United States Patent [19]

Endo et al.

[11] **3,895,611**

[45] **July 22, 1975**

[54] **AIR-FUEL RATIO FEEDBACK TYPE FUEL INJECTION SYSTEM**

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Nov. 7, 1972	Japan	47-111750
Nov. 9, 1972	Japan	47-112440

[52] **U.S. Cl.** ..... **123/32 EA**; 60/276

[51] **Int. Cl.** **F02b 3/00**

[58] **Field of Search** ..... 123/32 EA; 235/150.21

[56] **References Cited**

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Primary Examiner—Manuel A. Antonakas
Assistant Examiner—James W. Cranson, Jr.
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

There is provided an air-fuel ratio feedback type fuel injection system of the type in which the fuel quantity is controlled to suit various operating conditions of an engine by a computing unit for generating injection pulses which determine the duration of the opening of electromagnetic valves connected to a fuel line in which the pressure is maintained at a constant value. The system further comprises an oxygen concentration detector for detecting the concentration of oxygen contained in the exhaust gases, an air-fuel ratio discriminating circuit for comparing the detected signal from the oxygen concentration detector with a preset value to make a discrimination, a samplying signal generating circuit for generating a samplying signal having a predetermined frequency to sample the discrimination signals from the air-fuel ratio discriminating circuit, and a feedback system for providing negative feedback to the computing unit to reverse the discrimination signal.

9 Claims, 21 Drawing Figures

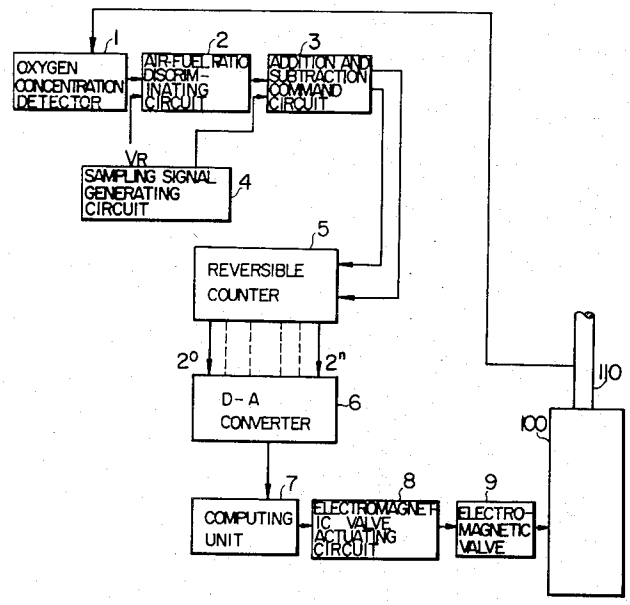


FIG. 1

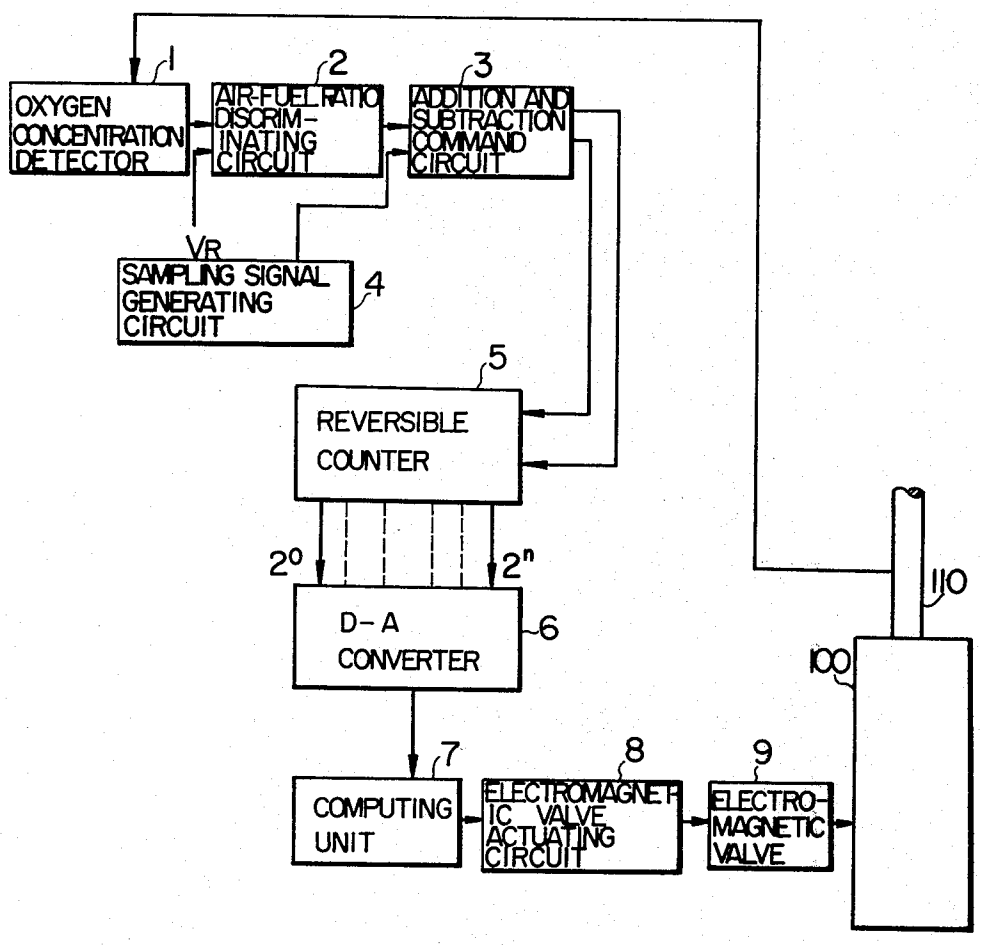

1
OXYGEN CONCENTRATION DETECTOR
2
AIR-FUEL RATIO DISCRIM-INATING CIRCUIT
3
ADDITION AND SUBTRACTION COMMAND CIRCUIT
VR
SAMPLING SIGNAL GENERATING CIRCUIT
4
5
REVERSIBLE COUNTER
2^0
2^n
D-A CONVERTER
6
7
COMPUTING UNIT
8
ELECTROMAGNETIC VALVE ACTUATING CIRCUIT
9
ELECTRO-MAGNETIC VALVE
110
100

FIG.2

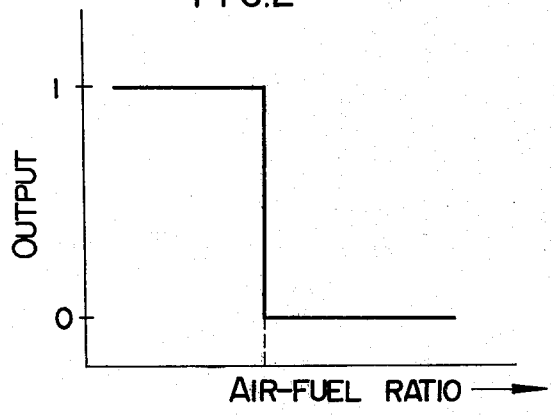

1
0
OUTPUT
AIR-FUEL RATIO

FIG.3

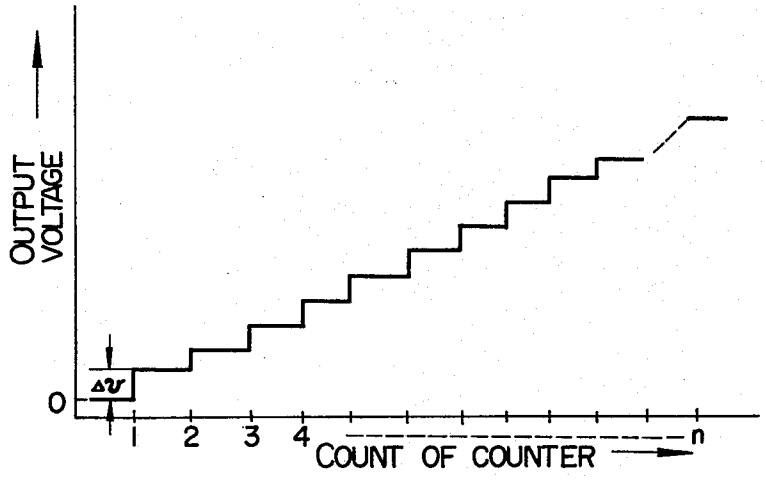

OUTPUT VOLTAGE
0
ΔV
1
2
3
4
n
COUNT OF COUNTER

FIG.4

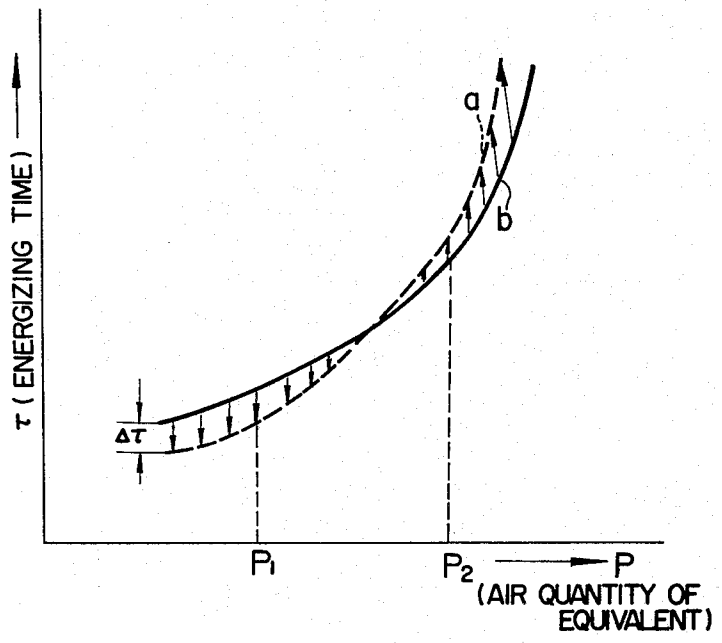

τ (ENERGIZING TIME)
a
b
Δτ
P1
P2
P
(AIR QUANTITY OF EQUIVALENT)

FIG.6

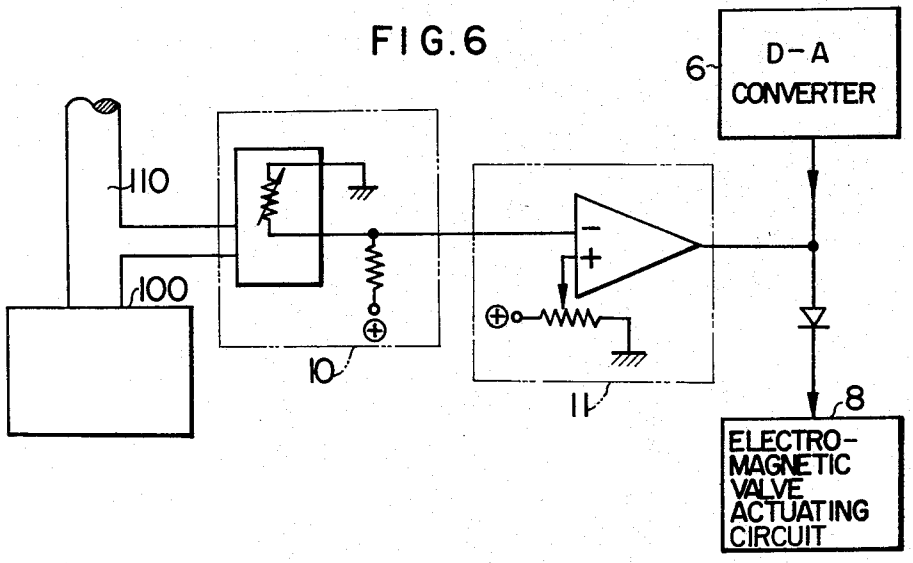

6
D-A CONVERTER
110
100
10
11
8
ELECTRO-MAGNETIC VALVE ACTUATING CIRCUIT

FIG.5

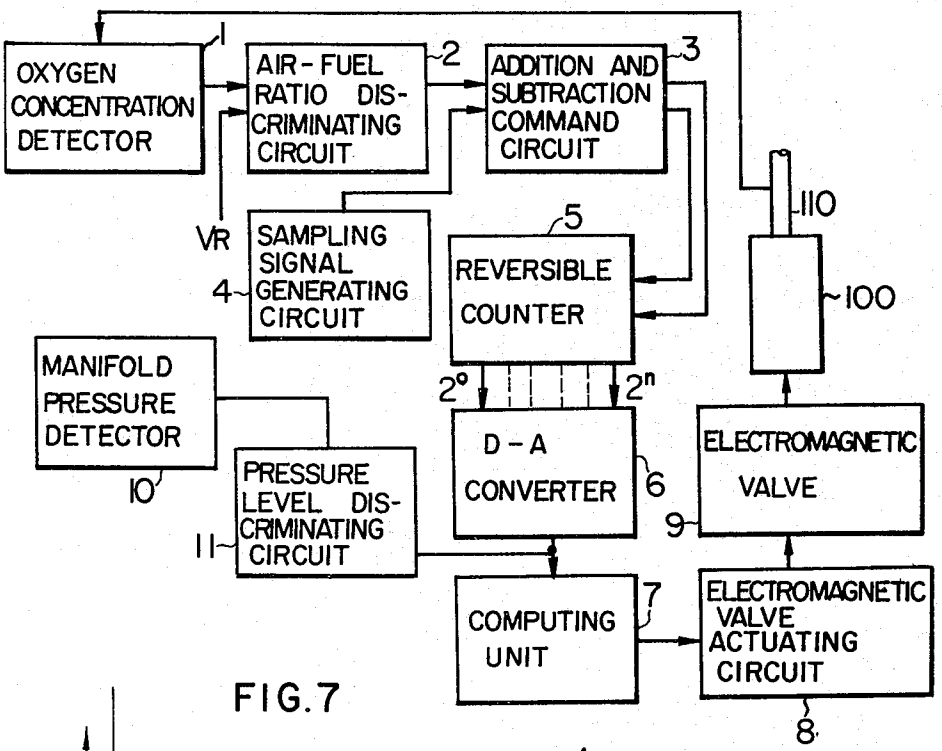

OXYGEN CONCENTRATION DETECTOR
1
AIR-FUEL RATIO DISCRIMINATING CIRCUIT
2
ADDITION AND SUBTRACTION COMMAND CIRCUIT
3
VR
SAMPLING SIGNAL GENERATING CIRCUIT
4
REVERSIBLE COUNTER
5
110
100
MANIFOLD PRESSURE DETECTOR
10
PRESSURE LEVEL DISCRIMINATING CIRCUIT
11
2°
2ⁿ
D-A CONVERTER
6
ELECTROMAGNETIC VALVE
9
COMPUTING UNIT
7
ELECTROMAGNETIC VALVE ACTUATING CIRCUIT
8

FIG.7

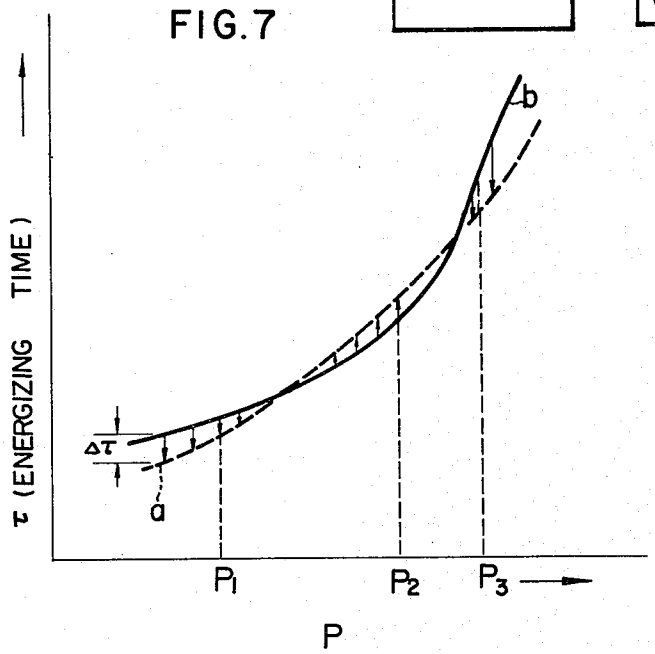

τ (ENERGIZING TIME)
Δτ
a
b
P1
P2
P3
P

FIG.8

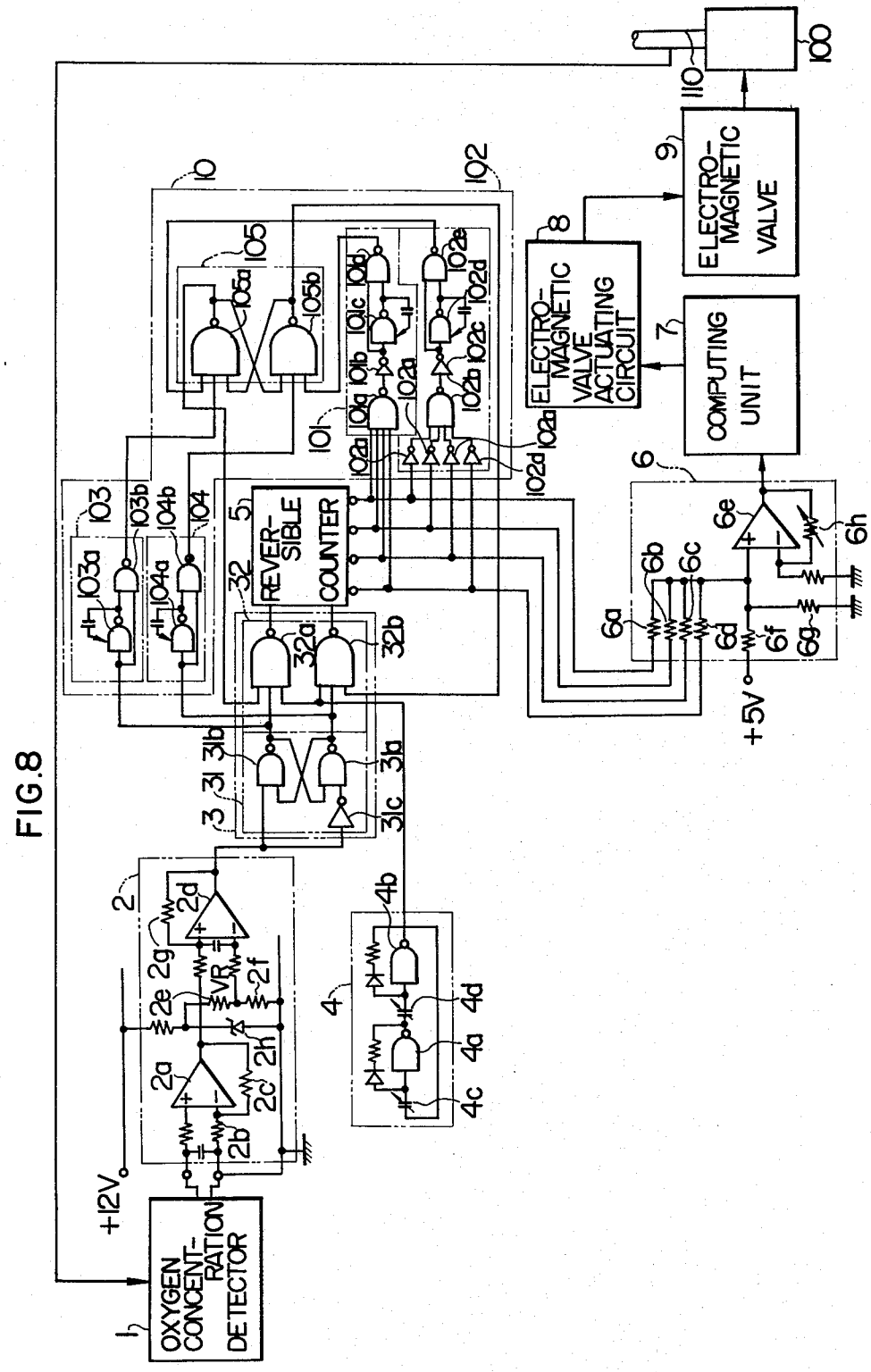

OXYGEN CONCENTRATION DETECTOR
+12V
+5V
REVERSIBLE COUNTER
ELECTRO-MAGNETIC VALVE ACTUATING CIRCUIT
COMPUTING UNIT
ELECTRO-MAGNETIC VALVE

FIG.9

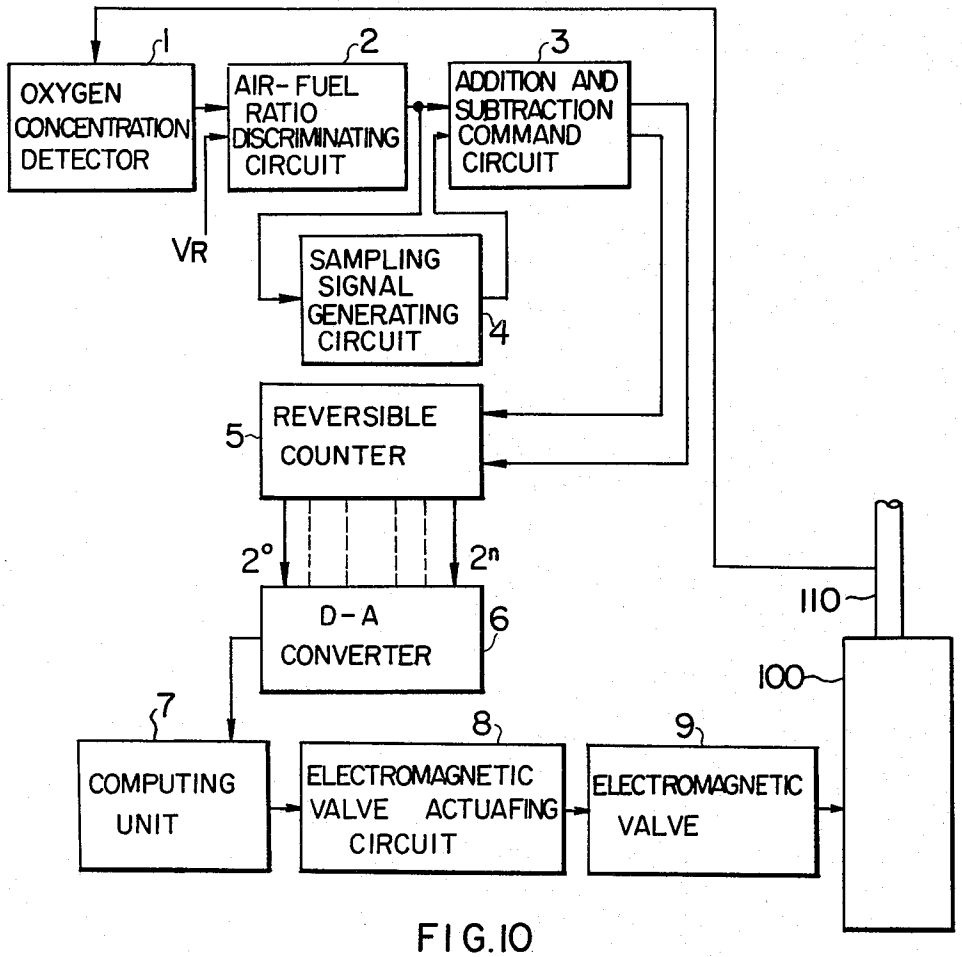

1
2
3
OXYGEN CONCENTRATION DETECTOR
AIR-FUEL RATIO DISCRIMINATING CIRCUIT
ADDITION AND SUBTRACTION COMMAND CIRCUIT
VR
SAMPLING SIGNAL GENERATING CIRCUIT
4
5
REVERSIBLE COUNTER
2°
2ⁿ
D-A CONVERTER
6
110
100
7
8
9
COMPUTING UNIT
ELECTROMAGNETIC VALVE ACTUAFING CIRCUIT
ELECTROMAGNETIC VALVE

FIG.10

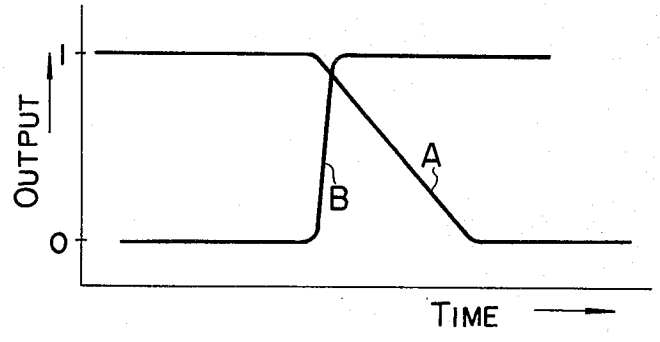

OUTPUT
1
0
A
B
TIME

FIG. 11

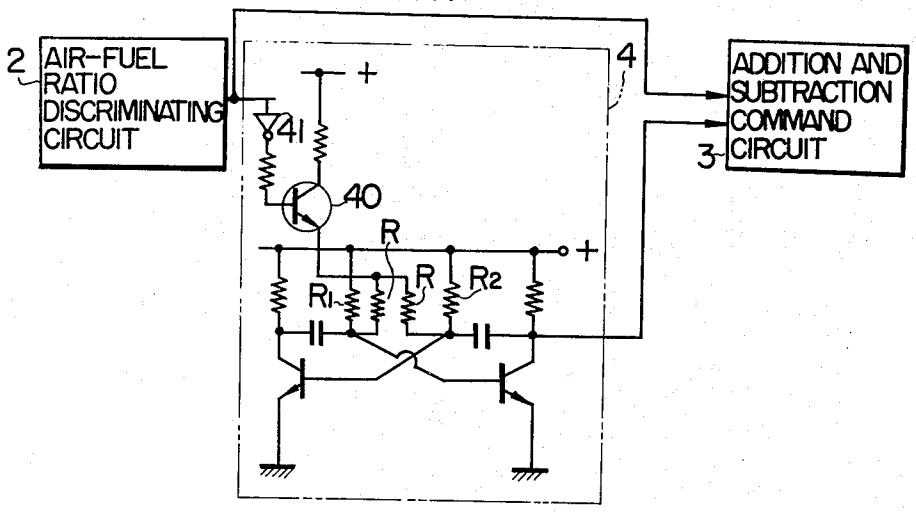

2
AIR-FUEL RATIO DISCRIMINATING CIRCUIT
+
41
40
R
R
R2
R1
4
ADDITION AND SUBTRACTION COMMAND CIRCUIT
3

FIG. 12

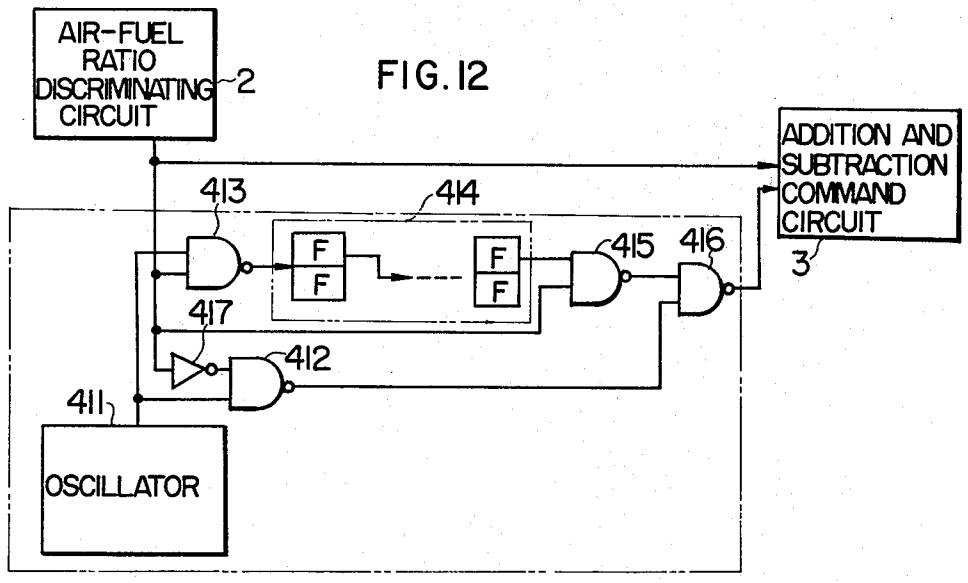

AIR-FUEL RATIO DISCRIMINATING CIRCUIT
2
ADDITION AND SUBTRACTION COMMAND CIRCUIT
3
413
414
F
F
F
F
415
416
417
412
411
OSCILLATOR

FIG.13

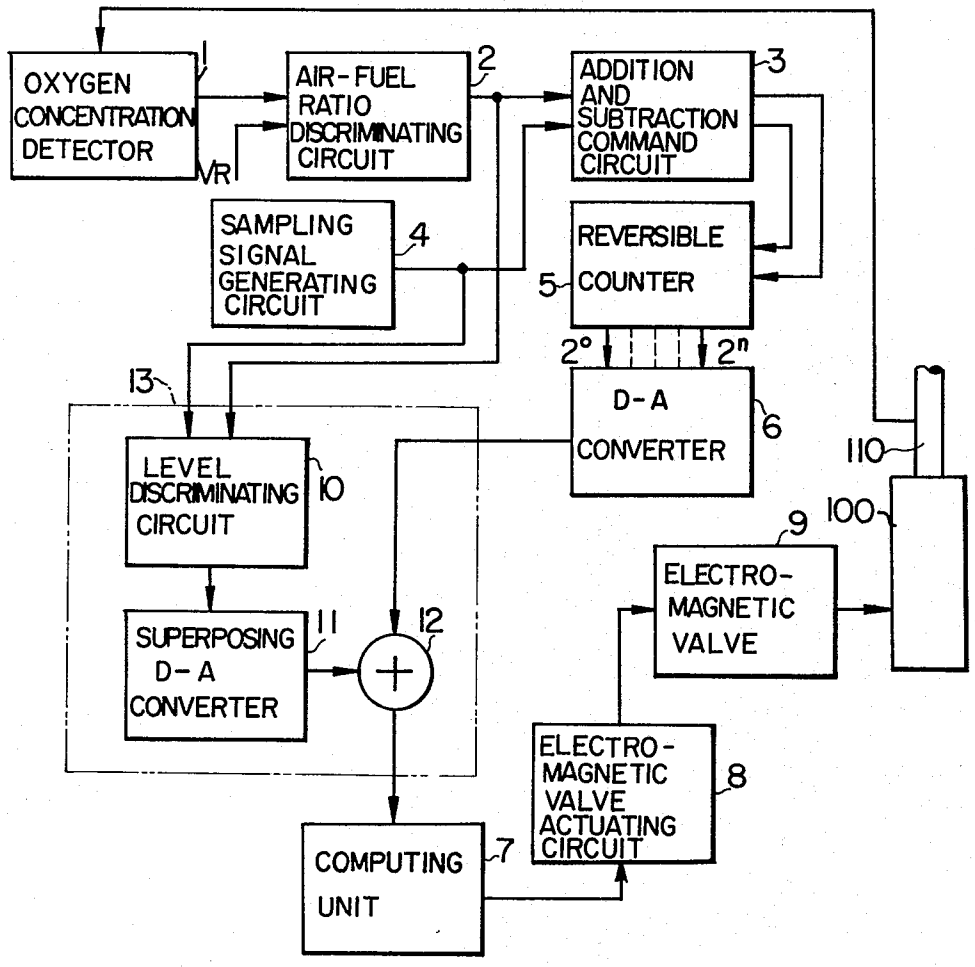

OXYGEN CONCENTRATION DETECTOR
1
VR
AIR-FUEL RATIO DISCRIMINATING CIRCUIT
2
ADDITION AND SUBTRACTION COMMAND CIRCUIT
3
SAMPLING SIGNAL GENERATING CIRCUIT
4
REVERSIBLE COUNTER
5
2°
2ⁿ
D-A CONVERTER
6
13
LEVEL DISCRIMINATING CIRCUIT
10
SUPERPOSING D-A CONVERTER
11
12
110
100
9
ELECTRO-MAGNETIC VALVE
ELECTRO-MAGNETIC VALVE ACTUATING CIRCUIT
8
COMPUTING UNIT
7

FIG.14

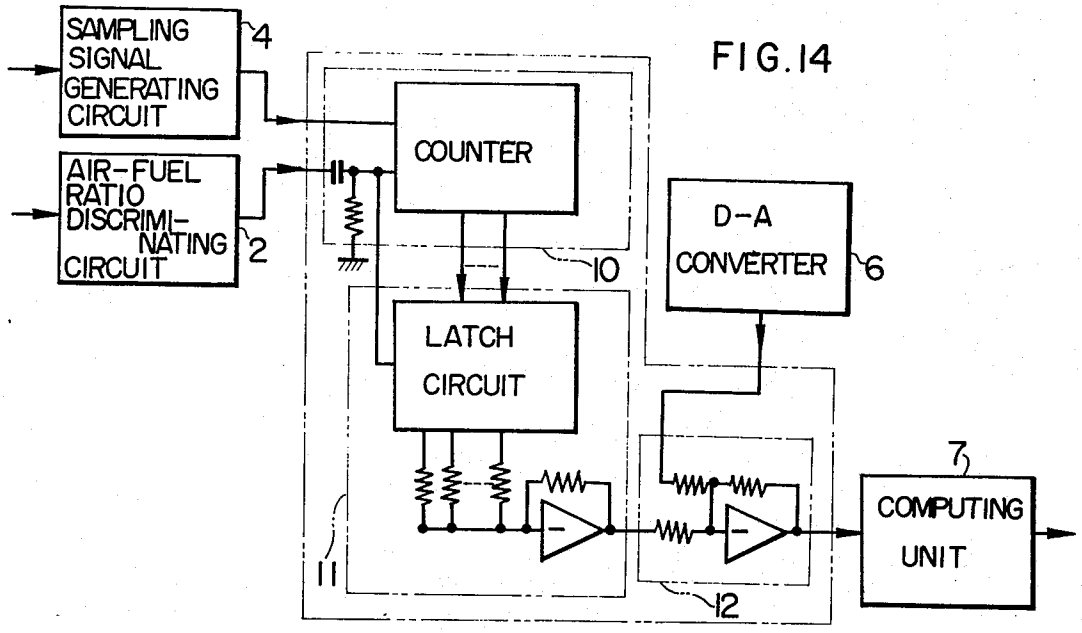

SAMPLING SIGNAL GENERATING CIRCUIT
4
AIR-FUEL RATIO DISCRIMI-NATING CIRCUIT
2
COUNTER
10
D-A CONVERTER
6
LATCH CIRCUIT
11
12
7
COMPUTING UNIT

FIG.15

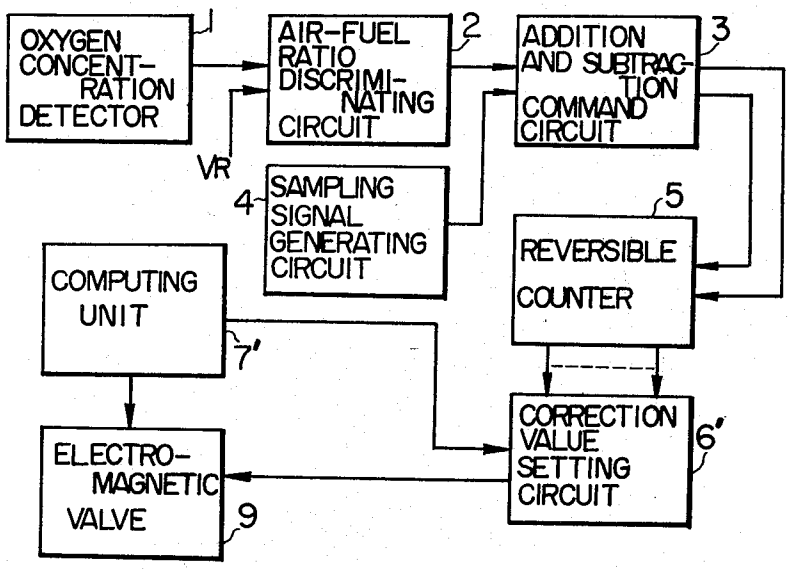

OXYGEN CONCENT-RATION DETECTOR
1
AIR-FUEL RATIO DISCRIMI-NATING CIRCUIT
2
ADDITION AND SUBTRAC-TION COMMAND CIRCUIT
3
VR
4
SAMPLING SIGNAL GENERATING CIRCUIT
5
REVERSIBLE COUNTER
COMPUTING UNIT
7'
CORRECTION VALUE SETTING CIRCUIT
6'
ELECTRO-MAGNETIC VALVE
9

FIG.16

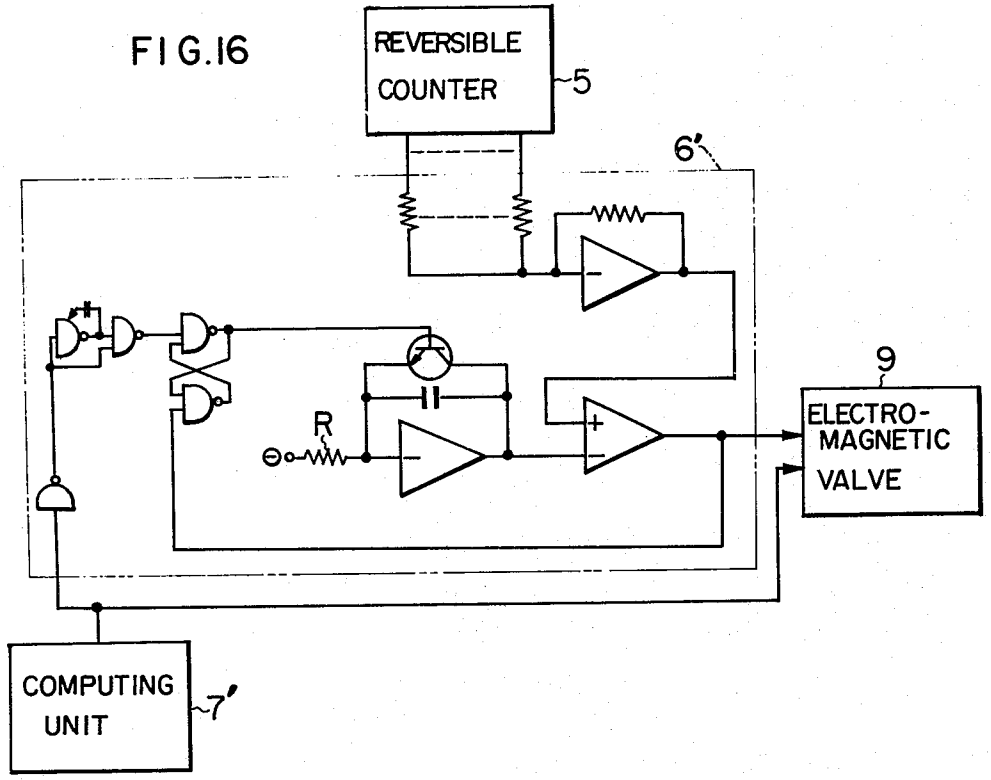


FIG.17

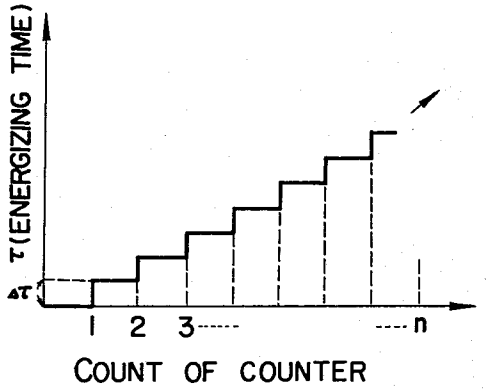


FIG.18

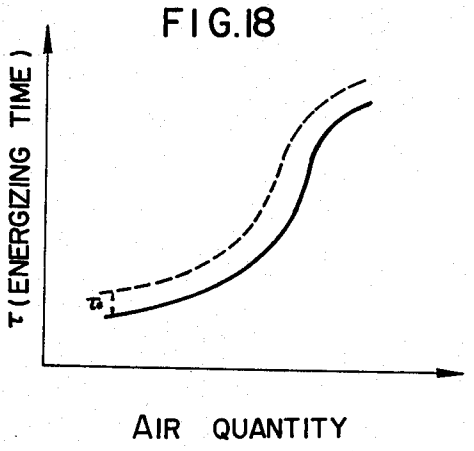


FIG.19

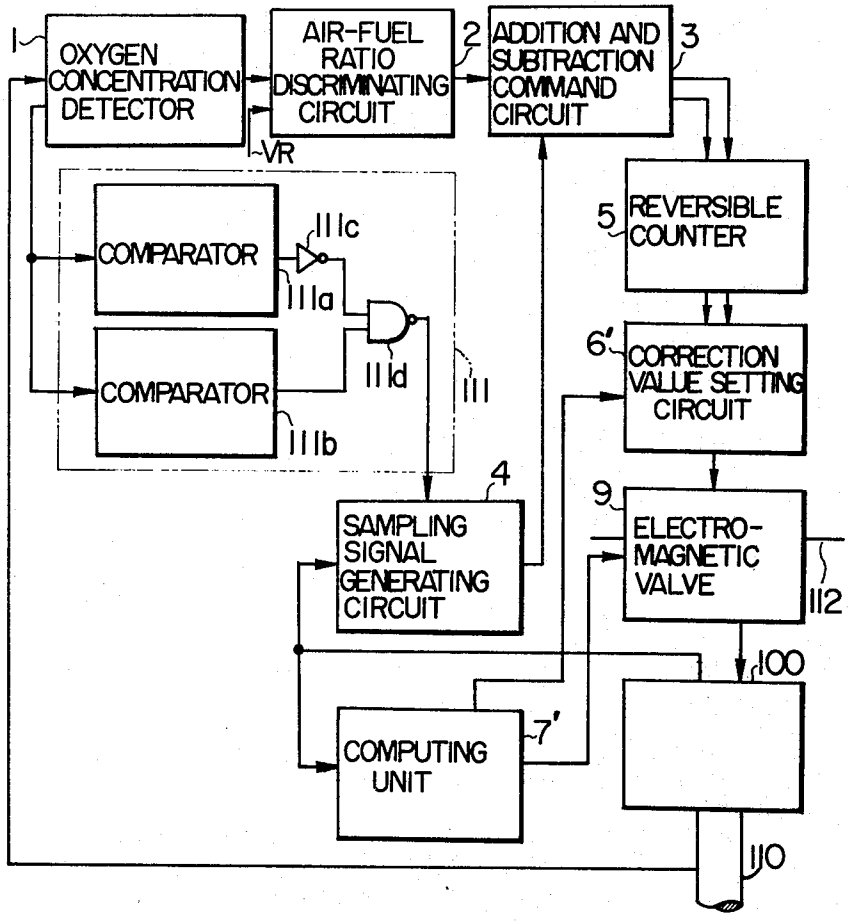

1
OXYGEN CONCENTRATION DETECTOR
AIR-FUEL RATIO DISCRIMINATING CIRCUIT
2
ADDITION AND SUBTRACTION COMMAND CIRCUIT
3
VR
COMPARATOR
111c
111a
COMPARATOR
111d
111b
111
5
REVERSIBLE COUNTER
6'
CORRECTION VALUE SETTING CIRCUIT
4
SAMPLING SIGNAL GENERATING CIRCUIT
9
ELECTRO-MAGNETIC VALVE
112
100
COMPUTING UNIT
7'
110

FIG.20

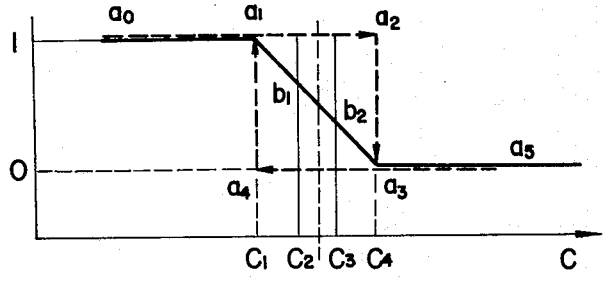
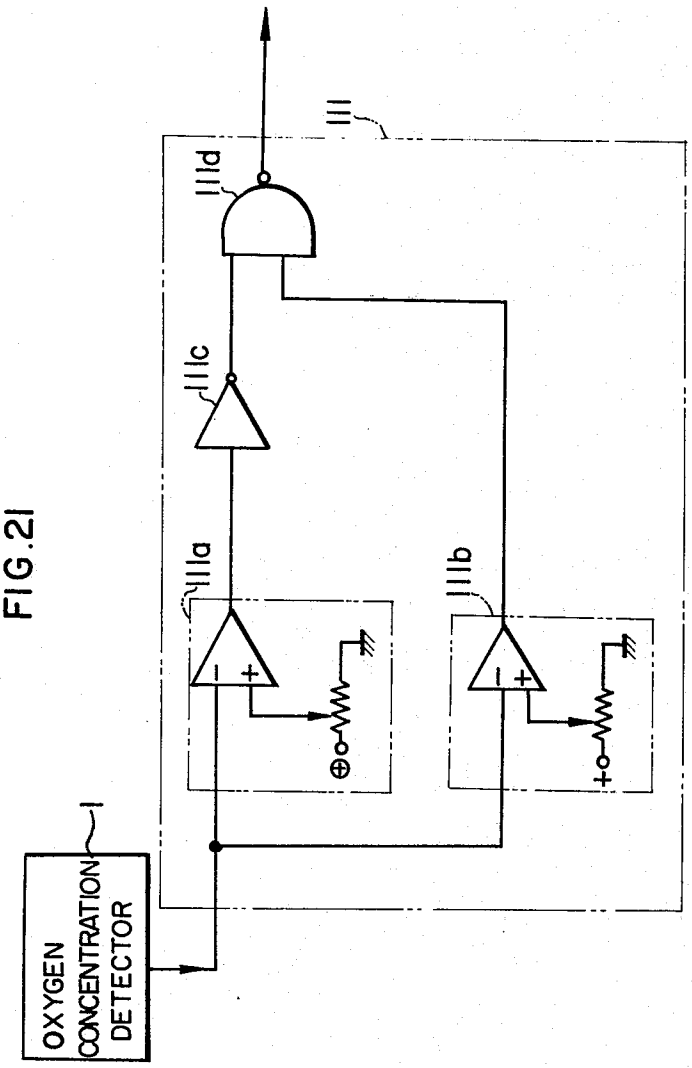

a0
a1
a2
1
b1
b2
a5
0
a4
a3
C1
C2
C3
C4
C

FIG. 21



AIR-FUEL RATIO FEEDBACK TYPE FUEL INJECTION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to fuel injection systems and more particularly to an electric fuel injection system which incorporates an air-fuel ratio feedback control.

2. Description of the Prior Art

Fuel injection systems are known in the art in which the quantity of fuel fed to the engine is controlled by measuring the quantity of air drawn into the engine and programming the fuel quantity predetermined in accordance with the quantity of air in terms of the duration of the energization of electromagnetic valves. A disadvantage of this type of fuel injection system is that even if various engine parameters such as the manifold vacuum and engine temperature are detected to control the fuel quantity, it is extremely difficult to compensate for the ever changing operating conditions of the engine, the variations by different engines and so on so as to always operate the engine with a predetermined air-fuel ratio. The difficulty especially gives rise to a serious problem with an engine equipped for example with a catalytic purifier for purifying the exhaust gases.

SUMMARY OF THE INVENTION

With a view to overcoming the foregoing difficulty, it is an object of the present invention to provide an air-fuel ratio feedback type fuel injection system wherein the concentration of oxygen contained in the exhaust gases is detected so that the duration of the energization of the electromagnetic valves is corrected in accordance with the detected output to operate the engine with a predetermined air-fuel ratio.

It is another object of the present invention to provide such air-fuel ratio feedback type fuel injection system wherein a signal representing the detected oxygen concentration is compared with a reference value for discrimination and the resultant discrimination signal is sampled to cause a reversible counter to perform the operation of addition or subtraction in accordance with the sampled signal and wherein there are included a feedback system for negatively feeding back the count of the reversible counter to a computing unit of the fuel injection system which generates injection pulses for controlling the fuel quantity and a holding circuit whereby the count of the reversible counter greater than its maximum counting capacity is held at the allowable maximum or minimum value, thereby always operating the engine with a predetermined air-fuel ratio and further minimizing possible negative feedback errors due to the limitation by the maximum counting capacity of the reversible counter.

It is still another object of the present invention to provide such air-fuel ratio feedback type fuel injection system wherein when the response speed of the oxygen concentration detector decreases, the frequency of sampling signals for the negative feedback control is decreased to correct the duration of the energization of the electromagnetic valves to ensure a predetermined air-fuel ratio with an improved accuracy.

It is still another object of the present invention to provide such air-fuel ratio feedback type fuel injection system comprising superposing means for superposing

an additional correction signal corresponding to the number of sampling by the sampling signals effected in the time interval up to the reversal of the polarity of the feedback, whereby when a correction value is used which is varied by a predetermined amount for each sampling by the sampling signal or varied according to the load, the correction value is increased as a means of eliminating such inconvenience that the occurrence of a large discrepancy between the reference characteristic and the desired air-fuel ratio characteristic results in a large time delay in attaining a predetermined air-fuel ratio or a stable point for the correction value, whereas such inconvenience which may be caused by the limitation to the response speed of the oxygen concentration detector when the frequency of the sampling signal is increased is also prevented.

It is still another object of the present invention to provide such air-fuel ratio feedback type fuel injection system wherein dead zone detecting means is provided to detect the fact that the output of the oxygen concentration detector has reached the intermediate dead zone between the "D" level and the "1" level and disable the sampling operation, whereby the engine is operated with a predetermined air-fuel ratio and moreover the sampling operation is stopped when the air-fuel ratio comes to the intermediate dead zone about the predetermined value thereof to thereby prevent the occurrence of undesired forward and backward swing of the air-fuel ratio that may be caused when the engine is operated under a constant load.

The fuel injection system according to the present invention has a remarkable advantage in that since it incorporates a feedback control whereby the concentration of oxygen contained in the exhaust gases is detected by an oxygen concentration detector to cause an air-fuel ratio discriminating circuit to determine whether the air-fuel ratio is richer or leaner than a predetermined value and the count of a reversible counter is increased or decreased to obtain a predetermined air-fuel ratio until the air-fuel ratio discriminating circuit makes a different decision, the air-fuel ratio can be controlled with much greater accuracy as compared with conventional electronically controlled fuel injection systems.

Another remarkable advantage of the system of this invention is the use of a D–A converter which produces the necessary correction value in the form of a voltage so that when the present invention is incorporated in a known type of electronically controlled fuel injection system, the correction value can be easily controlled by using it as one of the parameters of an internal combustion engine.

A further remarkable advantage is the fact that since the correction is effected by changing upward and downward the air-fuel ratio characteristic of the electronically controlled fuel injection system installed in an internal combustion engine, such difficulty as heretofore encountered during the starting period can be eliminated and the capacity of the required reversible counter can also be reduced comparatively.

A still further remarkable advantage of the system of this invention is the use of a power range detector for detecting the power range of a load range which requires a large output torque to open and close the feedback system, whereby the air-fuel ratio is normally maintained at a constant value, whereas in the load range requiring a large output torque the air-fuel ratio

is not maintained at a constant value to provide a satisfactory output torque.

A still further remarkable advantage is the use of a holding circuit whereby when the count of the reversible counter exceeds its maximum counting capacity, the count is held at the allowable maximum or minimum value to thereby minimize the occurrence of errors due to the limits to the maximum counting capacity of the reversible counter.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of the present invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a block diagram showing a first embodiment of an air-fuel ratio feedback type fuel injection system.

FIG. **2** is an input-output characteristic diagram of the air-fuel ratio discriminating circuit used in the embodiment of FIG. **1.**

FIG. **3** is an input-output characteristic diagram of the D–A converter used in the embodiment of FIG. **1.**

FIG. **4** is an air-fuel ratio characteristic diagram useful for explaining the operation of the embodiment shown in FIG. **1.**

FIG. **5** is a block diagram showing a second embodiment of the fuel injection system of this invention.

FIG. **6** is an electric wiring diagram shwoing one form of the principal part of the embodiment shown in FIG. **5.**

FIG. **7** is an air-fuel ratio characteristic diagram usefuel for explaining the operation of the embodiment shown in FIG. **5.**

FIG. **8** is an electric wiring diagram showing a third embodiment of the air-fuel ratio feedback type fuel injection system according to the invention.

FIG. **9** is an electric wiring diagram showing a fourth embodiment of the fuel injection system according to the present invention.

FIG. **10** is a time versus output characteristic diagram of the oxygen concentration detector used in the embodiment shown in FIG. **9.**

FIG. **11** and **12** are electric wiring diagrams showing respectively a first and second embodiments of the sampling signal generating circuit used in the embodiment shown in FIG. **9.**

FIG. **13** is a block diagram showing a fifth embodiment of the fuel injection system according to the present invention.

FIG. **14** is an electric wiring diagram showing one form of the principal part of the embodiment shown in FIG. **13.**

FIG. **15** is a block diagram showing a sixth embodiment of the fuel injection system according to the present invention.

FIG. **16** is an electric wiring diagram showing one form of the principal part of the embodiment shown in FIG. **15.**

FIG. **17** is an input-output characteristic diagram of the correction value setting circuit used in the embodiment shown in FIG. **15.**

FIG. **18** is an air content in the exhaust gases versus reference air-fuel ratio characteristic diagram for the embodiment shown in FIG. **15.**

FIG. **19** is a block diagram showing a seventh embodiment of the fuel injection system according to the present invention.

FIG. **20** is an air-fuel ratio versus output characteristic diagram for the oxygen concentration detector and the air-fuel ratio discriminating circuit used in the embodiment of FIG. **18.**

FIG. **21** is an electric wiring diagram showing one form of the principal part of the embodiment shown in FIG. **18.**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described in grater detail with reference to the illustrated embodiments.

Referring first to FIG. **1** showing a first embodiment of the air-fuel ratio feedback type fuel injection system according to the present invention, numeral **1** designates an oxygen concentration detector which comprises a metal oxide such as zirconium dioxide or titanium dioxide and whose output voltage varies in accordance with the concentration of oxygen contained in the exhaust gases from an internal combustion engine. Numeral **2** designates an air-fuel ratio discriminating circuit for comparing the output of the oxygen concentration detector **1** with an air-fuel ratio setting voltage VR to generate a discrimination output signal which is either a "**0**" or "**1**" signal as shown in FIG. **2** depending on whether the detected oxygen concentration of the exhaust gases is greater than or less than a preset oxygen concentration or preset air-fuel ratio. Numeral **3** designates an addition and subtraction command circuit whereby each time a sampling signal arrives, a command signal which is either "**1**" level or "**0**" level is generated to direct the operation of addition or subtraction in accordance with the discrimination signal. Numeral **4** designates a sampling signal generating circuit for generating sampling signals having a preset frequency or synchronized with the revolution of the engine and supplying them to the addition and subtraction command circuit **3.** Numeral **5** designates a reversible counter adapted for operation in response to the command signal from the addition and subtraction command circuit **3** to generate at its output a binary signal representing its count. The reversible counter **5** is designed so that when the count of the reversible counter **5** exceeds its maximum counting capacity, the count is held at the maximum value if the addition is being performed, whereas the count is held at "**0**" if the subtraction is being performed. The output of the reversible counter **5** which is represented by a binary code is applied to a D–A converter **6** representing a binary code of $2^n \sim 2^0$ to generate a stairstep voltage as shown in FIG. **3.** This output voltage is applied to a computing unit **7** of the kind used in a known type of electronically controlled fuel injection system for internal combustion engines and it is used as one of the conventional correction terms or engine parameters to control the pulse width of the injection pulses. Numeral **8** designates an electromagnetic valve actuating circuit for amplifying the injection pulse signals. Numeral **9** designates an electromagnetic valve which is connected to a constant pressure fuel line and whose duration of the opening is controlled by the injection pulses. Numeral **100** designates an engine, **110** an exhaust pipe.

With the construction described above, the operation of the first embodiment will be described. Let it be assumed that in FIG. **4** illustrating an air quantity versus injection time characteristic (hereinafter referred to as

an air-fuel ratio characteristic) of the electronically controlled fuel injection system installed in the engine, a curve *b* shows the actual air-fuel ratio characteristic and a curve *a* represents a preset air-fuel ratio characteristic to be attained. The oxygen concentration detector **1** and the air-fuel ratio discriminating circuit **2** determine whether the actual air-fuel ratio is greater than or less than the preset air-fuel ratio and the reversible counter **5** performs the addition or subtraction in accordance with the predetermined sampling signals. The count of the reversible counter **5** is then applied to the D–A converter **6** to produce a corresponding output voltage and the computing unit **7** calculates a pulse width corresponding to the output voltage of the D–A converter **6** to thereby effect an additive or subtractive correction of the pulse width of the injection pulses to stabilize it at the proper air-fuel ratio. This stable point is such that the correction value is stabilized for example in a range which is approximately corresponding to the count value nx of the reversible counter **5** (e.g., $nx + 1$). However, the amount of change with respect to the air-fuel ratio of unit voltage Δv shown in FIG. **3** may be reduced or the capacity of the reversible counter **5** may be increased so that the correction value is stabilized with the tolerance corresponding to $\pm$ **1** count, and this is settable without giving rise to any practical inconvenience. Further, depending on the operation of the computing unit **7** which converts the unit voltage Δv to a unit correction value $\Delta\tau$, it is possible to preset so that $\Delta v = \Delta\tau$, or alternatively the correction value may be varied according to the engine load if it appears to be more advantageous in consideration of the amount of change of the unit voltage Δv. Assuming now that the operating condition of the engine is at a point P_1 in FIG. **4**, the oxygen concentration detector **1** and the air-fuel ratio discriminating circuit **2** determine that the mixture is too rich and thus generate a discrimination signal. As a result, sampling signals are applied to the reversible counter **5** storing the then current condition and the count is successively deduced. In other words, the count is deduced as many times as there are the applied sampling signals until the output or the discrimination signal of the air-fuel ratio discriminating circuit **2** is eventually reversed, that is the count is successively deduced for example by Δv, $2\cdot\Delta v$, $3\cdot\Delta v$, . . . , $n\cdot\Delta v$ until a predetermined air-fuel ratio is attained.

On the other hand, when the operating condition of the engine moves to a point P_2 shown in FIG. **4**, the oxygen concentration detector **1** and the air-fuel ratio discriminating circuit **2** determine that the air-fuel ratio is less than the desired air-fuel ratio, that is, the mixture is too lean and a corresponding discrimination signal is generated. Consequently, the reversible counter **5** storing the then current condition increases its count as many times as there are the sampling signals applied thereto until the output or the discrimination signal of the air-fuel ratio discriminating circuit **2** is reversed, that is, the reversible counter **5** repeats its operation so that its count is successively increased as by Δv, $2\cdot\Delta v$, $3\cdot\Delta v$, . . . , $n\cdot\Delta v$ until a predetermined air-fuel ratio is attained. Further, the pulse width of the injection pulse signals is corrected upon each injection by a value corresponding to the then current $nx\cdot\Delta v$ to provide the proper injection pulse signals.

Repetition of the above-described process enables the engine to operate with a predetermined air-fuel ratio over the entire operating range thereof.

FIG. **5** shows a second embodiment of the present invention which differs from the first embodiment of FIG. **1** in that a power range detector comprising a manifold pressure detector **10** and a pressure level discriminating circuit **11** as shown in FIG. **6** is added to detect the power range or the load range as in the first embodiment of FIG. **1**. In this power range, therefore, the negative feedback for maintaining the air-fuel ratio of for example **14.8** is interrupted to achieve a considerable increase in the output torque of the engine. In other words, the pressure level discriminating circuit **11** determines whether the output of the manifold pressure detector **10** is higher than a preset pressure so that the D–A converter **6** and the computing unit **7** are switched on or off in accordance with the output signal of the pressure level discriminating circuit **11**. When the D–A converter **6** and the computing unit **7** are switched off, the negative feedback is interrupted. Consequently, as shown in the air-fuel ratio characteristic diagram of FIG. **7**, the engine is operated along the characteristic curve *a* up to point P_3, whereas after the point P_3 the negative feedback is interrupted and the engine is operated along the characteristic curve *b* with an air-fuel ratio of for example **1.3** to **1.35**. In this case, the manifold pressure detector **10** is of the type which is necessarily provided in any known type of electronically controlled fuel injection system and therefore it needs not be additionally provided and the conventional pressure indicator may concurrently be used as the manifold pressure detector **10** of this invention. Further, since the detection of the power range, i.e., the comparison of the manifold pressure with the preset pressure by the pressure level discriminating circuit **11** requires as a matter of fact the detection of the differential pressure between the manifold pressure and the atmospheric pressure, good results may also be obtained, if a pressure switch which is turned on or off when the differential pressure between the manifold pressure and the atmospheric pressure is higher than a predetermined pressure is used and the signals of the D–A converter **6** and the computing unit **7** are switched on or off in accordance with the output of the pressure switch to switch on and off the negative feedback. Further, the position of a baffle plate placed within the intake manifold to detect the amount of air flow may also be detected to thereby similarly effect the required on-off control of the negative feedback.

The circuit construction and operation of a third embodiment of the air-fuel ratio feedback type fuel injection system according to the present invention will be described in detail with reference to the detailed circuit diagram shown in FIG. **8**. The third embodiment differs from the first embodiment of FIG. **1** in that it further comprises a holding circuit **12**. In FIG. **8**, numeral **2***a* designates a buffer amplifier whereby the output voltage of the oxygen concentration detector **1** is amplified according to the value of ratio R_{2c}/R_{2b} between resistance values R_{2b} and R_{2c} of an input resistor **2***b* and a feedback resistor **2***c* and delivered to a comparator **2***d*. In the comparator **2***d*, the output of the amplifier **2***a* is compared with the reference voltage VR obtained by dividing the potential determined by a Zener diode **2***h* with resistors **2***e* and **2***f*, so that a "**1**" signal is generated when the output of the amplifier **2***a* is higher than

the reference voltage, whereas a "0" signal is generated when the former is lower than the latter. In other words, it is arranged so that the output of the comparator 2*d* is a "0" signal when the air-fuel ratio is greater than a predetermined value, whereas the comparator 2*d* generates a "1" signal when the air-fuel ratio is lower than the predetermined value. Further, the comparator 2*d* is provided with a resistor 2*g* which provides a suitable hysteresis to prevent any misoperation of the output of the comparator 2*d* (at a speed higher than the response speed) which may be caused by for example the presence of ripple components in the output signal of the oxygen concentration detector **1**. The output of the air-fuel ratio discriminating circuit **2**, i.e., the output of the comparator 2*d* is applied to the addition and subtraction command circuit **3**. The addition and subtraction command circuit **3** comprises a flip-flop **31** and a gating circuit **32**. In operation, a "1" signal appears at the output of one NAND gate **31***a* of the flip-flop **31** when there is a "1" signal at the output of the comparator 2*d*, whereas a "1" signal appears at the output of the other NAND gate **31***b* when there is a "0" signal at the output of the comparator 2*d*. Numeral **31***c* designates an inverter for inverting the output of the comparator 2*d* and supplying it to the NAND gate **31***a*. In this way, a different input signal is always applied to the flip-flop **31** comprising the NAND gates **31***a* and **31***b*. The gating circuit **32** comprises two three-input NAND gates **32***a* and **32***b*, whereby the sampling signals from the sampling signal generating circuit **4** are added or subtracted depending on the command signal from the addition and subtraction command circuit **3**.

The holding circuit **12** for the reversible counter **5** operates so that when the count of the reversible counter **5** is held at the maximum value when the count during the addition exceeds the maximum counting capacity, whereas the count is held at zero when the count exceeds the counting capacity during the subtraction, thereby preventing the application of further sampling signals from changing the count of the reversible counter **5** and thus minimizing the occurrence of errors due to the limitation to the capacity of the counter **5**. A maximum count detecting circuit **101** comparises a NAND gate **101***a*, an inverter **101***b*, a NAND gate **101***c* with an expander and a NAND gate **101***d* and generates pulse signals in such a manner that the output of the NAND gate **101***d* has a "0" signal only at the moment when all the outputs of the reversible counter **5** have a "1" signal. In other circumstances, a "1" signal appears at the output of the NAND gate **101***d*. The NAND gate **101***a* and the inverter **101***b* may be replaced with an AND gate. On the other hand, a zero detecting circuit **102** comprising four inverters **102***a*, a NAND gate **102***b*, an inverter **102***c*, a NAND gate **102***d* with an expander and a NAND gate **102***e* generates pulse signals in such a manner that a "0" signal appears at the output of the NAND gate **102***e* only at the moment when all the outputs of the reversible counter **5** have a "0" signal. Otherwise, a "1" signal appears at the output of the NAND gate **102***e*. A timing pulse generating circuit **103** comprising a NAND gate **103***a* with an expander and a NAND gate **103***b* generates timing pulse signals in such a manner that a "0" signal appears at the output of the NAND gate **103***b* at the moment when the output signal of the NAND gate **31***b* in the addition and subtraction command circuit **3** changes from "0" to "1." Otherwise, a "1" signal normally appears at the output of the NAND gate **103***b*. In the like manner, a timing pulse generating circuit **104** comprising a NAND gate **104***a* with an expander and a NAND gate **104***b* generates timing pulse signals so that a "0" signal appears at the output of the NAND gate **104***b* only at the moment when the signal at the NAND gate **31***a* changes from "0" to "1." In other circumstances, a "1" signal normally appears at the output of the NAND gate **104***b*. A flip-flop **105** comprising NAND gates **105***a* and **105***b* is operated by the command signal or the output of the addition and subtraction command circuit **3**. In other words, in response to the timing signals from the NAND gates **103***b* and **104***b*, a "1" signal appears at the output of the NAND gate **105***a* for the operation of addition, whereas a "1" signal appears at the output of the NAND gate **105***b* for the operation of subtraction. When the count of the reversible counter **5** reaches its maximum counting capacity so that all the output have a "1" signal, the flip-flop **105** is reset by the NAND gate **101***d* with the result that the output of the NAND gate **105***a* has a "0" signal and the output of the NAND gate **105***b* has a "1" signal. The output signal of the NAND gate **105***a* is applied to the NAND gate **32***a* and thus a "1" signal continuously appears at the output of the NAND gate **32***a*. Consequently, no sampling signal is applied to the reversible counter **5** and its count is maintained at the maximum value. Similarly, in the case of the subtraction, when all the outputs of the reversible counter **5** have a "0" signal, the flip-flop **105** is reset by the NAND gate **102***e* so that a "1" signal appears at the output of the NAND gate **105***a* and a "0" signal appears at the output of the NAND gate **105***b*. The output signal of the NAND gate **105***b* is applied to the NAND gate **32***b* and thus a "1" signal is continuously produced at the output of the NAND gate **32***b*. As a result, no sampling signal is applied to the reversible counter **5** to maintain its count at zero.

The count of the reversible counter **5** obtained in the above-described manner is applied to the D–A converter **6** where it is subjected to digital to analog convertion by means of resistors **6***a*, **6***b*, **6***c* and **6***d* and a summing amplifier **6***e*. Therefore, the output count of the reversible counter **5** is converted to obtain the stair-step output V*n* shown in FIG. **3** which corresponds to the output count of the reversible counter **5**. In this case, the output of the reversible counter **5** is represented in the **8421** code and thus the resistors having the corresponding resistance values are provided. In other words, the resistor **6***a* having a resistance value R is connected to the output of the reversible counter **5** representing the of "**8**," the weighted resistor **6b** having a resistance value **2R** is connected to the output representing "**4**," the resistor **6***c* having a resistance value **4R** is connected to the output representing "**2**" and the resistor **6***d* having a resistance value **8R** is connected to the output representing "**1**." Further, dividing resistors **6***f* and **6***g* are provided so that when the operation of the summing amplifier **6***e* is to be started at a potential other than a zero potential, a suitably divided potential by the dividing resistors **6***f* and **6***g* is applied to the non-inverting input of the summing amplifier **6***e*. Therefore, if the operation of the summing amplifier **6***e* needs not be started at the zero potential (from the standpoint of the operation of the computing section), the dividing resistors **6***f* and **6***g* may be eliminated. A feedback resistor **6***h* is provided to maintain the unit voltage Δv

shown in FIG. 3 at a predetermined value. The output signal of the summing amplifier 6*e* is suitably corrected and converted into injection pulses by the computing unit 7 of the kind used in a known type of electronically controlled fuel injection system and the injection pulses are used to actuate the electromagnetic valuve 9 through the electromagnetic valve actuating circuit 8. The sampling signal generating circuit 4 comprising two NAND gates 4a and 4b generates sampling signals of a predetermined frequency by suitably selecting capacitances C_1 and C_2 of capacitors 4*c* and 4*d*.

Next, the fourth embodiment of the present invention shown in FIG. 9 will be described. The fourth embodiment differs from the first embodiment of FIG. 1 in that when the response speed of the oxygen concentration detector 1 decreases, the frequency of the sampling signals for negative feedback control is decreased to correct the duration of the energization of the electromagnetic valve 9 and thereby to control the air-fuel ratio with improved accuracy. For this purpose, the frequency of the sampling signals from the sampling signal generating circuit 4 is changed in accordance with the discrimination output signal from the air-fuel ratio discriminating circuit 2. This constitutes the only difference of the fourth embodiment from the first embodiment of FIG. 1. The response speed of the oxygen concentration detector 1 mounted in the exhaust pipe 110 of the internal combustion engine 100 has a gradually falling characteristic as shown by the characteristic curve A in FIG. 10 when the air-fuel ratio becomes greater than a predetermined air-fuel ratio so that a transition occurs from the direction of the signal indicative of "rich" mixture to the direction of the signal indicative of "lean" mixture, while in the reverse situation it has an abruptly rising characteristic as shown by the characteristic curve B in FIG. 10. In other words, it is believed that the transition from the "rich" mixture state to the "lean" mixture state is caused by the fact that the deposited fuel and the like on the wall of the inlet manifold are drawn into the engine 100 along with the injected fuel.

Accordingly, the output signal of the air-fuel ratio discriminating circuit 2 is introduced into the sampling signal generating circuit 4 as shown in FIG. 9, whereby when the output signal or discrimination signal is a "1" signal, the sampling period is decreased to reduce the frequency of the sampling signals as compared with the case when the discrimination signal is a "0" signal. FIG. 11 shows one form of the arrangement for varying the oscillation frequency of such sampling signal generating circuit 4 comprising a known type of astable multivibrator. The construction and operation of this sampling signal generating circuit 4 are as follows. When the discrimination output signal of the air-fuel ratio discriminating circuit 2 is a "0" signal, it is inverted by an inverter 41 so that a transistor 40 is turned on and parallel resistors R are connected to resistors R_1 and R_2 to increase the oscillation frequency. In other words, the oscillation period is reduced. In this case, the resistance value of the resistors R is suitably selected to obtain a proper value for the oscillation frequency. On the other hand, when the discrimination output signal of the air-fuel ratio discriminating circuit 2 changes to "1" signal, the transistor 40 turned off to decrease the oscillation frequency.

FIG. 12 shows another arrangement wherein the sampling signal generating circuit 4 has a fixed frequency of oscillation, whereby when the discrimination output signal of the air-fuel ratio discriminating circuit 2 is a "0" signal, said oscillation frequency is used as the frequency of the sampling signals, whereas when the discrimination output signal is a "1" signal, an oscillation frequency which is $1/n$ of the fixed oscillation frequency is used as the oscillation frequency of the sampling signals. The construction and operation of this sampling signal generating circuit 4 are as follows. When the discrimination output signal is a "0" signal, the output signal of an oscillator 411 is directly supplied through a NAND gate 412 and a NAND gate 416 and its frequency as such is used as the frequency of the sampling signals. In this case, the output of a NAND gate 415 always has a "1" signal.

On the other hand, when the discriminator output signal is a "1" signal, one input to the NAND gate 412 is applied through an inverter 417 and thus it is alway a "0" signal causing the NAND gate 412 to continuously produce a "1" signal. The discrimination output signal is passed through a NAND gate 413 and it is subjected to frequency division by a factor of *n* by a scale-of-*n* counter 414 from which the signal is passed through the NAND gate 415 and further through the NAND gate 416. In this way, a frequency which is one *n*-th of that of an oscillator 411 is used as the frequency of the sampling signals. In this case, the NAND gate 415 serves to maintain a "1" signal at the output of the NAND gate 415 irrespective of the state of the flip-flop at the output stage of the scale-of-*n* counter 414 when the discrimination output signal is passed through the NAND gate 412.

Next, the fifth embodiment of the present invention shown in FIG. 13 will be described. This embodiment differs from the previously described embodiments in that it further comprises superposing means whereby an additional correction signal corresponding to the number of sampling by the sampling signals in the time period up to the reversal of the polarity of the feedback is superposed on the negative feedback system provided by the detection of the concentration of oxygen contained in the exhaust gases. In this way, where a correction value is used which is varied by a predetermined amount for each sampling by the sampling signals or in accordance with the load, such correction value is increased as a means of eliminating such inconvenience that the occurrence of a large discrepancy between the reference characteristic and the desired air-fuel ratio characteristic results in a large time delay in attaining a predetermined air-fuel ratio or a stable point for the correction value. Moreover, it is possible to prevent such inconvenience which may be caused by the limitation to the response speed of the oxygen concentration detector when the frequency of sampling signals is increased.

In FIG. 13, numeral 13 designates a superposing D–A converter for generating an output voltage proportional to the number of sampling which is dependent on the determination of a level discriminating circuit 11. Numeral 14 designates an adder for producing the sum of the output voltage of the D–A converter 6 and the output voltage of the superposing D–A converter 13, whereby the resultant sum signal is applied to the computing unit 7 of the kind used in a known type of electronically controlled fuel injection system for internal combustion engines and it is used as one of the conventional correction terms, i.e., as one of the engine pa-

rameters to control the pulse width of the injection pulses produced by the computing unit 7 and thereby to open the electromagnetic valve 9 connected to the electromagnetic valve actuating circuit 8 in accordance with the injection pulses. The level discriminating circuit 11, the superposing D–A converter 13 and the adder 14 constitute superposing means 15 whose detailed circuit diagram is illustrated in FIG. 14. In FIG. 14, the same reference numerals as used in the first embodiment of FIG. 1 designate the identical or like component parts.

With the construction described above, the operation of the fifth embodiment is as follows.

In the same manner as described with reference to the first embodiment of FIG. 1, the D–A converter 6 generates the required output signal. On the other hand, the level discriminating circuit 11 determines the number of the sampling signals generated in the time period up to the reversal of the discrimination output signal of the air-fuel ratio discrimination circuit 2, i.e., in the time period during which the discrimination output signal remained at the same level. In response to the thus determined number of sampling, the superposing D–A converter 11 produces a superposing output voltage corresponding to the determined sampling number. To superpose this superposing output voltage on the output voltage of the D–A converter 6, the two voltages are added together in the adder 14. Consequently, the computing unit 7 calculates a pulse width corresponding to the superposed output voltage of the adder 14 and effects an additive or subtractive correction on the pulse width of the injection pulses to stabilize it at a value corresponding to a predetermined air-fuel ratio. In this case, the addition by the superposing means 15 may include not only simple additions, but also such additions as including constant multiples depending on the engine which is to be controlled.

The system according to the fifth embodiment has a remarkable advantage in that by virtue of the operation of the superposing means, the stable point can be reached quickly even in a region where there is a large discrepancy between the fundamental characteristic of the system installed in the engine and a predetermined air-fuel ratio characteristic and moreover the range of the stable region is narrow and the control can be effected with extremely high accuracy.

Referring now to FIG. 15, a sixth embodiment of the system according to this invention will be described. The sixth embodiment differs from the previously described first to fifth embodiments in that while, in the latter, the D–A converter 6 converts the output of the reversible counter 5 into a stairstep output voltage as shown in FIG. 3, a correction value setting circuit 6′ of the sixth embodiment converts the output of the reversible counter 5 into a stairstep valve energization time or injection time duration as shown in FIG. 17.

In the sixth embodiment of FIG. 15, the correction value setting circuit 6′ generates correction pulses which correct the injection time by the rate of unit correction value $\Delta\tau$ per each count in accordance with the output of the reversible counter 5 as shown in FIG. 17 (if necessary, this correction value may be varied in accordance with the load of the engine). In this way, the injection time according to the reference air-fuel ratio characteristic shown by the solid line in FIG. 18 is varied. The reference injection time is varied in accordance with the adjustment of a reference correction value τC and the electromagnetic valves are opened during the thus modified injection time. Numeral 7′ designates a computing unit by which injection pulses having a time width corresponding to engine parameters such as the manifold vacuum and engine temperature are generated and the correction value setting circuit 6′ generates correction pulses in synchronism with the termination of the injection pulses to extend the duration of the opening of the electromagnetic valves by the injection pulses.

With the construction described above, the operation of the sixth embodiment is as follows. The reference air-fuel ratio characteristic is predetermined to provide a lean mixture in all the load ranges and the reference correction value τC which is a multiple of the unit correction value $\Delta\tau$ is added to ensure a mixture of approximately the predetermined air-fuel ratio. When the engine is started, the reversible counter 5 is first set to the maximum count. The reason for setting the reversible counter 5 to the maximum count is that the supply of a relatively rich mixture is required until the warming up of the engine is over and thereafter the oxygen concentration detector 1, the air-fuel ratio discriminating circuit 2 and the addition and subtraction command circuit 3 cause the reversible counter 5 to count in a direction which performs the subtraction. Consequently, the correction value τC is gradually reduced so that if the count corresponding to the predetermined air-fuel ratio is designated as nx, the correction value is stabilized within a range on either side of the count nx ($nx \pm 1$). By decreasing the amount of change of the unit correction value $\Delta\tau$ with the air-fuel ratio or alternately by increasing the capacity of the reversible counter 5, the stabilization of the correction value with the tolerance of ± 1 count can be made without giving rise to any practical inconvenience and a highly accurate control can be ensured. Further, when the operating conditions of the engine change so that the time width of the correction pulses is to be varied in a direction which increases the reference correction value τC, the first sampling causes the oxygen concentration detector 1, the air-fuel ratio discriminating circuit 2 and the addition and subtraction command circuit 3 to operate in a dirction which enriches the air-fuel ratio and consequently the correction pulses having a time width $\tau C + \Delta\tau$ are supplied from the correction value setting circuit 6′ to the electromagnetic valve 9. Further, when the air-fuel ratio discriminating circuit 2 determines as the result of the second sampling that the quantity of fuel is insufficient, the correction value setting circuit 6′ is caused to generate the correction pulses having a time width $\tau C + 2\Delta\tau$. When the further sampling indicates that the amounts of the previously made corrections are still inadequate, the correction pulses having a time width $\tau C + 3\Delta\tau$ are supplied to the electromagnetic valve 9 from the correction value setting circuit 6′ and thus the correction by the air-fuel ratio feedback is stabilized at the point of $\tau C + n\Delta\tau \pm \Delta\tau$. Further change in the operating conditions of the engine also causes the subtractive operation to take place and thus the correction value is stabilized at the point of $\tau C - n\Delta\tau \pm \Delta\tau$.

As described hereinbefore, the result of the determination of the air-fuel ratio by the preceeding sampling is stored in the reversible counter 5 so that the addition or subtraction of the unit correction value $\Delta\tau$ is effected depending on the result of the succeeding sampling and in this way a predetermined air-fuel ratio can

be maintained over the entire operating ranges of the engine.

FIG. **19** shows a seventh embodiment of the system according to the present invention. This seventh embodiment differs from the sixth embodiment of FIG. **15** in that it further comprises a dead zone detecting circuit **111.** In this embodiment, the air-fuel ratio discriminating circuit **2** compares the output of the oxygen concentration detector **1** with the setting voltage VR for setting the air-fuel ratio c and it has a hysteresis characteristic as shown by the broken line in FIG. **20** depending on whether the concentration of oxygen contained in the exhaust gases is greater than or less than the preset oxygen concentration corresponding to the preset air-fuel ratio to thereby generate a discrimination output signal which is either a "**0**" or "**1**" level. The dead zone detecting circuit **111** provides a means for detecting the dead zone and it detects the fact that the output voltage of the oxygen concentration detector **1** has reached the level of the intermediate dead zone between the "**0**" level and the "**1**" level and prevents the generation of the sampling signals. FIG. **21** shows a detailed circuit diagram of the dead zone detecting circuit **111.** In FIG. **21,** numeral **111**a designates a lower limit comparator for detecting the lower limit of the intermediate dead zone, **111***b* an upper limit comparator for detecting the upper limit of the intermediate dead zone, **111***c* an inverter, **111***d* a NAND gate, **112** a constant pressure fuel line.

With the construction described above, the operation of the seventh embodiment is as follows. Assuming now that the air-fuel ratio c is lower than the value at point c_1 in FIG. **20** and the output of the air-fuel ratio discriminating circuit **2** is at the "**1**" level, the addition and subtraction command circuit **3** generates a command signal for addition each time the sampling signal is applied to the addition and subtraction command circuit **3.** Consequently, the reversible counter **5** comes into operation in accordance with the count stored therein as the result of the preceeding sampling and the time width of the correction pulses generated by the correction value setting circuit **6'** in accordance with the count of the reversible counter **5** is increased each time a further sampling is effected. In this way, the negative feedback control is performed wherein the duration of the opening of the electromagnetic valve **9** is corrected to increase it by an amount corresponding to the pulse width of the correction pulses in addition to the duration of the injection pulses from the computing unit **7'** to thereby increase the air-fuel ratio c.

On the other hand, when the air-fuel ratio c is greater than the value at point c_4 in FIG. **20** and the output of the air-fuel ratio discriminating circuit **2** is at the "**0**" level, the addition and subtraction command circuit **3** generates a command signal for subtraction each time it receives the sampling signal and the reversible counter **5** performs the subtraction operation to decrease the time width of the correction pulses in accordance with the count of the reversible counter **5.** In this way, the negative feedback control is effected in which the extension of the duration of the opening of the electromagnetic valve **9** is decreased to reduce the air-fuel ratio c. Further, since the output of the oxygen concentration detector **1** has the output characteristic shown by the solid line connecting points a_0, a_1, a_3 and a_5 in FIG. **20,** the air-fuel ratio discriminating circuit **2** generates its discrimination output signals of "**1**" and "**0**" levels with the hysteresis characteristic having the loop shown by the broken line connecting points a_1, a_2, a_3 and a_4 in FIG. **20.** Thus, the dead zone detecting circuit **111** is provided to prevent the occurrence of a phenomenon that the air-fuel ratio c swings back and force between the points c_1 and c_4 due to the fact that the fuel quantity is increased or decreased until the level of the discriminating signal from the air-fuel ratio discriminating circuit **2** changes. In the dead zone detecting circuit **111,** the lower limit comparator **111***a* detects a point b_1 of the characteristic shown in FIG. **20** so that it generates a detected lower limit signal of "**1**" level for the air-fuel ratio on the side of the point c_1 which is smaller than the air-fuel ratio c_2 corresponding to the point b_1 and the lower limit signal of "**0**" level for the air-fuel ratio on the side of the point c_4 which is greater than the air-fuel ratio c_2. The output signal of lower limit comparator **111***a* is inverted by the inverter **111***c* and it is then applied to one input of the NAND gate **111***d.* On the other hand, the upper limit comparator **111***b* detects a point b_2 of the characteristic shown in FIG. **20** so that it generates a detected upper limit signal of "**1**" level for the air-fuel ratio on the side of the point c_1 which is smaller than the air-fuel ratio c_3 corresponding to the point b_2 and the upper limit signal of "**0**" level for the air-fuel ratio on the side of the point c_4 which is greater than the air-fuel ratio c_3. The output of the upper limit comparator **111***b* is applied to the other input of the NAND gate **111***d.* Consequently, the detected output signal of "**0**" level is generated only when both of the inputs to the NAND gate **111***d* are of the "**1**" level. In other words, the detected output signal of the NAND gate **111**d becomes a detected dead zone signal of "**0**" level when the air-fuel ratio c reaches and stays within the range of the intermediate dead zone between the points c_2 and c_3. The dead zone detecting circuit **111** which generates the above-described detected signal controls the generation of the sampling signals so that the generation of the sampling signals is prevented when the air-fuel ratio reaches and stays between the points c_2 and c_3. As a result, the addition and subtraction command circuit **3** generates no command signal and thus the reversible counter **5** performs no adding or subtracting operation. When this occurs, the correction value setting circuit **6'** generates the correction pulses having the time width determined by the previous sampling and thereafter the fuel quantity is increased or decreased with the determined correction value. Accordingly, when the engine load is constant, the air-fuel ratio does not swing between the points c_1 and c_4, but it is controlled to stay at the lower limit point c_2 or upper limit point c_3 of the intermediate dead zone.

We claim:

1. An air-fuel ratio feedback type fuel injection system having electromagnetic valve means connected to a constant pressure fuel line to inject the fuel into an internal combustion engine mounting the fuel injection system and a computing unit connected through an electromagnetic valve actuating circuit to the electromagnetic valve means for generating an injection pulse signal to determine the opening duration of the electromagnetic valve means thereby to control the quantity of said fuel to suitable various operating conditions of the internal combustion engine, comprising:

an oxygen concentration detector mounted in an exhaust pipe of said engine for detecting the concen-

tration of oxygen contained in the exhaust gases of said engine,

an air-fuel ratio discriminating circuit means connected to said oxygen concentration detector for comparing an output signal of said detector with a predetermined value to generate an output signal,

a sampling signal generating circuit means for generating a sampling signal having a predetermined frequency,

an addition and subtraction command circuit means connected to said sampling signal generating circuit means and said air-fuel ratio discriminating circuit means for generating an output command signal in accordance with the output signal of said air-fuel ratio discriminating circuit each time said sampling signal is applied thereto,

a reversible counter connected to said addition and subtraction command circuit means to perform the operation of addition or subtraction on the count thereof in accordance with said output command signal of said addition and subtraction command circuit means for generating a correction signal, and

valve opening duration correcting means connected to said reversible counter and further to said computer unit for controlling the opening duration of said electromagnetic valve means in accordance with said correction signal of said reversible counter in cooperation with said computing unit to reverse the output signal of said air-fuel ratio discrimination circuit means by changing the quantity of said fuel through said valve means.

2. A fuel injection system according to claim **1**, wherein said valve opening duration correction means comprises a D–A converter.

3. A fuel injection system according to claim **1**, wherein said valve opening duration correcting means comprises a correction value setting circuit means connected to said reversible counter and to said computing unit for generating a correction pulse signal corresponding to the correction signal of said reversible counter to extend the duration of the opening of said electromagnetic valve means.

4. A fuel injection system according to claim **1** further comprising a power range detector means connected to said valve opening duration correcting means for detecting a power range requiring a large torque in said engine and stopping the operation of said valve opening duration correcting means when said power range is detected.

5. A fuel injection system according to claim **1** further comprising a holding circuit means connected to said reversible counter for maintaining the count of said reversible counter at the maximum or minimum value thereof when the count of said reversible counter exceeds the maximum or minimum capacity of said reversible counter.

6. A fuel injection system according to claim **1** further comprising means connected to said sampling signal generating means for varying the frequency of the sampling signals from said sampling signal generating means in accordance with the response time of said oxygen concentration detector.

7. A fuel injection system according to claim **1** further comprising superposing means connected to said sampling signal generating circuit, to said valve opening duration correcting means and to said computing unit for superposing an additional correction signal corresponding to the number of the sampling of said sampling signals effected in a time interval up to the reversal of the output signal of said air-fuel ratio discriminating circuit means on the output signal of said valve opening duration correcting means.

8. A fuel injection system according to claim **1** further comprising dead zone detecting means connected to said oxygen concentration detector and to said sampling signal generating circuit means for preventing the generation of the output signal of said addition and subtraction command circuit when the output of said oxygen concentration detector reaches the level of an intermediate zone.

9. A fuel injection system according to claim **1**, wherein said sampling signal generating circuit means generates said sampling signals in synchronism with the rotation of said engine.

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