US 20040006973A1

(19) United States
(12) Patent Application Publication
Makki et al.
(10) Pub. No.: US 2004/0006973 A1
(43) Pub. Date: Jan. 15, 2004

(54) SYSTEM AND METHOD FOR CONTROLLING AN ENGINE

(76) Inventors: **Imad Hassan Makki**, Dearborn Heights, MI (US); **James Michael Kerns**, Trenton, MI (US)

Correspondence Address:
FORD GLOBAL TECHNOLOGIES, LLC.
SUITE 600 - PARKLANE TOWERS EAST
ONE PARKLANE BLVD.
DEARBORN, MI 48126 (US)

(21) Appl. No.: **10/460,470**

(22) Filed: **May 23, 2003**

Related U.S. Application Data

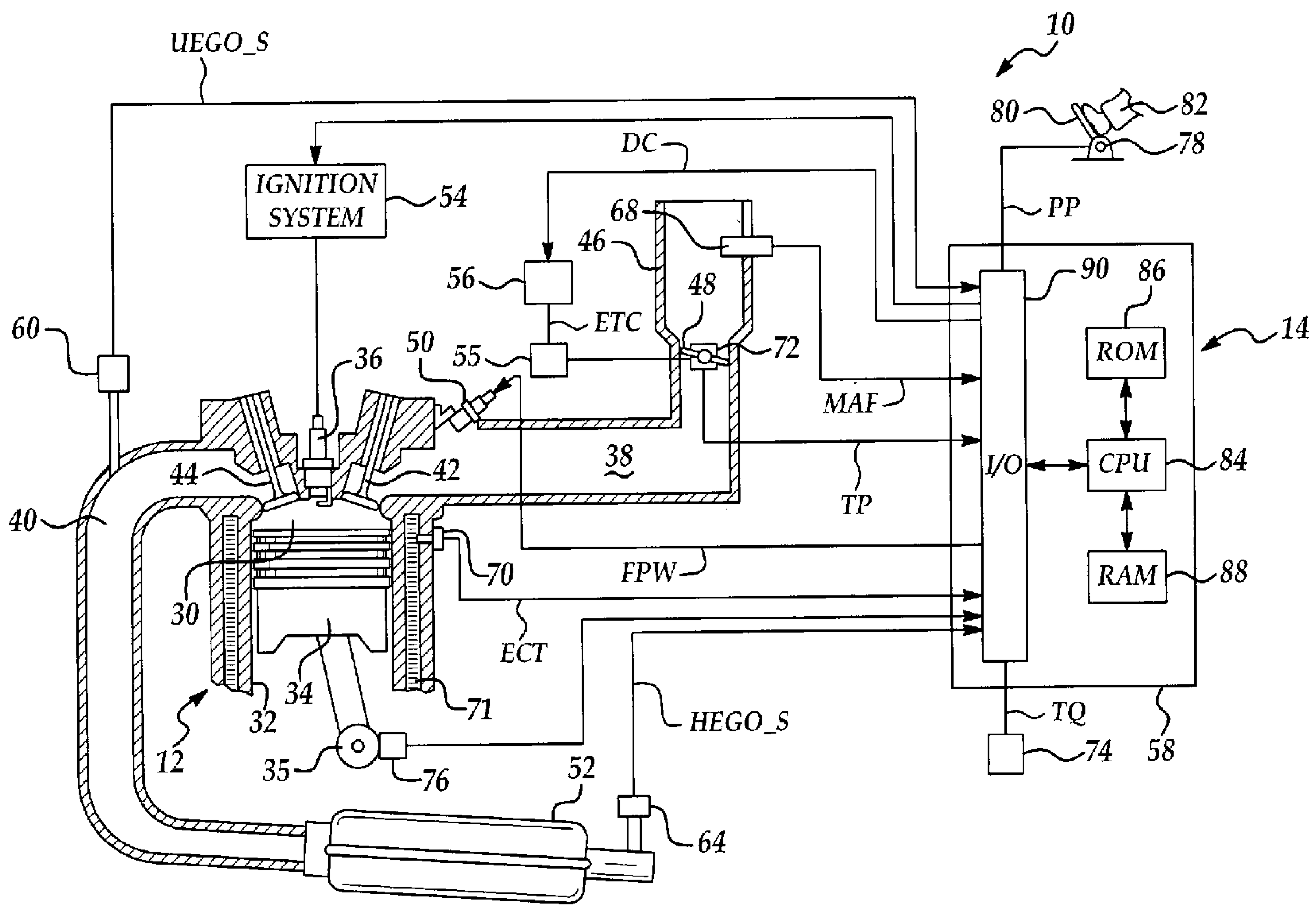
(63) Continuation-in-part of application No. 09/991,519, filed on Nov. 21, 2001, now abandoned.

Publication Classification

(51) Int. Cl.[7] F01N 3/00
(52) U.S. Cl. 60/285

(57) **ABSTRACT**

A system and method for controlling an engine coupled to an emission system is provided. The system includes an emission catalyst and a HEGO sensor disposed downstream of the catalyst. The method includes adjusting an air-fuel ratio of the engine to substantially maintain an output signal from the downstream HEGO sensor within a predetermined linear operating range.



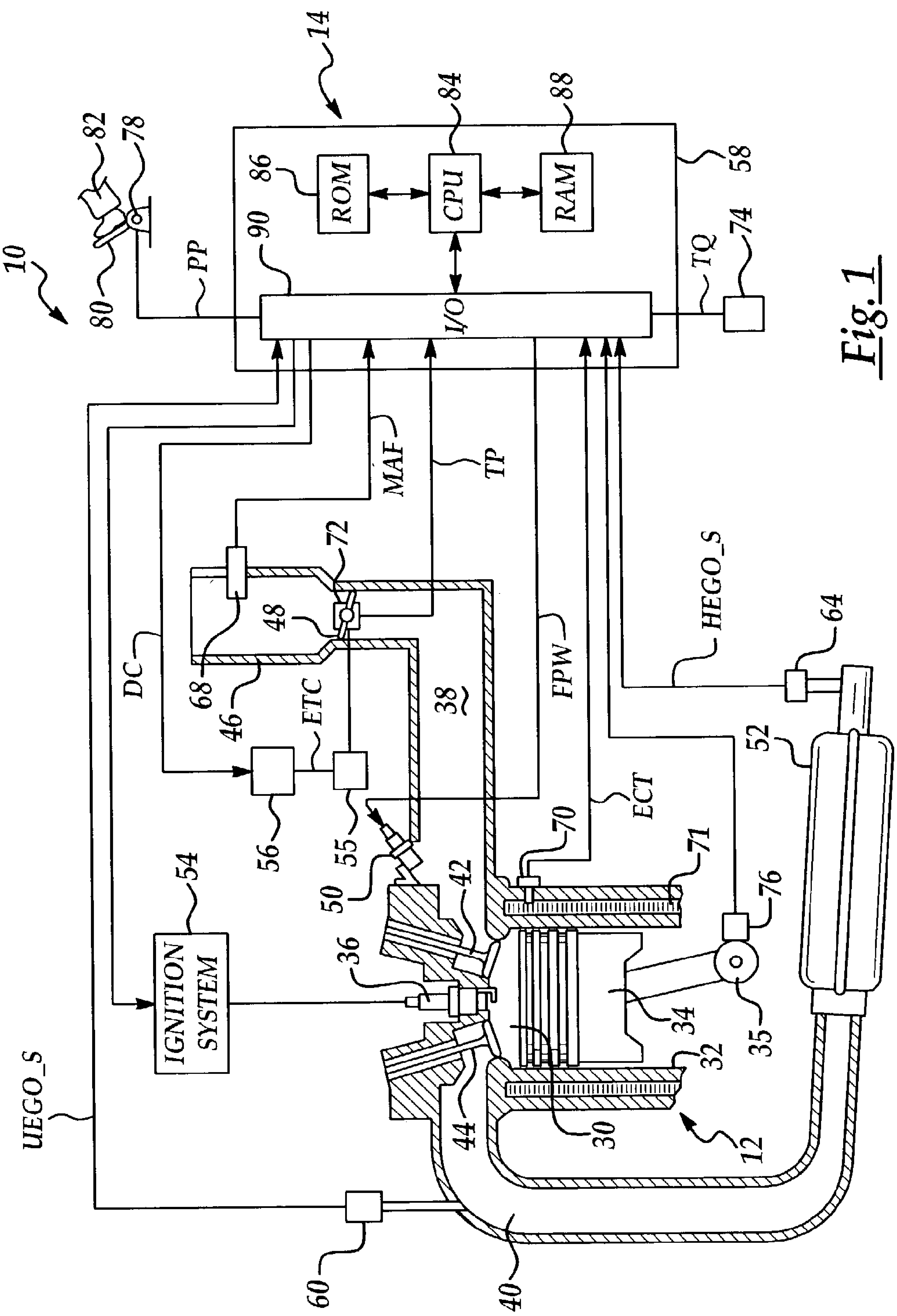

10
80
82
78
PP
90
14
ROM
CPU
RAM
86
84
88
58
I/O
TQ
74
MAF
TP
DC
72
48
68
46
ETC
38
FPW
HEGO_S
64
52
56
55
50
54
IGNITION SYSTEM
42
70
ECT
71
76
36
34
35
32
30
44
12
UEGO_S
60
40

Fig. 1

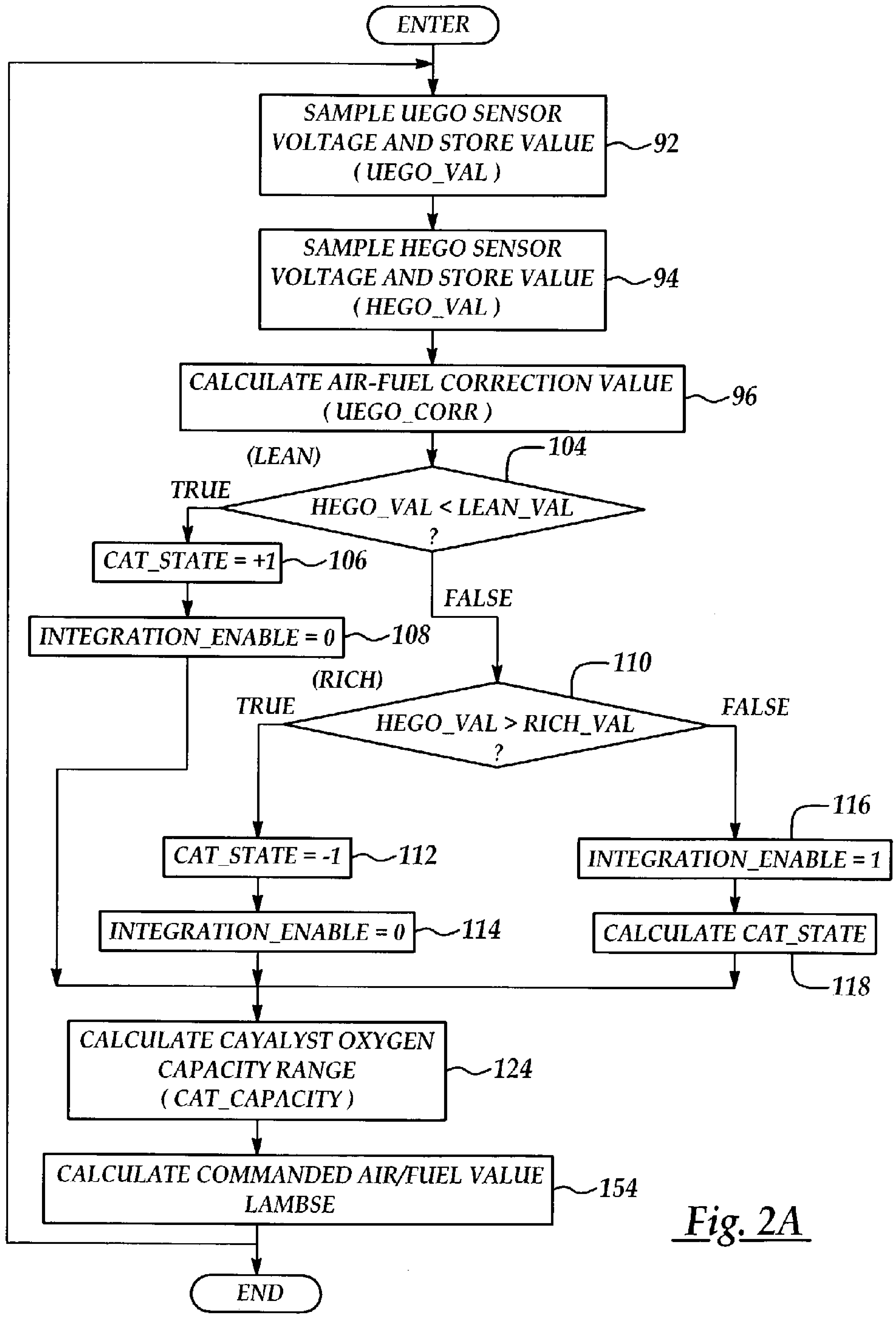

ENTER
SAMPLE UEGO SENSOR VOLTAGE AND STORE VALUE (UEGO_VAL)
92
SAMPLE HEGO SENSOR VOLTAGE AND STORE VALUE (HEGO_VAL)
94
CALCULATE AIR-FUEL CORRECTION VALUE (UEGO_CORR)
96
(LEAN)
104
TRUE
HEGO_VAL < LEAN_VAL ?
CAT_STATE = +1
106
FALSE
INTEGRATION_ENABLE = 0
108
(RICH)
110
TRUE
HEGO_VAL > RICH_VAL ?
FALSE
116
CAT_STATE = -1
112
INTEGRATION_ENABLE = 1
INTEGRATION_ENABLE = 0
114
CALCULATE CAT_STATE
118
CALCULATE CAYALYST OXYGEN CAPACITY RANGE (CAT_CAPACITY)
124
CALCULATE COMMANDED AIR/FUEL VALUE LAMBSE
154
END

Fig. 2A

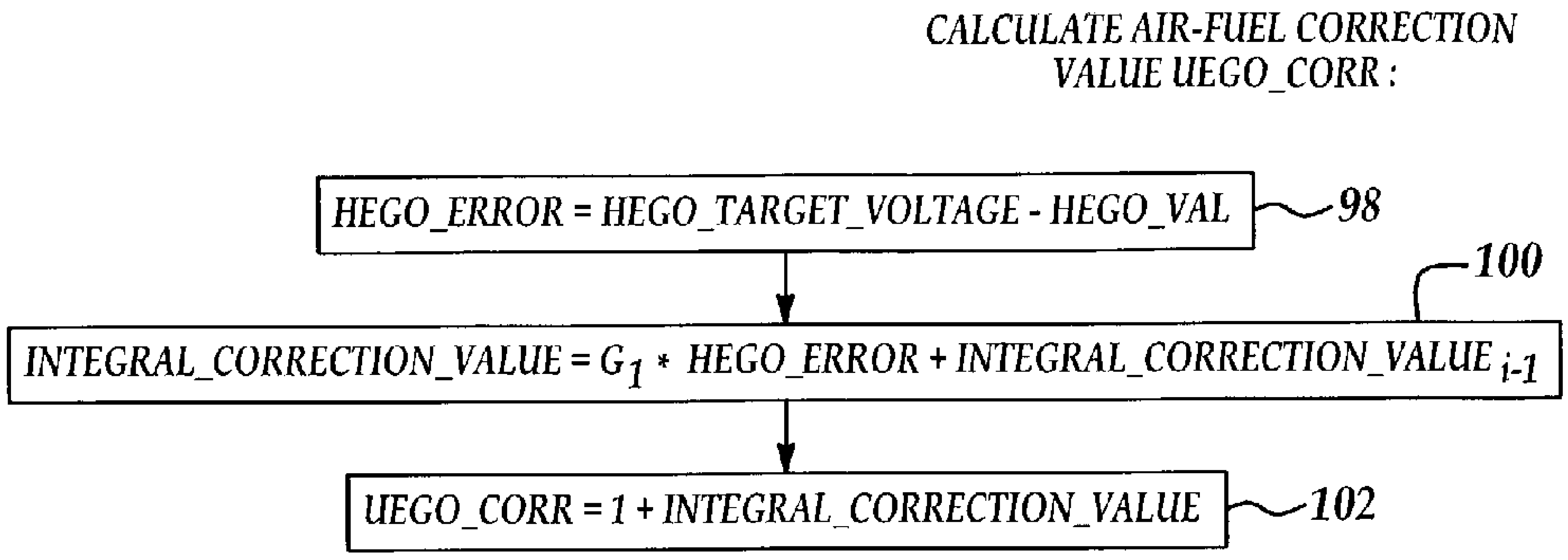


Fig. 2B

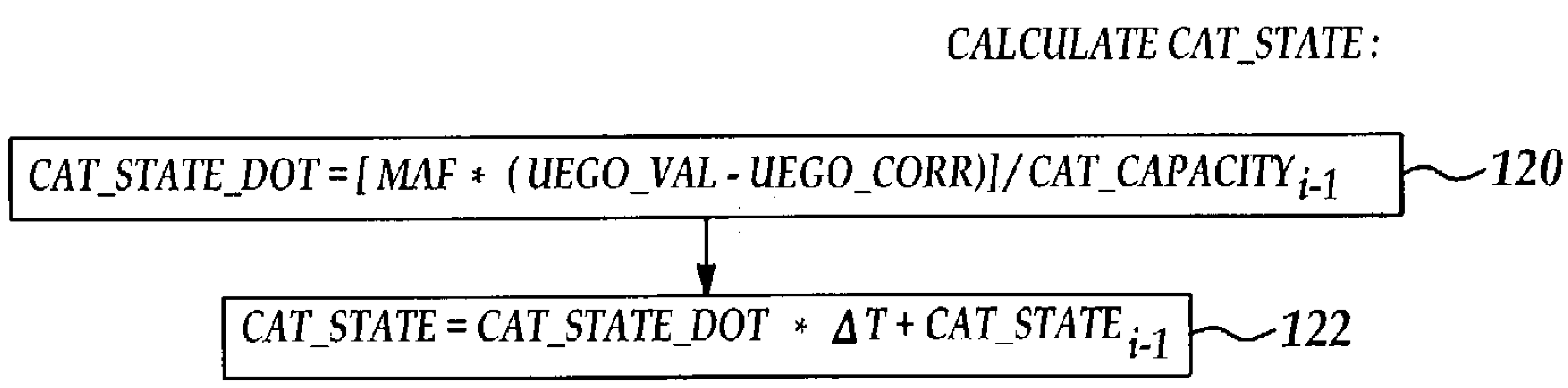


Fig. 2C

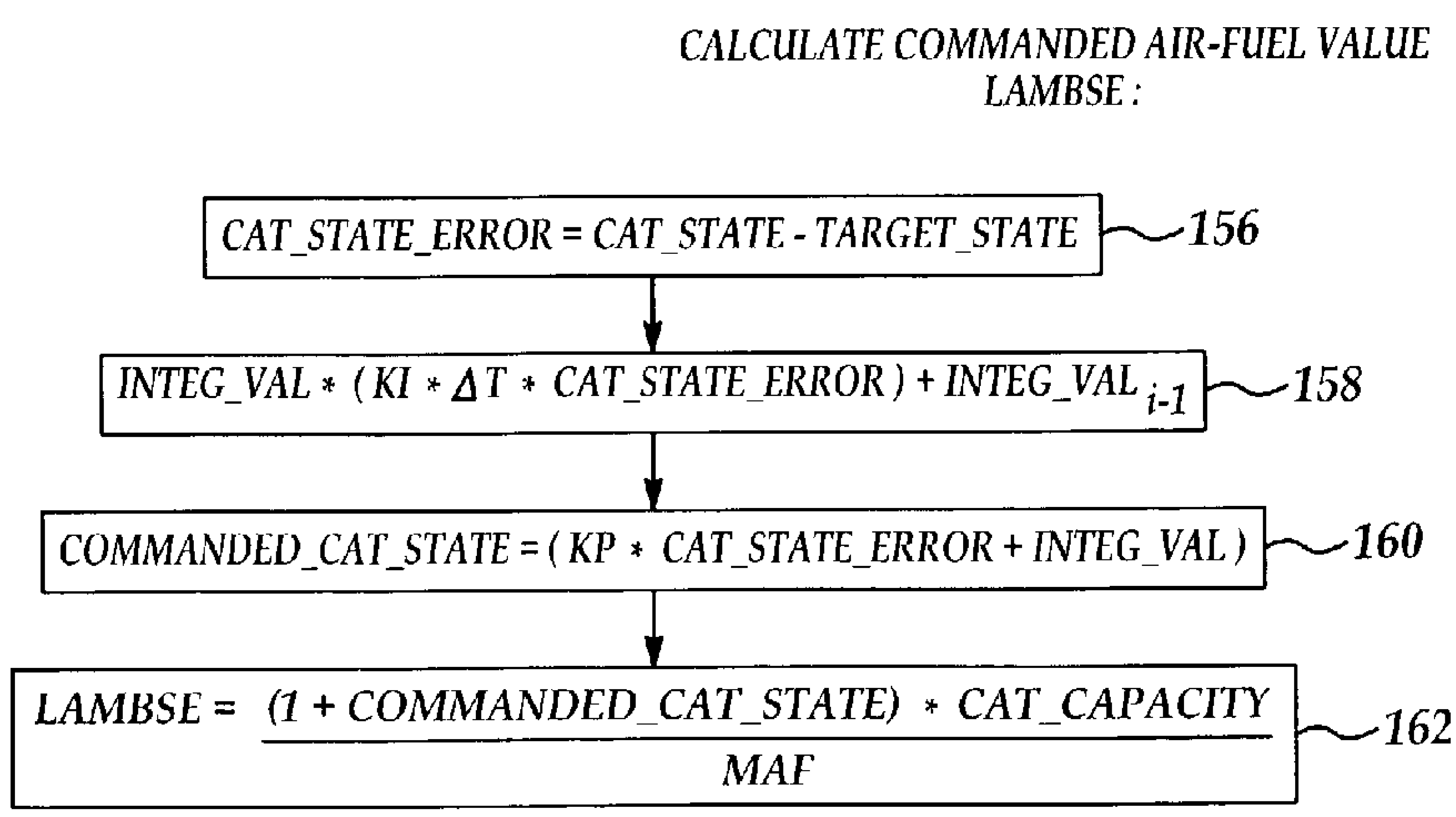


Fig. 2E

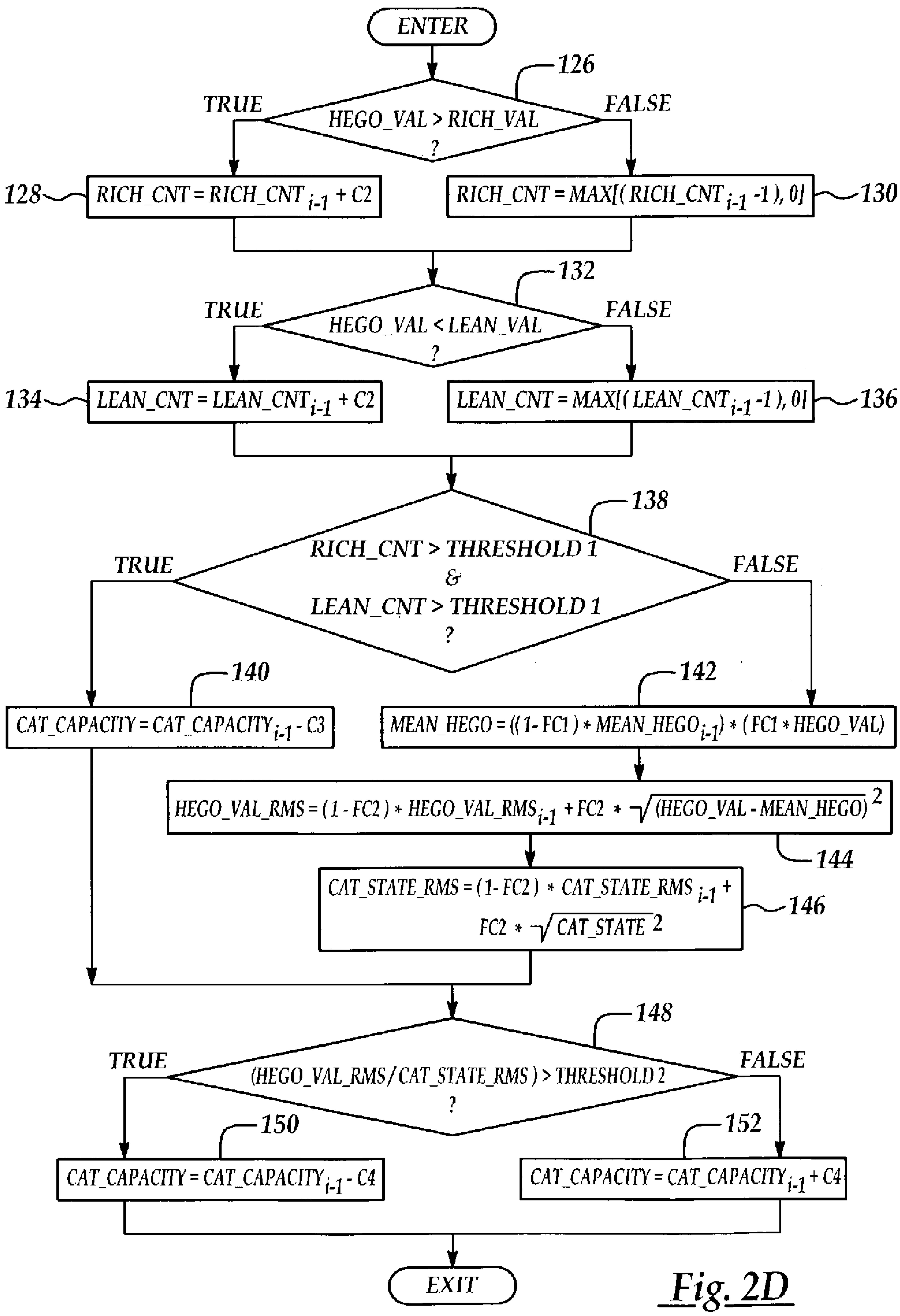

ENTER
126
HEGO_VAL > RICH_VAL ?
TRUE
FALSE
128
RICH_CNT = RICH_CNT i-1 + C2
RICH_CNT = MAX[(RICH_CNT i-1 -1), 0]
130
132
HEGO_VAL < LEAN_VAL ?
TRUE
FALSE
134
LEAN_CNT = LEAN_CNT i-1 + C2
LEAN_CNT = MAX[(LEAN_CNT i-1 -1), 0]
136
138
RICH_CNT > THRESHOLD 1 & LEAN_CNT > THRESHOLD 1 ?
TRUE
FALSE
140
CAT_CAPACITY = CAT_CAPACITY i-1 - C3
142
MEAN_HEGO = ((1- FC1) * MEAN_HEGO i-1) * (FC1 * HEGO_VAL)
HEGO_VAL_RMS = (1 - FC2) * HEGO_VAL_RMS i-1 + FC2 * √(HEGO_VAL - MEAN_HEGO)2
144
CAT_STATE_RMS = (1- FC2) * CAT_STATE_RMS i-1 + FC2 * √CAT_STATE 2
146
148
(HEGO_VAL_RMS / CAT_STATE_RMS) > THRESHOLD 2 ?
TRUE
FALSE
150
CAT_CAPACITY = CAT_CAPACITY i-1 - C4
152
CAT_CAPACITY = CAT_CAPACITY i-1 + C4
EXIT

Fig. 2D

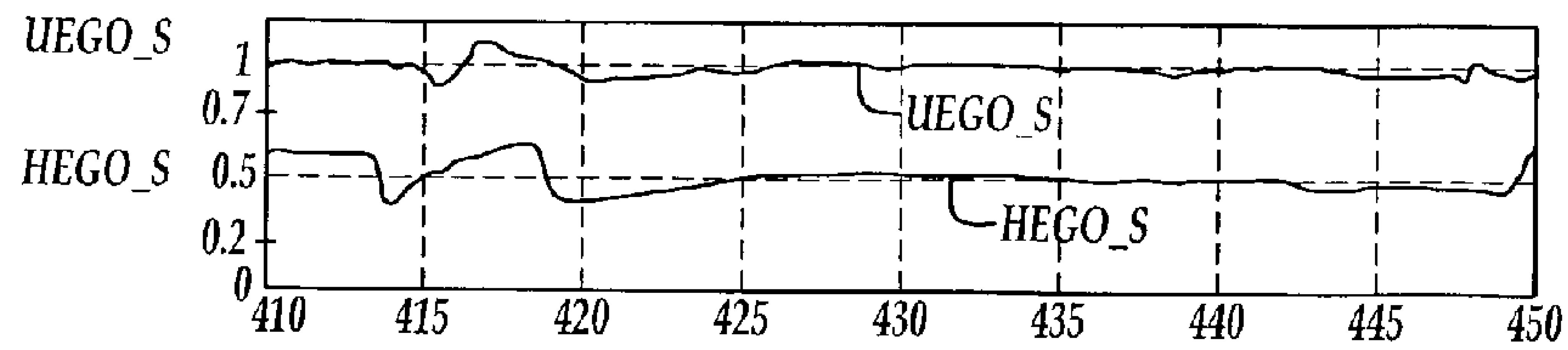


Fig. 3A

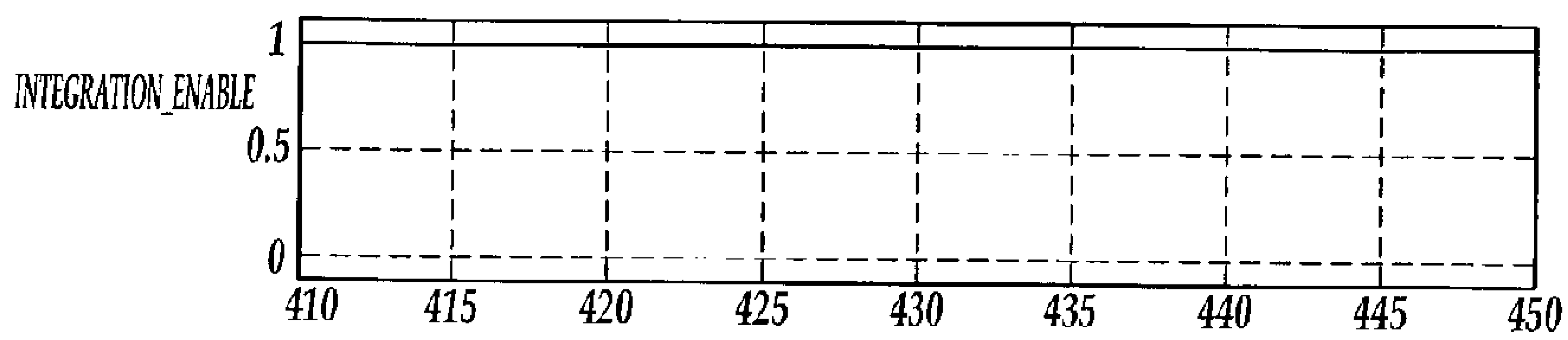


Fig. 3B

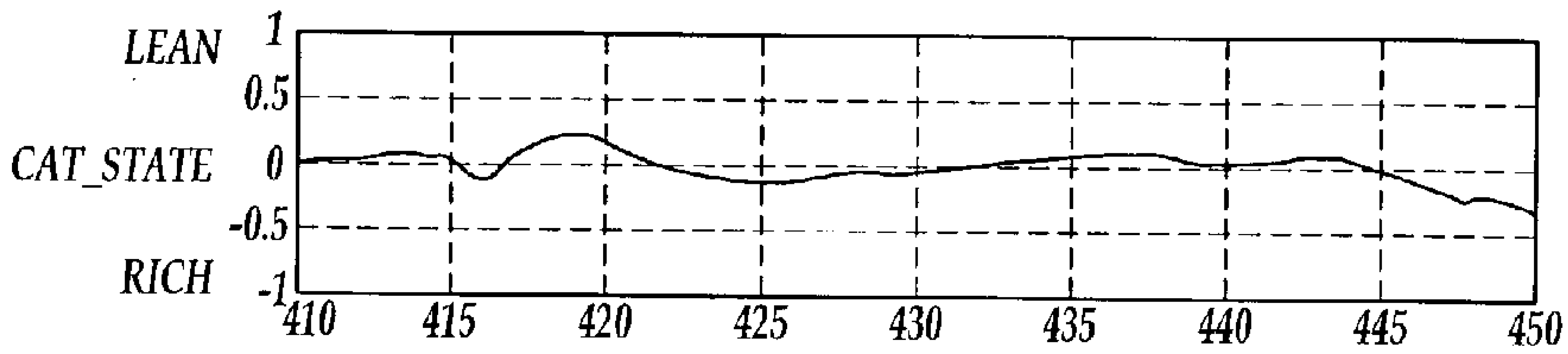


Fig. 3C

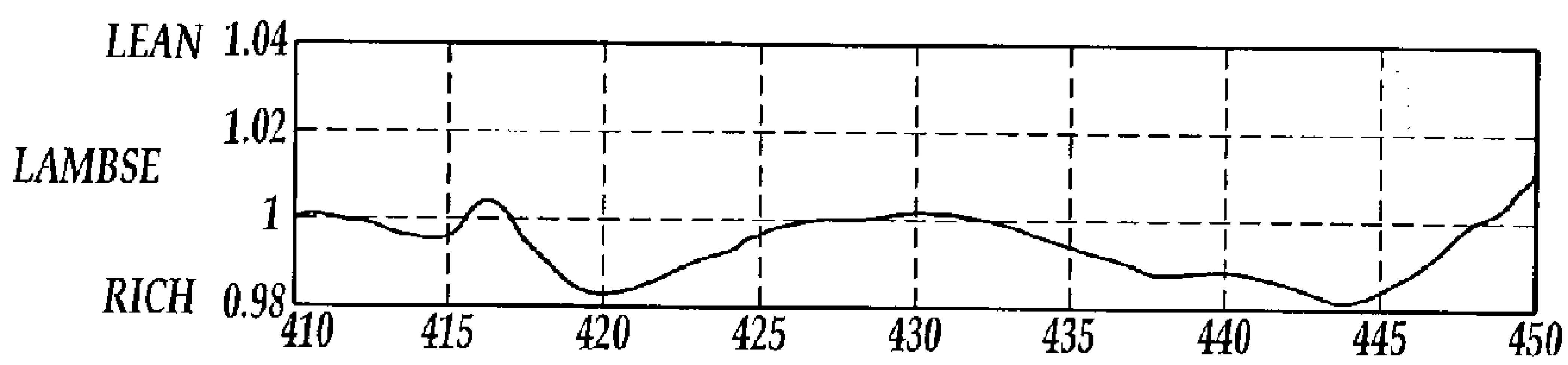


Fig. 3D

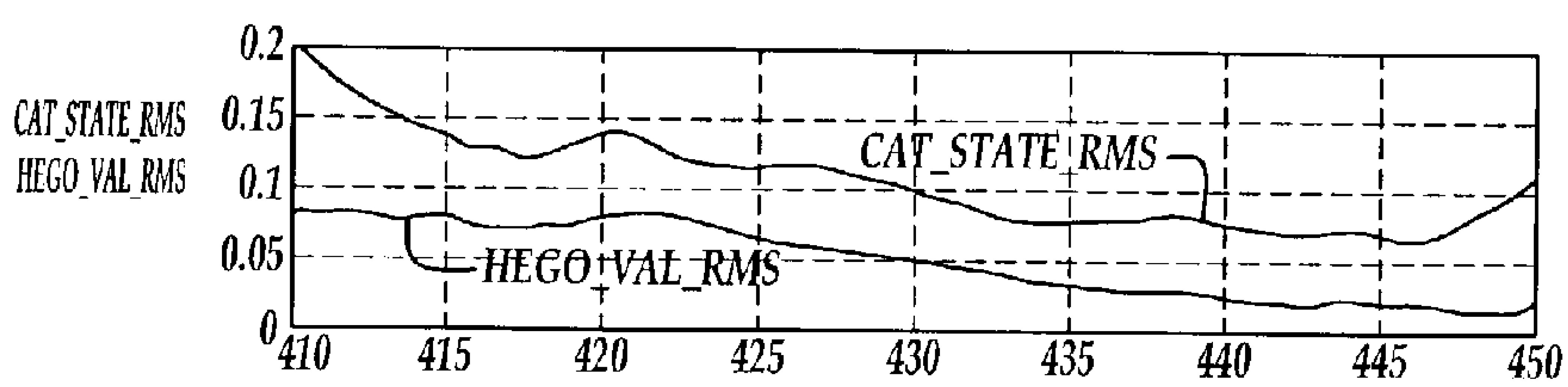


Fig. 3E

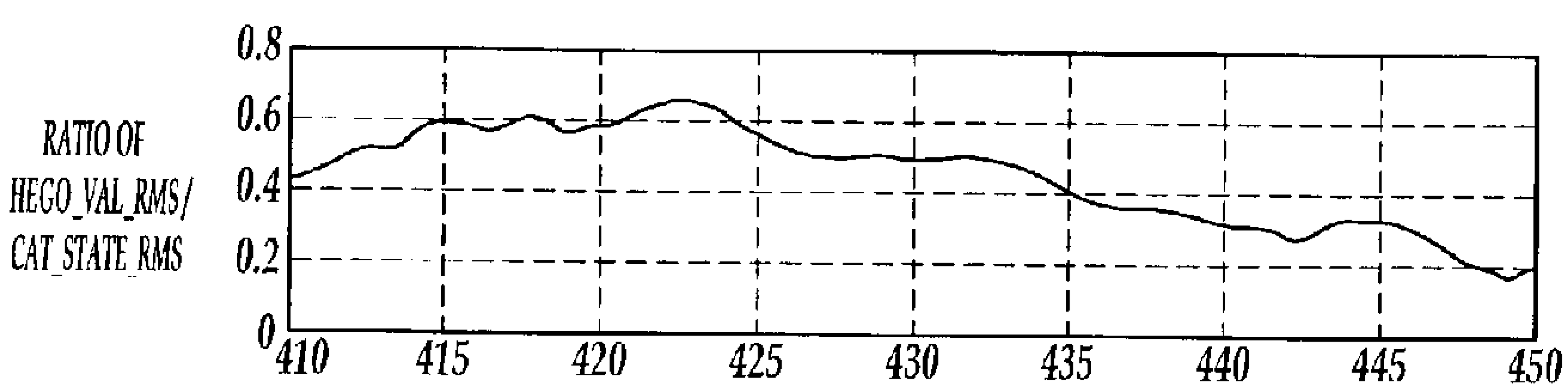


Fig. 3F

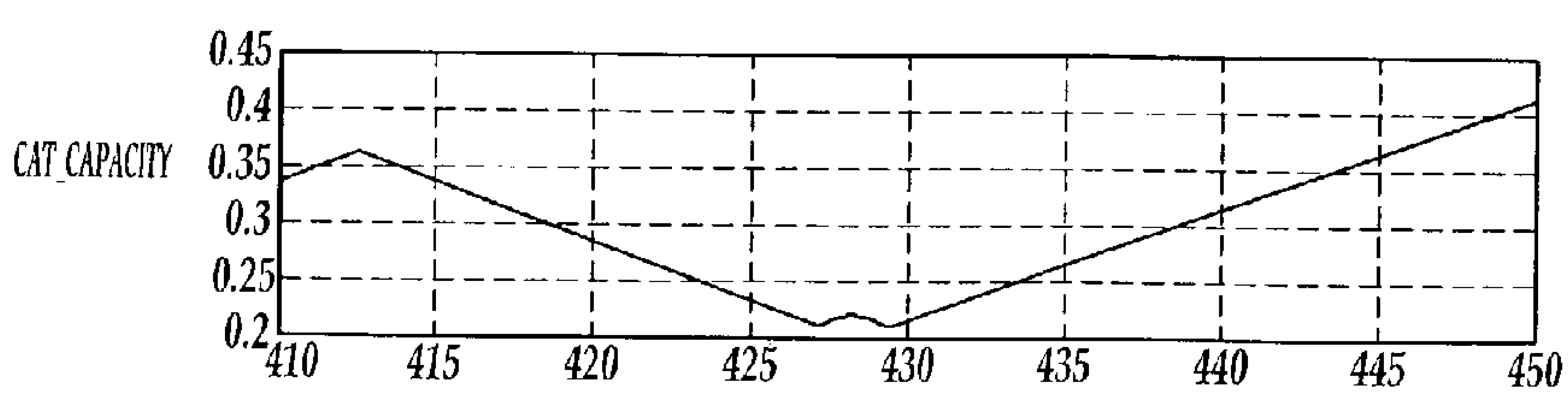


Fig. 3G

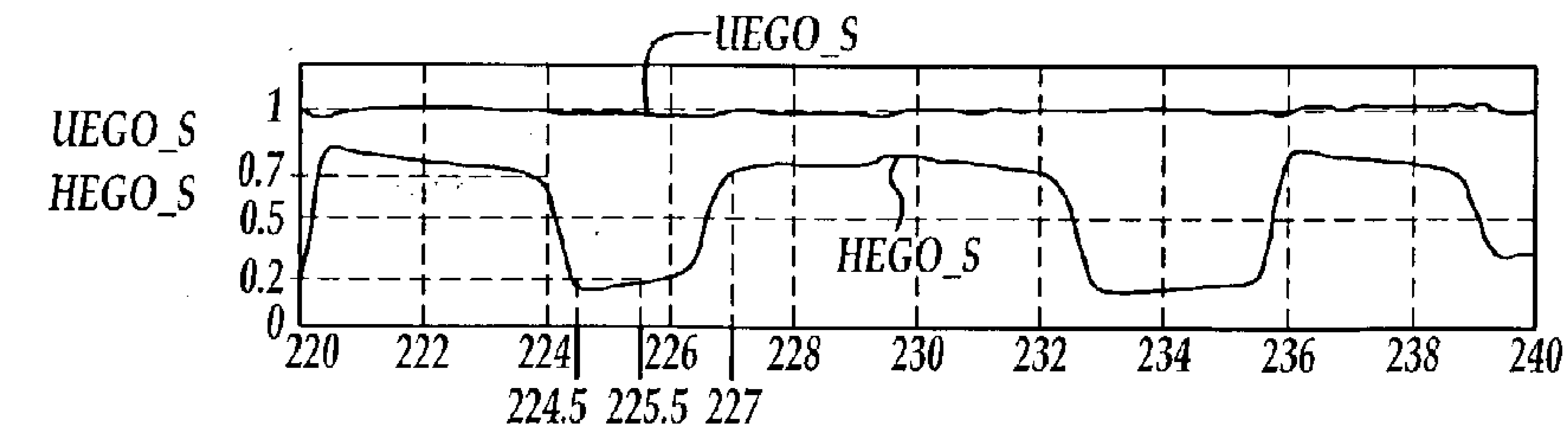


Fig. 4A

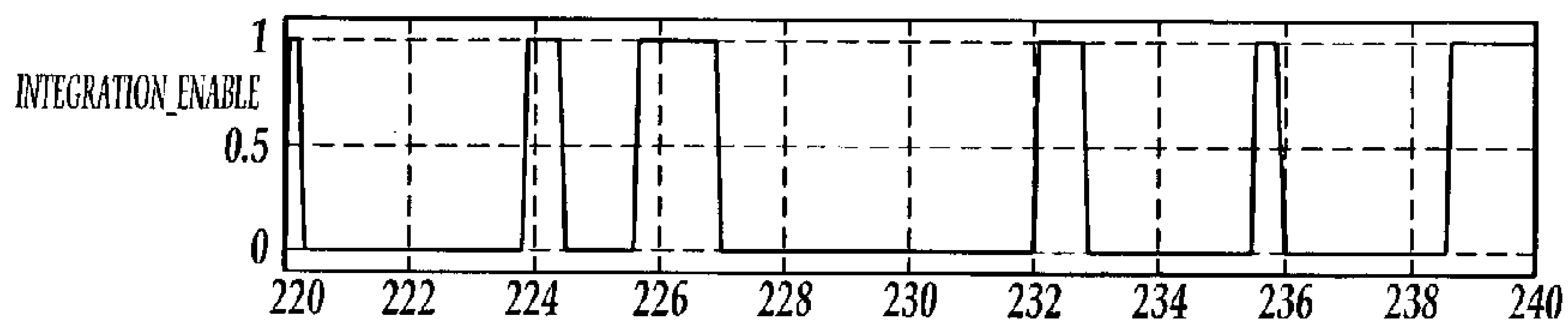


Fig. 4B

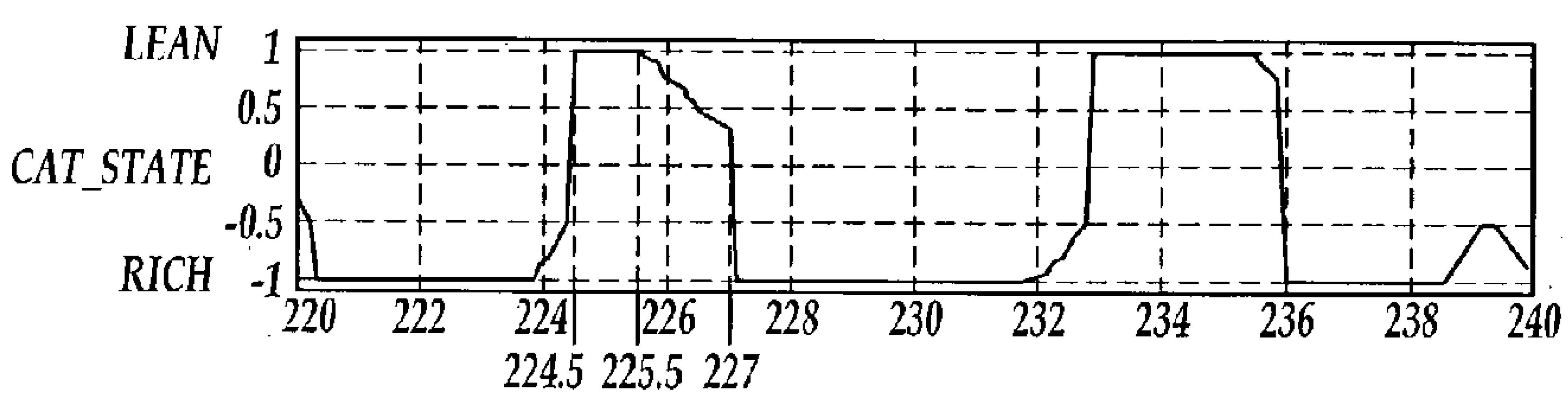


Fig. 4C

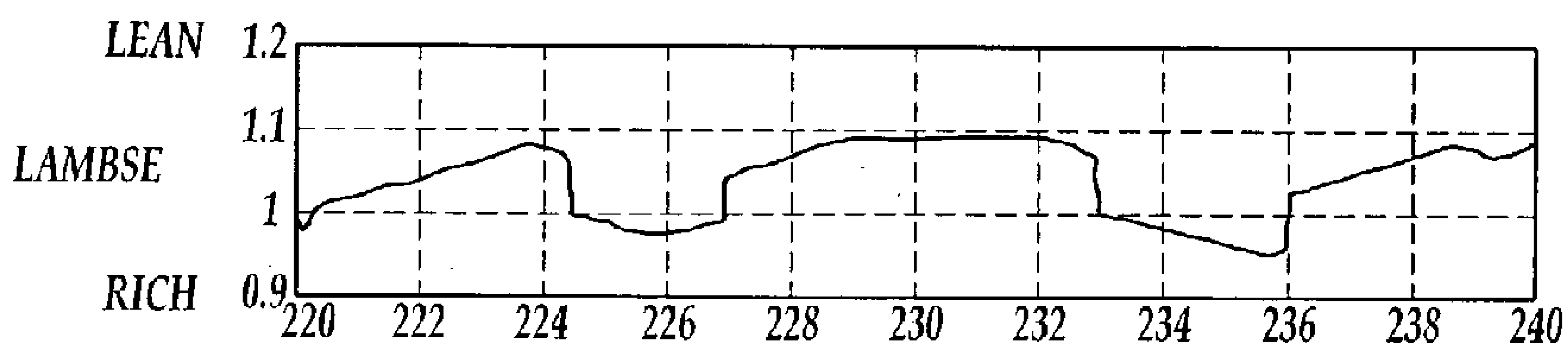


Fig. 4D

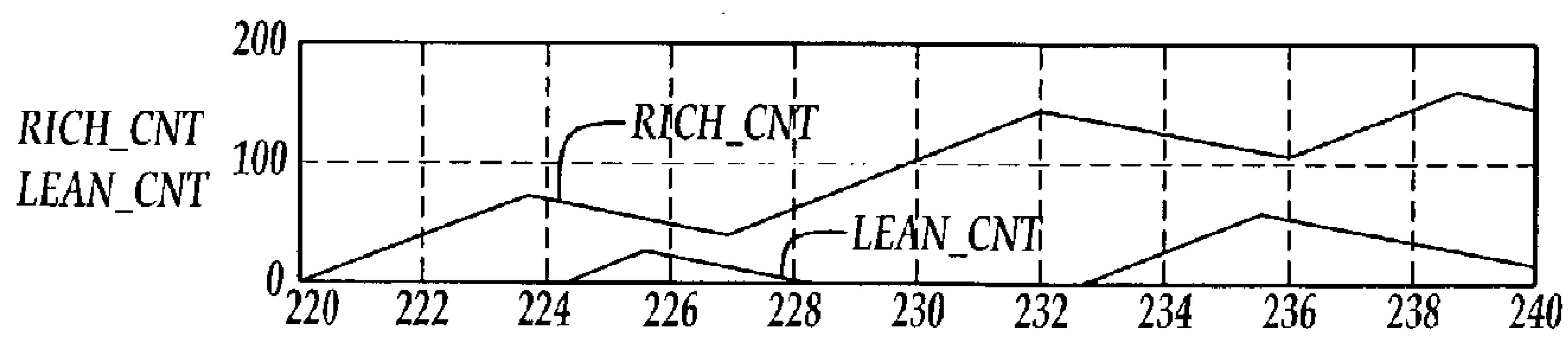


Fig. 4E

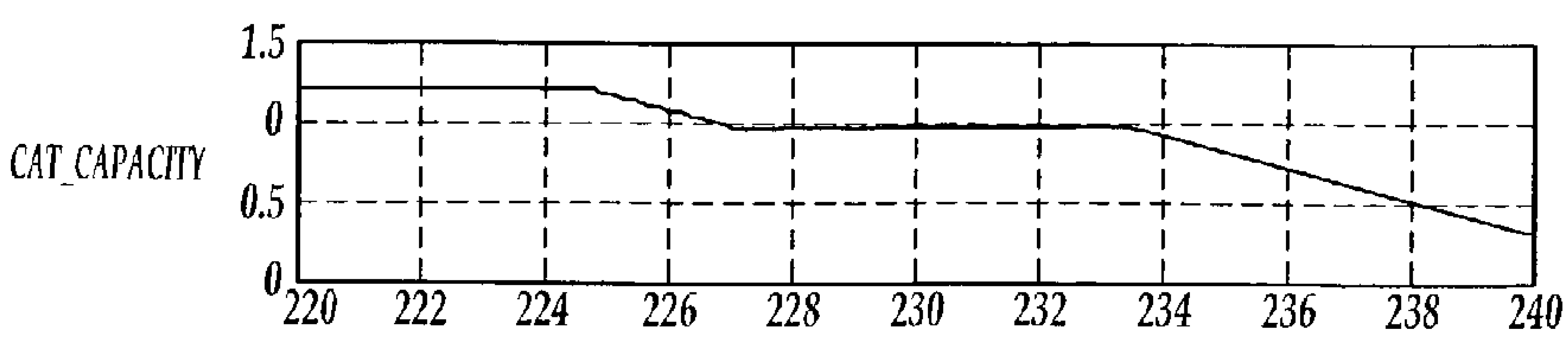


Fig. 4F

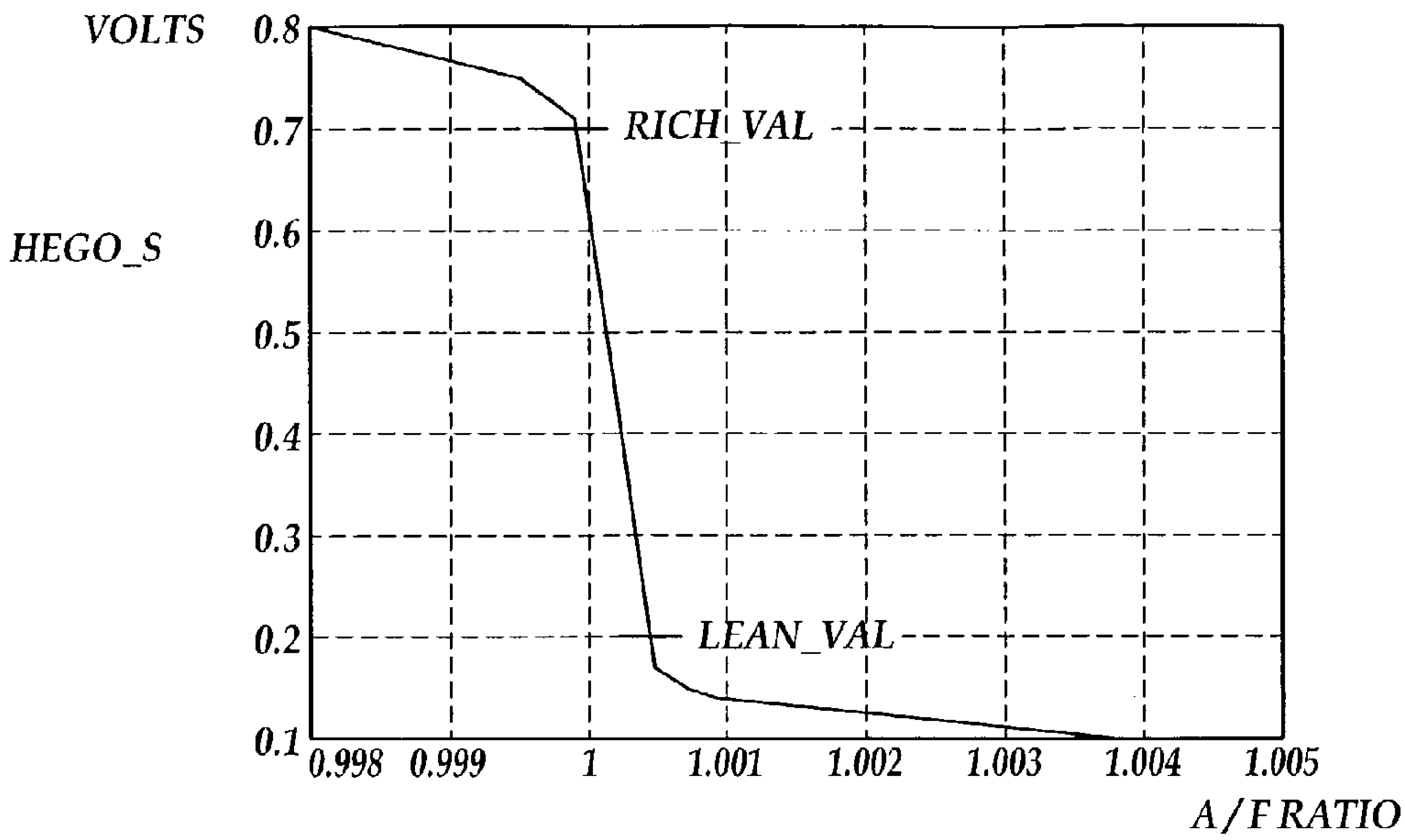

VOLTS
HEGO_S
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
RICH_VAL
LEAN_VAL
0.998
0.999
1
1.001
1.002
1.003
1.004
1.005
A/F RATIO

Fig. 5

SYSTEM AND METHOD FOR CONTROLLING AN ENGINE

[0001] This application is a continuation-in-part of application Ser. No. 09/991,519, filed Nov. 21, 2001.

FIELD OF THE INVENTION

[0002] This invention relates to a system and method for controlling an internal combustion engine.

BACKGROUND OF THE INVENTION

[0003] A known engine control system is disclosed in U.S. Pat. No. 5,842,340. The known system includes an engine coupled to an emission catalyst with an UEGO sensor disposed upstream of the catalyst and a HEGO disposed downstream of the catalyst. The system attempts to maintain a predetermined level of oxygen in an emission catalyst using a UEGO output signal and a binary HEGO output signal. A drawback of the system however, is that relatively complex integration algorithms are utilized to estimate the oxygen stored in the catalyst when only using the binary states of the downstream HEGO output signal.

[0004] The inventors herein have recognized that the control algorithms for maintaining a catalyst at an optimal oxygen storage level can be greatly simplified. In particular, the inventors herein have recognized that a narrow linear operating range of the HEGO output signal corresponds to an optimal catalyst oxygen storage capacity range. Thus, by controlling an air-fuel ratio in the engine to maintain the HEGO output signal within the linear operating range, optimal performance of the catalyst is maintained. Further, because the inventive system utilizes the linear operating region of the HEGO sensor, the equations utilized to determine the oxygen storage level in the catalyst are greatly simplified.

SUMMARY OF THE INVENTION

[0005] The present invention provides a system, a method, and an article of manufacture for controlling an engine.

[0006] The method for controlling an engine coupled to an emission system in accordance with a first aspect of the present invention is provided. The emission system includes an emission catalyst and a HEGO sensor disposed downstream of at least a portion of the catalyst. The method includes adjusting an air-fuel ratio of the engine to substantially maintain an output signal from the downstream HEGO sensor within a predetermined linear operating range.

[0007] A system for controlling an engine coupled to a downstream emission catalyst in accordance with a second aspect of the present invention is provided. The system includes a HEGO sensor disposed downstream of at least a portion of the catalyst generating a first output signal. The system further includes a controller receiving the output signal and configured to adjust an air-fuel ratio of the engine to substantially maintain the output signal from the HEGO sensor within a predetermined linear operating range.

[0008] An article of manufacture in accordance with a third aspect of the present invention is provided. The article of manufacture includes a computer storage medium having a computer program encoded therein for controlling an engine coupled to an emission system. The system has an emission catalyst and a HEGO sensor disposed downstream of at least a portion of the catalyst generating an output signal. The computer storage medium includes code for adjusting an air-fuel ratio of the engine to substantially maintain an output signal from the downstream HEGO sensor within a predetermined linear operating range.

[0009] The system and method for controlling an engine represent a significant improvement over conventional systems and methods. In particular, the system utilizes greatly simplified oxygen storage algorithms for air-fuel control by maintaining a downstream HEGO sensor within the linear operating range of the HEGO sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **FIG. 1** is a schematic of a vehicle having an engine and a control system in accordance with the present invention.

[0011] FIGS. **2A-2E** is a flowchart of a method for controlling an engine in accordance with the present invention.

[0012] FIGS. **3A-3G** are signal schematics illustrating operation of the control system when maintaining the HEGO sensor output signal within a linear operating region.

[0013] FIGS. **4A-4F** are signal schematics illustrating operation of the control system when the system is adjusting the estimated catalyst capacity range to induce the HEGO sensor output signal move toward a linear operating region.

[0014] **FIG. 5** is a signal schematic of the HEGO sensor output signal illustrating the linear operating region of the sensor.

DESCRIPTION OF AN EMBODIMENT

[0015] Referring now to the drawings, like reference numerals are used to identify identical components in the various views. Referring to **FIG. 1**, an automotive vehicle **10** is shown. Vehicle **10** includes an internal combustion engine **12** and an engine control system **14** in accordance with the present invention.

[0016] Referring to **FIG. 1**, only one cylinder of a plurality of cylinders is shown for purposes of clarity. Engine **12** includes a combustion chamber **30**, cylinder walls **32**, a piston **34**, a crankshaft **35**, a spark plug **36**, an intake manifold **38**, an exhaust manifold **40**, an intake valve **42**, an exhaust valve **44**, a throttle body **46**, a throttle plate **48**, a fuel injector **50**, and an emission catalyst **52**.

[0017] Combustion chamber **30** communicates with intake manifold **38** and exhaust manifold **40** via respective intake and exhaust valves **42**, **44**. Piston **34** is positioned within combustion chamber **30** between cylinder walls **32** and is connected to crankshaft **35**. Ignition of an air-fuel mixture within combustion chamber **30** is controlled via spark plug **36** which delivers ignition spark responsive to a signal from distributorless ignition system **54**.

[0018] Intake manifold **38** communicates with throttle body **46** via throttle plate **48**. Throttle plate **48** is controlled by electric motor **55** which receives a signal from ETC driver **56**. ETC driver **56** receives a control signal (DC) from a controller **58**. Intake manifold **38** is also shown having fuel injector **50** coupled thereto for delivering fuel in proportion to the pulse width of signals (FPW) from controller **58**. Fuel is delivered to fuel injector **50** by a conventional fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (now shown). Although port fuel injection is shown, direct fuel injection could be utilized instead of port fuel injection.

[**0019**] Catalyst **52** reduces exhaust gas constituents such as nitrous oxides (NOx) and oxidizes carbon monoxide (CO) and hydrocarbons (HC).

[**0020**] Control system **14** is provided to control the operation of engine **12** in accordance with the present invention. Control system **14** includes distributorless ignition system **54**, an electric motor **55** for controlling the throttle plate **48**, an ETC driver **56**, exhaust gas sensors **60**, **64**, a mass air flow sensor **68**, a temperature sensor **70**, a throttle position sensor **72**, a torque sensor **74**, an engine speed sensor **76**, a pedal position sensor **78**, an accelerator pedal **80**, and controller **58**.

[**0021**] Mass air flow sensor **68** generates a signal indicating the inducted mass air flow (AM) that is transmitted to controller **58**. Sensor **68** may be coupled to the throttle body **46** or intake manifold **38**.

[**0022**] Temperature sensor **70** generates a signal indicating the engine coolant temperature (ECT) received by controller **58**. Sensor **70** may be coupled to cooling jacket **71** in cylinder wall **36**.

[**0023**] Throttle position sensor **72** generates a signal indicating a throttle position (TP) of throttle plate **48** received by controller **58** for closed-loop control of plate **48**.

[**0024**] Torque sensor **74** generates a signal (TQ) that may indicate one of following torque values: (i) an engine crankshaft torque, ii) a transmission torque, such as for example, a torque converter turbine torque or a transmission output shaft torque, or (iii) an axle torque.

[**0025**] Engine speed sensor **76** may comprise a hall effect sensor that generates a signal (N) indicating an engine speed. Sensor **76** may be coupled to crankshaft **35** and transmits signal (N) to controller **58**.

[**0026**] Accelerator pedal **80** is shown communicating with a driver's foot **82**. Pedal position sensor **78** generates a signal indicating acceleration pedal position (PP) that is transmitted to controller **58**.

[**0027**] A universal exhaust gas oxygen (UEGO) **60** sensor, also known as a proportional oxygen sensor generates a signal whose magnitude is proportional to the oxygen level (and the air-fuel ratio) in the exhaust gases. UEGO sensor **60** is disposed upstream of catalyst **52** and generates a signal (UEGO_S) proportional to an oxygen concentration in the exhaust gases.

[**0028**] Heated exhaust gas oxygen sensor (HEGO) sensor **64** is disposed downstream of at least some portion of a catalyst **52**. For example, HEGO sensor **64** could be disposed downstream a predetermined distance from catalyst **52**. Alternately, for example, HEGO sensor **64** could be disposed at least partially within catalyst **52** at a predetermined location along an axial length of catalyst **52**. HEGO sensor **64** generates a signal (HEGO_S) indicative of the oxygen concentration in exhaust gases downstream of catalyst **52**. Referring to **FIG. 5**, the signal (HEGO_S) generated by the HEGO sensor **64** is illustrated. Between the oxygen concentrations values (LEAN_VAL) and (RICH_VAL), the HEGO sensor **64** generates output signal (HEGO_S) that has a linear output voltage to oxygen concentration relationship. The inventive control system **14** controls the air-fuel ratio in engine **12** to maintain the output signal (HEGO_S) within a relatively narrow linear operating region, as will be described in greater detail below.

[**0029**] The controller **58** is provided to implement the method for controlling an engine in accordance with the present invention. The controller **58** includes a microprocessor **84** communicating with various computer-readable storage media. The computer readable storage media preferably include nonvolatile and volatile storage in a read-only memory (ROM) **86** and a random-access memory (RAM) **88**. The computer readable media may be implemented using any of a number of known memory devices such as PROMs, EPROMs, EEPROMs, flash memory or any other electric, magnetic, optical or combination memory device capable of storing data, some of which represent executable instructions, used by microprocessor **84** in controlling engine **12**. Microprocessor **84** communicates with various sensors and actuators (discussed above) via an input/output (I/O) interface **90**. Of course, the present invention could utilize more than one physical controller to provide engine/vehicle control depending upon the particular application.

[**0030**] Referring to FIGS. 3A-3G, the signals utilized for controlling the engine **12** will now be explained. As shown in **FIG. 3**A, the signal (UEGO_S) corresponds to output signal generated by the UEGO sensor **60**. The value (UEGO_VAL) corresponds to a sampled voltage of the signal (UEGO_S). The signal (HEGO_S) corresponds to the output signal generated by the HEGO sensor **64**. The value (HEGO_VAL) corresponds to a sampled voltage of the signal (HEGO_S).

[**0031**] Referring to **FIGS. 3B, 3C**, **3G**, the catalyst state (CAT_STATE) is a scalar value indicative of the current amount of oxygen stored in catalyst **52**. When the output signal (HEGO_S) is within its linear operation region, the value (CAT_STATE) is between the scalar values "−1" and "1" and optimal reduction of nitrogen oxides (NOx) and oxidation of hydrocarbons (HC) and carbon monoxide (CO) is obtained. In this case, the controller **58** sets the (INTEGRATION_ENABLE) flag equal to "1" indicating the oxygen capacity range (CAT_CAPACITY) of catalyst **52** is being updated. The value (CAT_CAPACITY) corresponds to a desired range of the stored oxygen amount in catalyst **52**, with the desired oxygen range being centered about a desired scalar value "0" indicative of the optimal amount of stored oxygen in catalyst **52**.

[**0032**] When the

[**0033**] the output signal (HEGO_S) is not within its linear operation region, controller **58** sets the (INTEGRATION_ENABLE) flag equal to "0" indicating the calculation of the oxygen capacity range (CAT_CAPACITY) is being discontinued.

[**0034**] Referring to **FIG. 3**D, the air-fuel control signal (LAMBSE) is illustrated. The controller **58** adjusts the signal (LAMBSE) to maintain the signal (HEGO_S) within its linear operating region. In particular, the controller **58** adjusts the value (CAT_CAPACITY) in order for the signal (CAT_STATE) to correlate with the HEGO output signal (HEGO_S). In other words, the value (CAT_STATE) should indicate a relatively large amount of stored oxygen (e.g., CAT_STATE=1) when the value (HEGO_VAL) indicates a lean air-fuel ratio. Further, the value (CAT_STATE) should indicate a relatively small amount of stored oxygen (e.g., CAT_STATE=−1) in catalyst **52** when the value (HEGO_VAL) indicates a rich air-fuel ratio.

[**0035**] Referring to **FIGS. 3E, 3F** the signal (CAT_STATE_RMS) corresponds to the root mean square value of the signal (CAT_STATE). Further, the value (HEGO_VAL_RMS) corresponds to the root mean square of the value (HEGO_VAL). The ratio of the signals (CAT_STATE_RMS) and (HEGO_VAL_RMS) are utilized by controller **58** for providing minor adjustments to the catalyst capacity range (CAT_CAPACITY). In particular, when the ratio of (HEGO_VAL_RMS)/(CAT_STATE_RMS) is greater than a predetermined threshold, the ratio indicates that the variations in the estimated catalyst state (CAT_STATE) is smaller than expected when compared to the measured variations in the HEGO output signal (HEGO_S). In other words, the ratio suggests that the estimated catalyst capacity range (CAT_CAPACITY) is larger than the actual catalyst capacity range, the actual catalyst capacity range corresponding to the linear range of HEGO sensor **64**. In this case, the controller **58** decreases (CAT_CAPACITY), as will be explained in greater detail below.

[**0036**] Alternately, when the ratio of (HEGO_VAL_RMS)/(CAT_STATE_RMS) is less than the predetermined threshold, the ratio indicates that the variations in the estimated catalyst state (CAT_STATE) is larger than expected when compared to the measured variations in the HEGO output signal (HEGO_S). In other words, the ratio suggests that the estimated catalyst capacity range (CAT_CAPACITY) is smaller than the actual catalyst capacity range. As a result, controller **58** increases (CAT_CAPACITY), as will be explained in greater detail below.

[**0037**] Referring to **FIG. 4**E, the signals (RICH_CNT) and (LEAN_CNT) correspond to time weighted counts utilized by controller **58** for aggressively decreasing the value (CAT_CAPACITY) when the catalyst **52** is substantially depleted of oxygen or substantially saturated with oxygen, respectively.

[**0038**] Referring to FIGS. **4A-4F**, the operation of the control system **14** will be explained during non-stabilized operating conditions. As shown, between T=221 seconds and T=224 seconds, the HEGO output signal (HEGO_S) is greater than 0.7 volts (i.e., RICH_VAL) which is outside the linear operating range of HEGO sensor **64**. Accordingly, controller **58** sets the value (CAT_STATE) equal to "−1" indicating the catalyst **52** is saturated rich. Further, controller **58** disables the (INTEGRATION_ENABLE) flag so that the value of (CAT_STATE) will be maintained at the value "−1". Further, controller **58** ramps the air-fuel control signal (LAMBSE) toward a leaner air-fuel value in order to return the system **14** back to the desired state (i.e., CAT_STATE=0).

[**0039**] Between T=224-224.5 seconds, the HEGO output signal (HEGO_S) decreases into the desired linear operating range (e.g., 0.2-0.7 volts) and controller **58** updates the value (CAT STATE) by setting the (INTEGRATION_ENABLE) flag equal to "1". Further, controller **58** adjusts the air-fuel control signal (LAMBSE) towards a richer air-fuel ratio as the estimated state (CAT_STATE) moves toward the desired state (i.e., CAT_STATE=0).

[**0040**] At T=224.5 seconds, the output signal (HEGO_S) falls below 0.2 volts indicating the catalyst **52** is saturated lean. As a result, controller **58** sets the value (CAT_STATE) equal to "1" indicating the catalyst **52** is saturated lean. Further, controller **58** disables the (INTEGRATION_ENABLE) flag so that the value of (CAT_STATE) will be maintained at the value "1". Further, controller **58** ramps the air-fuel control signal (LAMBSE) aggressively toward a richer air-fuel ratio in order to return the system **14** back to the desired state (i.e., CAT_STATE=0).

[**0041**] At T=225.5 seconds, the output signal (HEGO_S) again moves into the linear operating region. As a result, controller **58** updates the value (CAT_STATE) by setting the (INTEGRATION_ENABLE) flag equal to "1". Further, controller **58** adjusts the air-fuel control signal (LAMBSE) towards a leaner air-fuel ratio as the estimated state (CAT_STATE) moves toward the desired state (i.e., CAT_STATE=0). However, at T=227 seconds, the output signal (HEGO_S) again moves outside the linear operation region.

[**0042**] Referring to FIGS. **3A-3C**, the operation of control system **14** will be explained under stabilized operating conditions. As shown, the HEGO output signal (HEGO_S) is maintained within the linear operating range (e.g., 0.2-0.7 volts). As a result, the value (CAT_STATE) indicative of the amount of stored oxygen in catalyst **52**, is maintained between the desired scalar limits of "1" and "−1". Further, because the HEGO output signal (HEGO_S) is maintained with the desired linear operating range, optimal catalyst performance is obtained from catalyst **52**.

[**0043**] Referring to FIGS. **2A-2E**, a flowchart of the inventive method for controlling an engine will now be discussed. The method may be implemented using software stored in memory **86** of controller **58**.

[**0044**] Initially at step **92**, the signal (UEGO_S) from UEGO sensor **60** is sampled by controller **58** and the corresponding value (UEGO_VAL) is stored in memory **88**.

[**0045**] Next at step **94**, the signal (HEGO_S) from HEGO sensor **64** is sampled by controller **58** and the corresponding value (HEGO_VAL) is stored in memory **88**.

[**0046**] Next at step **96**, the long-term air-fuel correction value (UEGO_CORR), also known as a stoichiometric reference value, is determined. Referring to **FIG. 2**B, steps **98-102** are utilized to calculate (UEGO_CORR). At step **98**, the value (HEGO_ERROR) which is indicative of the difference of the signal (HEGO) from a desired value, is calculated using the following equation:

$$HEGO\_ERROR=HEGO\_TARGET\_VOLTAGE-HEGO\_VAL$$

[**0047**] where HEGO_TARGET_VOLTAGE corresponds to a stoichiometric oxygen concentration, such as 0.6 volts for example

[**0048**] Next at step **100**, an (INTEGRAL_CORRECTION_VALUE) is calculated using the following equation:

$$INTEGRAL\_CORRECTION\_VALUE=G1*HEGO\_ERROR+INTEGRAL\_CORRECTION\_VALUE_{I-1}$$

[**0049**] where G1 corresponds to a gain value that is determined empirically.

[**0050**] Next at step **102**, the correction value (UEGO_CORR) is calculated using the following equation:

$$UEGO\_CORR=1+INTEGRAL\_CORRECTION\_VALUE$$

[0051] Referring again to **FIG. 2**A, after step **96**, the method advances to step **104** which determines whether the value (HEGO_VAL) is less than the value (LEAN_VAL). The value (LEAN_VAL) corresponds to the lower lean limit of the linear operating region of output signal (HEGO_S) of the HEGO sensor **64**. If the value of step **104** is True, indicating a lean-air fuel ratio, the step **106** sets the catalyst state variable (CAT_STATE) equal to the value "1". Next, the step **108** sets the flag (INTEGRATION_ENABLE) equal to the value "**0**" and the method advances to step **124**.

[0052] Referring again to step **104**, if the value of step **104** is False, the method advances to step **110** which determines whether the value (HEGO_VAL) is greater than the value (RICH_VAL). The value (RICH_VAL) corresponds to the upper rich limit of the linear operating region of the output signal (HEGO_S) of the HEGO sensor **64**. If the value of step **110** is True, the step **112** sets the value (CAT_STATE) equal to the value "−1". Next, the step **114** sets the flag (INTEGRATION_ENABLE) equal to the value "0" and the method advances to step **124**.

[0053] Referring again to step **110**, if the value of step **110** is False, the step **116** sets the flag (INTEGRATION_ENABLE) equal to the value "1" and the step **118** calculates the value (CAT_STATE).

[0054] Referring to **FIG. 2**C, the steps **120**, **122** used to implement the step **118** will be explained. At step **120**, the rate of change of the catalyst state (CAT_STATE_DOT) is calculated using the following equation:

$$CAT\_STATE\_DOT=[MAF*(UEGO\_VAL-UEGO\_CORR)]/CAT\_CAPACITY_{I-1}$$

[0055] where:

[0056] MAF corresponds to the mass flow rate into the intake manifold **38**;

[0057] UEGO_VAL corresponds to voltage of the signal (UEGO_S);

[0058] $CAT\_CAPACITY_{I-1}$ corresponds to the oxygen storage capacity range of the catalyst **52**.

[0059] Next at step **122**, the catalyst state value (CAT_STATE) is calculated using the following integration equation:

$$CAT\_STATE=CAT\_STATE\_DOT*\Delta T+CAT\_STATE_{I-1}$$

[0060] where ΔT corresponds to the elapsed time since the last updated calculation of the value (CAT_STATE).

[0061] Referring again to **FIG. 2**A, after any of steps **108**, **114**, **118**, the method advances to step **124** which calculates the catalyst oxygen capacity range (CAT_CAPACITY). Referring to **FIG. 2**D, the steps utilized to implement step **124** will now be discussed.

[0062] At step **126**, a determination as to whether the value (HEGO_VAL) is greater than the value (RICH_VAL). If the value of step **126** is True, the step **128** calculates the value (RICH_CNT) using the following equation:

$$RICH\_CNT=RICH\_CNT_{i-1}+C2$$

[0063] RICH_CNT corresponds to a time weighted count for aggressively decreasing the value (CAT_CAPACITY) when the catalyst **52** is substantially depleted of oxygen for a relatively large period of time;

[0064] C2 corresponds a constant value, such as 4 for example. Alternately, if the value of step **126** is False, the step **130** calculates the value (RICH_CNT) using the following equation:

$$RICH\_CNT=MAX\ [(RICH\_CNT-1),)0]$$

[0065] Thus, the value (RICH_CNT) is equal to the greater of the value RICH_CNT−1 or the value "0".

[0066] After either of steps **128**, **130**, the method advances to step **132** which determines whether the value (HEGO_VAL) is less than the value (LEAN_VAL). If the value of step **132** is True, the step **134** calculates the value (LEAN_CNT) using the following equation:

$$LEAN\_CNT=LEAN\_CNT_{i-1}+C2$$

[0067] LEAN_CNT corresponds to a time weighted count for aggressively decreasing the value (CAT_CAPACITY) when the catalyst **52** is substantially saturated with oxygen for a relatively large period of time;

[0068] C2 corresponds to a constant value, such as 4 for example. Alternately, if the value of step **132** is False, the step **136** calculates the value (LEAN_CNT) using the following equation:

$$LEAN\_CNT=MAX\ [(LEAN\_CNT_{i-1}-1),)0]$$

[0069] Thus, the value (LEAN_CNT) is equal to the greater of the value (LEAN_CNT−1) or the value "0".

[0070] After either of steps **134**, **136**, the method advances to step **138** which makes a determination of whether the value (RICH_CNT) is greater than the value (THRESHOLD1) and whether the value (LEAN_CNT) is greater than the value (THRESHOLD1). If the value of step **138** is True, the step **140** decreases the value (CAT_CAPACITY) using the following equation:

$$CAT\_CAPACITY=CAT\_CAPACITY_{i-1}-C3$$

[0071] After step **140**, the method advances to step **148** which will be discussed in further detail below.

[0072] Referring again to step **138**, if the value of step **138** is False, the step **142** mathematically filters the value (HEGO_VAL) to remove an average DC value, using the following equation:

$$MEAN\_HEGO=((1-FC1)*MEAN\_HEGO_{I-1})*(FC1*HEGO\_VAL))$$

[0073] where FC1 is a filter constant that is empirically determined.

[0074] Next at step **144**, the root-mean square of the value (HEGO_VAL) is calculated using the following equation:

$$HEGO\_VAL\_RMS=(1-FC2)*HEGO\_VAL\_RMS_{i-1}+FC2*\sqrt{(HEGO\_VAL-MEAN\_HEGO)^2}$$

[0075] Next at step **146**, the root-mean square of the value (CAT_STATE) is calculated using the following equation:

$$CAT\_STATE\_RMS=(1-FC2)*CAT\_STATE\_RMS_{i-1}+FC2*\sqrt{(CAT\_STATE)^2}$$

[0076] It should be noted that other equations for measuring the variation of the values (HEGO_VAL) and (CAT_STATE) could have been used, instead of the two foregoing equations. For example, equations utilizing peak-to-peak values, standard deviation of the values, or the average difference between measured and averaged values could be used.

[0077] After either of steps **140**, **146**, the step **148** determines whether the ratio (HEGO_VAL_RMS/CAT_STATE_RMS) is greater than a value (THRESHOLD2). The value (THRESHOLD2) is determined empirically and may have a value of 0.2 for example. If the value of step **148** is True, the step **150** decreases the value (CAT_CAPACITY) using the following equation:

$$CAT\_CAPACITY = CAT\_CAPACITY_{i-1} - C4$$

[0078] where the constant C4 may have a value of 0.1 for example. Alternately, if the value of step **148** is False, the step **152** increases the value (CAT_CAPACITY) using the following equation:

$$CAT\_CAPACITY = CAT\_CAPACITY_{i-1} + C4$$

[0079] After either of steps **150**, **152**, the method advances to step **154** of **FIG. 2A**. At step **154**, the commanded air-fuel value (LAMBSE) is calculated using steps **156-162** of **FIG. 2E**. At step **156**, the value (CAT_STATE_ERROR) is calculated using the following equation:

$$CAT\_STATE\_ERROR = CAT\_STATE - TARGET\_STATE$$

[0080] where the TARGET_STATE corresponds to an oxygen concentration indicative of stoichiometry.

[0081] Next at step **158**, an integration value (INTEG_VAL) is calculated using the following equation:

$$INTEG\_VAL = (KI * \Delta T * CAT\_STATE\_ERROR) + INTEG\_VAL_{I-1}$$

[0082] where KI is a predetermined gain that is empirically determined; ΔT corresponds to the elapsed time since the last updated calculation of the value (INTEG_VAL).

[0083] Next at step **160**, the value (COMMANDED_CAT_STATE) is calculated using the following equation:

$$COMMANDED\_CAT\_STATE = (KP * CAT\_STATE\_ERROR) + INTEG\_VAL$$

[0084] where KP is a predetermined gain that is empirically determined. The foregoing equation comprises a simple proportional/integral equation for calculating the (COMMANDED_CAT_STATE). However, other control equations known to those skilled in the art could be utilized.

[0085] Next at step **162**, the value (LAMBSE) is calculated using the following equation:

$$LAMBSE = \frac{(1 + COMMANDED\_CAT\_STATE) * CAT\_CAPACITY}{MAF}$$

[0086] Referring again to **FIG. 2**A, after step **154**, the method advances back to step **92**.

[0087] The above-described system and method for controlling an engine represent a significant improvement over conventional systems and methods. In particular, the system utilizes greatly simplified oxygen storage algorithms for air-fuel ratio in an engine by maintaining a downstream HEGO sensor within the linear operating region of the HEGO sensor.

We claim:

1. A method for controlling an engine coupled to an emission system, the system having an emission catalyst and a HEGO sensor disposed downstream of at least a portion of the catalyst, the method comprising:

adjusting an air-fuel ratio of said engine to substantially maintain an output signal from said downstream HEGO sensor within a predetermined linear operating range.

2. The method of claim 1 wherein said system includes an UEGO sensor disposed upstream of said catalyst, said adjusting step including:

determining a catalyst state indicative of an amount of oxygen stored in said emission catalyst based on an output signal from said UEGO sensor;

determining a catalyst oxygen capacity range based on said HEGO sensor; and,

generating a commanded air-fuel signal based on said catalyst state and said catalyst oxygen capacity range.

3. A system for controlling an engine coupled to a downstream emission catalyst, comprising:

a HEGO sensor disposed downstream of at least a portion of the catalyst generating a first output signal; and,

a controller receiving said output signal, said controller configured to adjust an air-fuel ratio of the engine to substantially maintain said output signal from said HEGO sensor within a predetermined linear operating range.

4. The system of claim 3 further including an UEGO sensor disposed upstream of said catalyst generating a second output signal, said controller being further configured to determine a catalyst state indicative of an amount of oxygen stored in said emission catalyst based on said second output signal, said controller being further configured to determine a catalyst oxygen capacity range based on said first output signal, said controller configured to further generate a commanded air-fuel signal based on said catalyst state and said catalyst oxygen capacity range.

5. An article of manufacture, comprising:

a computer storage medium having a computer program encoded therein for controlling an engine coupled to an emission system, the system having an emission catalyst an a HEGO sensor disposed downstream of at least a portion of the catalyst generating an output signal, the computer storage medium comprising:

code for adjusting an air-fuel ratio of said engine to substantially maintain an output signal from said downstream HEGO sensor within a predetermined linear operating range.

* * * * *