 28 January 2003

Field of Search:

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

G3N, G3R

Worldwide search of patent documents classified in the following areas of the IPC⁷:

F02D, F01N

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

WPI, EPODOC, JAPIO