

[54] EXHAUST GAS RECIRCULATION SYSTEM

[75] Inventor: **Michael P. Murphy**, Flint, Mich.

[73] Assignee: **General Motors Corporation,**
Detroit, Mich.

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[51] **Int. Cl.²** F02M 25/06

[58] **Field of Search**..... 123/119 A, 198 D, 198 R

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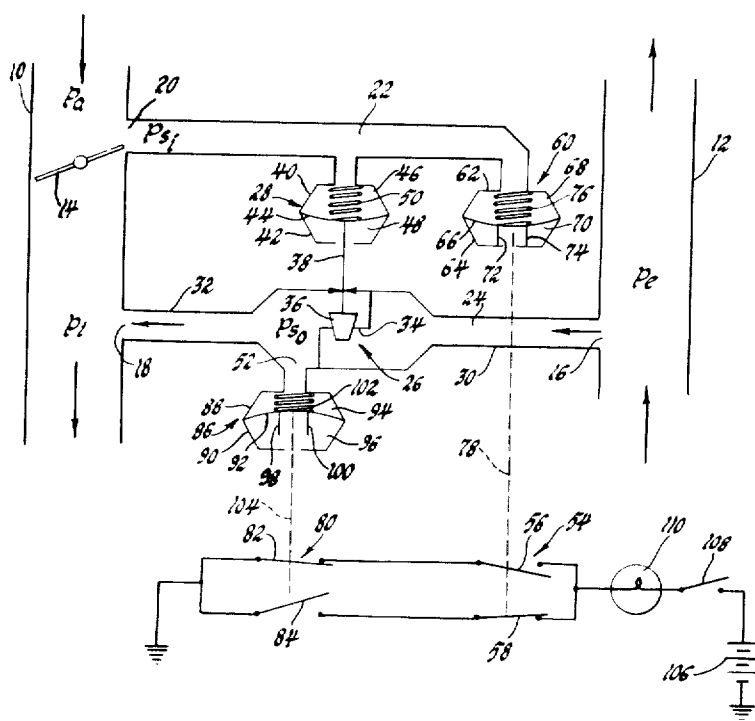
Primary Examiner—Wendell E. Burns
Attorney, Agent, or Firm—T. G. Jagodzinski

[57] **ABSTRACT**

In response to the operation of an internal combustion

engine, an input signal pressure is developed which differs from the atmospheric pressure by more than a first predetermined amount when exhaust gas recirculation is desirable. A recirculation valve opens to permit the recirculation of exhaust gases from the exhaust passage to the intake passage of the engine when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount. In response to operation of the recirculation valve, an output signal pressure is developed which differs from the atmospheric pressure by more than a second predetermined amount when the recirculation valve is closed. A perceptible indication is produced when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount and the output signal pressure differs from the atmospheric pressure by more than the second predetermined amount thereby to indicate that the recirculation valve is stuck closed. Further, a perceptible indication is produced when the input signal pressure differs from the atmospheric pressure by less than the first predetermined amount and the output signal pressure differs from the atmospheric pressure by less than the second predetermined amount thereby to indicate that the recirculation valve is stuck open.

2 Claims, 2 Drawing Figures



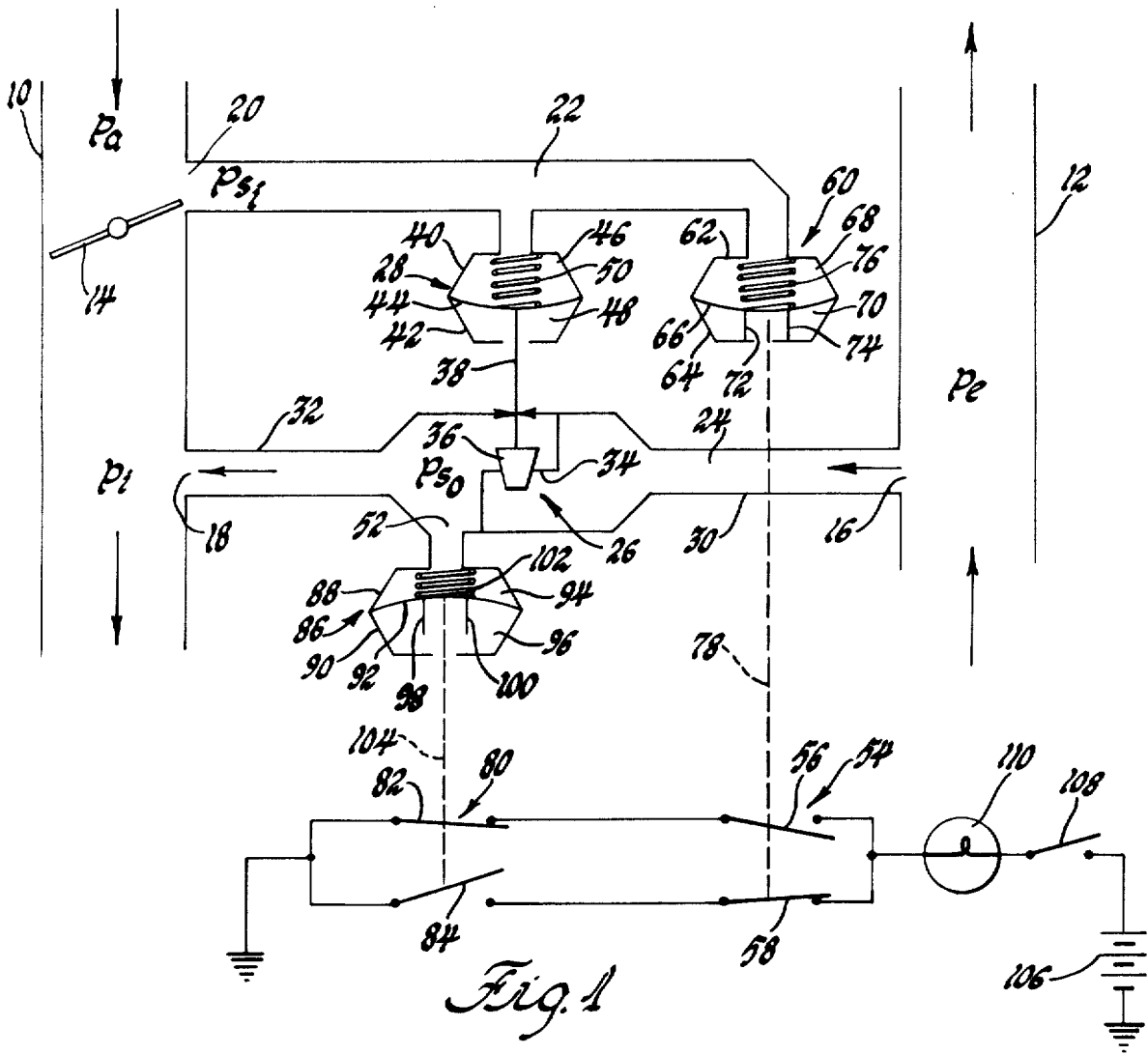


Fig. 1

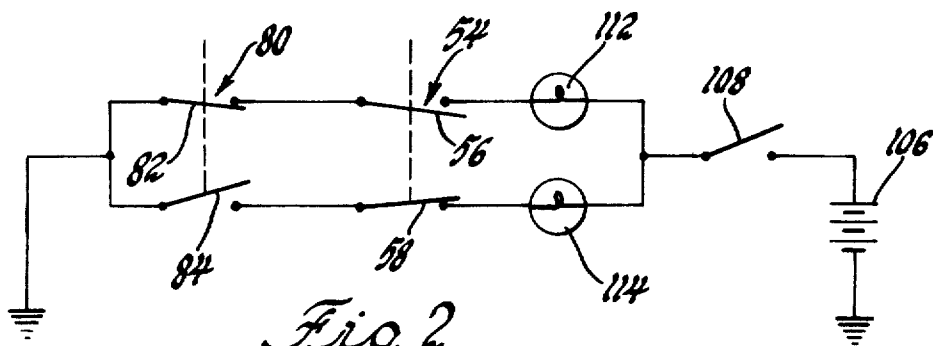


Fig. 2

EXHAUST GAS RECIRCULATION SYSTEM

This invention relates to an exhaust gas recirculation system including an apparatus for monitoring the malfunction of a recirculation valve.

Conventionally, an internal combustion engine includes an intake passage and an exhaust passage. Ambient air is drawn through the intake passage into the engine from the surrounding atmosphere due to the difference between the atmospheric pressure outside of the passage and the intake pressure inside of the passage which is substantially less than the atmospheric pressure. A throttle is mounted within the intake passage for regulating the flow of air through the passage as the throttle is moved from a fully closed position to a fully open position. Exhaust gases are forced through the exhaust passage from the engine into the surrounding atmosphere due to the difference between the atmospheric pressure outside of the passage and the exhaust pressure inside of the passage which is substantially greater than the atmospheric pressure.

According to one aspect of the invention, the intake passage includes a recirculation outlet port which is exposed to the intake pressure while the exhaust passage includes a recirculation inlet port which is exposed to the exhaust pressure. Further, the intake passage includes an input signal port which is located with respect to the throttle such that as the throttle is moved between the fully closed position and the fully open position, the signal port is exposed to an input signal pressure which differs from the atmospheric pressure by more than a first predetermined amount when exhaust gas recirculation is desirable and which differs from the atmospheric pressure by less than the first predetermined amount when exhaust gas recirculation is not desirable.

In another aspect of the invention, a recirculation valve is disposed within a recirculation passage coupled between the recirculation inlet port of the exhaust passage and the recirculation outlet port of the intake passage for regulating the recirculation of exhaust gases from the exhaust passage through the recirculation passage to the intake passage. A valve actuator opens the recirculation valve to permit exhaust gas recirculation when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount and closes the recirculation valve to prohibit exhaust gas recirculation when the input signal pressure differs from the atmospheric pressure by less than the first predetermined amount. Further, the recirculation passage includes an output signal port which is located with respect to the valve such that the signal port is exposed to an output signal pressure which differs from the atmospheric pressure by more than a second predetermined amount when the valve is closed and which differs from the atmospheric pressure by less than the second predetermined amount when the valve is open.

As contemplated by a further aspect of the invention, a first switch actuator shifts a first switching device from a first state to a second state when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount and shifts the first switching device from the second state to the first state when the input signal pressure differs from the atmospheric pressure by less than the first predetermined amount. Similarly, a second switch actuator shifts a second switching device from a first state to a second

state when the output signal pressure differs from the atmospheric pressure by less than the second predetermined amount and shifts the second switching device from the second state to the first state when the output signal pressure differs from the atmospheric pressure by more than the second predetermined amount.

In yet another aspect of the invention, an indicator provides a telltale signal when the first switching device is in the second state and the second switching device is in the first state thereby to indicate that the recirculation valve is stuck closed. Optionally, the indicator may also provide a telltale signal when the first switching device is in the first state and the second switching device is in the second state thereby to indicate that the recirculation valve is stuck open.

These and other aspects and advantages of the invention may be best understood by reference to the following detailed description of a preferred embodiment when considered in conjunction with the accompanying drawing.

In the drawing:

FIG. 1 is a schematic diagram of an exhaust gas recirculation system incorporating the principles of the invention.

FIG. 2 is a schematic diagram of an alternate embodiment of one portion of the exhaust gas recirculation system illustrated in FIG. 1.

Referring to FIG. 1, an internal combustion engine (not shown) includes an intake passage 10 and an exhaust passage 12. Ambient air is drawn through the intake passage 10 into the engine from the surrounding atmosphere under the influence of the difference between the atmospheric pressure P_a outside of the passage 10 and an intake pressure P_i inside of the passage 10 which is substantially less than the atmospheric pressure P_a . Exhaust gases are forced through the exhaust passage 12 from the engine into the surrounding atmosphere under the influence of the difference between the atmospheric pressure P_a outside of the passage 12 and an exhaust pressure P_e inside of the passage 12 which is substantially greater than the atmospheric pressure P_a . A throttle 14 is rotatably mounted within the intake passage 10 for movement between a fully closed position and a fully open position to regulate the flow of air through the passage 10 such that the intake pressure P_i rises toward the atmospheric pressure P_a as the throttle 14 is moved from the fully closed position to the fully open position.

It is well established that the emission of oxides of nitrogen into the surrounding atmosphere via the exhaust gases of the engine may be reduced by recirculating a portion of the exhaust gases from the exhaust passage 12 to the intake passage 10 under the influence of the difference between the exhaust pressure P_e and the intake pressure P_i . It is generally thought that the rate at which exhaust gases are recirculated from the exhaust passage 12 to the intake passage 10 should be proportional to the rate at which air is drawn through the intake passage 10 when the throttle 14 is between the fully closed position and the fully open position. Moreover, it is generally thought that exhaust gas recirculation should be prohibited entirely when the throttle 14 is in either the fully closed position or the fully open position. Accordingly, the present invention will be described as embodied within an exhaust gas recirculation system for producing the results outlined above. However, as will become more apparent hereinafter, the invention is equally applicable to virtually any type

of exhaust gas recirculation system.

Referring again to FIG. 1, the exhaust passage 12 includes a recirculation inlet port 16 located within the passage 12 so as to be exposed to the exhaust pressure P_e . Similarly, the intake passage 10 includes a recirculation outlet port 18 which is located within the passage 10 downstream of the throttle 14 so as to be exposed to the intake pressure P_i . Moreover, the intake passage 10 includes an input signal port 20 located within the passage 10 adjacent the throttle 14. Preferably, the signal port 20 extends substantially above and slightly below the upstream edge of the throttle 14 such that the signal port 20 is traversed by the upstream edge of the throttle 14 as it is moved from the fully closed position toward the fully open position. As a result, the input signal port 20 is exposed to an input signal pressure P_{si} which is developed within a signal passage 22 coupled to the signal port 20.

As the throttle 14 is moved from the fully closed position toward the fully open position, the input signal pressure P_{si} initially gradually falls from a maximum value to a minimum value which is substantially below the atmospheric pressure P_a and subsequently gradually rises from the minimum value back to the maximum value which is approximately equal to the atmospheric pressure P_a . When the throttle 14 is between the fully closed position and the fully open position, in which event exhaust gas recirculation is desirable, the input signal pressure P_{si} at the signal port 20 is below the atmospheric pressure P_a by at least a first predetermined amount. Conversely, when the throttle 14 is in either the fully closed position or the fully open position, in which event exhaust gas recirculation is not desirable, the input signal pressure P_{si} at the signal port 20 is not below the atmospheric pressure P_a by at least the first predetermined amount.

A recirculation passage 24 is connected between the recirculation inlet port 16 of the exhaust passage 12 and the recirculation outlet port 18 of the intake passage 10 for conducting the flow of exhaust gases from the exhaust passage 12 to the intake passage 10 under the influence of the difference between the exhaust pressure P_e and the intake pressure P_i . A recirculation valve assembly includes a recirculation valve 26 and a valve actuator 28.

The recirculation valve 26 is located within the recirculation passage 24 so as to divide the passage 24 into an inlet branch 30 on the exhaust passage side of the valve 26 and an outlet branch 32 on the intake passage side of the valve 26. The recirculation valve 26 includes a valve seat 34 which is disposed across the recirculation passage 24. A valve pintle 36 cooperates with the valve seat 34 to define a variable orifice therebetween. A valve stem 38 extends in vertically slidable relationship and in pressure sealing relationship through the outlet branch 32 of the recirculation passage 24. The lower end of the valve stem 38 is connected to the valve pintle 36.

The valve actuator 28 includes a housing having a pair of opposing upper and lower dished portions 40 and 42 separated by a flexible diaphragm 44 which divides the housing into upper and lower pressure chambers 46 and 48. The upper pressure chamber 46 is coupled to the signal passage 22 so that the pressure in the upper chamber 46 is approximately equal to the input signal pressure P_{si} . The lower pressure chamber 48 is coupled to the surrounding atmosphere so that the pressure within the lower chamber 48 is approximately

equal to the atmospheric pressure P_a . A coil spring 50 is seated in compression in the upper chamber 46 between the upper surface of the diaphragm 44 and the lower surface of the upper housing portion 40. The upper end of the valve stem 38 is attached to the diaphragm 44.

When the input signal pressure P_{si} in the upper chamber 46 is below the atmospheric pressure P_a in the lower chamber 48 by at least the first predetermined amount, the diaphragm 44 moves upwardly against the action of the spring 50 to pull the valve stem 38 upward. As the valve stem 38 slides upwardly, the valve pintle 36 disengages the valve seat 34 thereby opening the valve 26 to permit the flow of exhaust gases there-through. The rate at which exhaust gases are recirculated through the valve 26 is determined in proportion to the size of the orifice defined between the valve pintle 36 and the valve seat 34. In turn, the orifice size of the valve 26 is determined in proportion to the difference between the input signal pressure P_{si} and atmospheric pressure P_a as defined by the rate at which air is drawn through the intake passage 10 in response to the position of the throttle 14.

Alternately, when the input signal pressure P_{si} in the upper chamber 46 is not below the atmospheric pressure P_a in the lower chamber 48 by at least the first predetermined amount, the diaphragm 44 moves downwardly under the influence of the spring 50 to push the valve stem 38 downward. As the valve stem 38 slides downwardly, the valve pintle 36 engages the valve seat 34 thereby closing the valve 26 to prohibit the flow of exhaust gases therethrough. Hence, the recirculation valve 26 is opened when the throttle 14 is in other than the fully closed position or the fully open position and is closed when the throttle 14 is in either the fully closed position or the fully open position. A more detailed description of an exhaust gas recirculation similar to that so far described may be obtained by reference to U.S. Pat. No. 3,641,987 which is incorporated herein by reference.

The recirculation valve 26 exhibits two possible failure modes: stuck closed and stuck open. Although the stuck open failure mode is normally manifested by noticeably poor engine response, the stuck closed failure mode is not readily discernible from the engine response. Of course, it is the stuck closed failure mode which contributes to the emission of oxides of nitrogen in the exhaust gases of the engine. Therefore, it is advantageous to provide an apparatus for monitoring the operation of the recirculation valve 26 so as to indicate when the valve 26 is stuck closed. Optionally, it is also advantageous, albeit less necessary, to provide an apparatus for monitoring the operation of the recirculation valve 26 so as to indicate when the valve 26 is stuck open. The present invention provides an apparatus for monitoring the operation of the recirculation valve 26 in a manner which yields the desired results.

Specifically, the recirculation passage 24 includes an output signal port 52 located in the outlet branch 32 relative to the recirculation valve 26 such that the signal port 52 is exposed to an output signal pressure P_{so} developed on the intake manifold side of the valve 26. The output signal pressure P_{so} rises to an upper value near the exhaust pressure P_e when the recirculation valve 26 is open. Conversely, the outlet signal pressure P_{so} falls to a lower value near the intake pressure P_i when the recirculation valve 26 is closed. Thus, the output signal pressure P_{so} is below the atmospheric

pressure P_a by at least a second predetermined amount when the recirculation valve 26 is closed and is not below the atmospheric pressure P_a by at least the second predetermined amount when the recirculation valve 26 is open.

A first switching device 54 includes a pair of single pole-single throw switches 56 and 58. The switching device 54 is operable between alternate first and second states. In the first state, the switch 56 is open and the switch 58 is closed. In the second state, the switch 56 is closed and the switch 58 is open.

A switch actuator 60 includes a housing having a pair of opposing upper and lower dished portions 62 and 64 separated by a flexible diaphragm 66 which divides the housing into upper and lower pressure chambers 68 and 70, respectively. The upper pressure chamber 68 of the actuator 60 is coupled to the signal passage 22 so that the pressure in the upper chamber 68 is approximately equal to the input signal pressure P_{s_i} . The lower pressure chamber 70 is coupled to the surrounding atmosphere so that the pressure in the lower chamber is approximately equal to the atmospheric pressure P_a . A pair of stop members 72 and 74 are attached to the lower surface of the diaphragm 66 for limiting downward movement of the diaphragm 66. A coil spring 76 is seated in compression in the upper chamber 68 between the upper surface of the diaphragm 66 and the lower surface of the upper housing portion 62 for normally urging the diaphragm 66 downward to engage the stop members 72 and 74 with the upper surface of the lower housing portion 64. The diaphragm 66 is connected through a suitable linkage 78 to the switches 56 and 58 of the first switching device 54.

When the input signal pressure P_{s_i} in the upper chamber 68 is below the atmospheric pressure P_a in the lower chamber 70 by at least the first predetermined amount, in which event the throttle 14 is between the fully closed position and the fully open position, the diaphragm 66 moves upwardly against the action of the spring 76 to close the switch 56 and to open the switch 58 via the linkage 78 thereby shifting the first switching device 54 from the first state to the second state. Alternately, when the input signal pressure P_{s_i} in the upper chamber 68 is not below the atmospheric pressure P_a in the lower chamber 70 by at least the first predetermined amount, in which event the throttle 14 is in either the fully closed position or the fully open position, the diaphragm 66 moves downwardly under the influence of the spring 76 to open the switch 56 and to close the switch 58 via the linkage 78 thereby shifting the first switching device 54 from the second state to the first state.

A second switching device 80 includes a pair of single pole-single throw switches 82 and 84. The second switching device 80 is also operable between alternate first and second states. In the first state, the switch 82 is closed while the switch 84 is open. In the second state, the switch 82 is open and the switch 84 is closed.

A second switch actuator 86 includes a housing having a pair of opposing upper and lower dished portions 88 and 90 separated by a flexible diaphragm 92 which divides the housing into upper and lower pressure chambers 94 and 96, respectively. The upper pressure chamber 94 is coupled to the output signal port 52 in the outlet branch 32 of the recirculation passage 24 so that the pressure in the upper chamber 94 is approximately equal to the output signal pressure P_{s_o} . The lower pressure chamber 96 is coupled to the surround-

ing atmosphere so that the pressure in the lower chamber 96 is approximately equal to the atmospheric pressure P_a . A pair of stop members 98 and 100 are attached to the lower surface of the diaphragm 92 for limiting downward movement of the diaphragm 92. A coil spring 102 is seated in compression between the upper surface of the diaphragm 92 and the lower surface of the upper housing portion 88 for normally urging the diaphragm 92 downwardly to engage the stop members 98 and 100 with the upper surface of the lower housing portion 90. The diaphragm 92 is connected through a suitable linkage 104 to the switches 82 and 84 of the second switching device 80.

When the output signal pressure P_{s_o} in the upper chamber 94 is below the atmospheric pressure P_a in the lower chamber 96 by at least the second predetermined amount, in which event the recirculation valve 26 is closed, the diaphragm 92 moves upwardly against the action of the spring 102 to close the switch 82 and to open the switch 84 via the linkage 104 thereby shifting the second switching device 80 from the second state to the first state. Conversely, when the output signal pressure P_{s_o} in the upper chamber 94 is not below the atmospheric pressure P_a in the lower chamber 96 by at least the second predetermined amount, in which event the recirculation valve 26 is open, the diaphragm 92 moves downwardly under the influence of the spring 102 to open the switch 82 and to close the switch 84 via the linkage 104 thereby shifting the second switching device 80 from the first state to the second state.

An indicator circuit includes the series combination of a voltage source 106, a power switch 108, a telltale lamp 110, and a switching network formed by the first and second switching devices 54 and 80. Specifically, the switching network comprises the series combination of the switches 56 and 82 connected in parallel with the series combination of the switches 58 and 84. Assuming the power switch 108 is closed, the telltale lamp 110 is energized by the voltage source 106 to produce a perceptible indication in the form of radiated light when both of the switches 56 and 82 are simultaneously closed or when both of the switches 58 and 84 are simultaneously closed. The switches 56 and 82 are simultaneously closed only when the recirculation valve 26 is in the stuck closed failure mode. The switches 58 and 84 are simultaneously closed only when the recirculation valve 26 is in the stuck open failure mode. Accordingly, the emission of light from the telltale lamp 110 indicates that the recirculation valve 26 is either stuck closed or stuck open.

As applied to an automotive vehicle, the voltage source 106 may be conveniently provided by the storage battery of the vehicle electrical system while the power switch 108 may be conveniently provided by the ignition switch of the vehicle electrical system. The telltale lamp 110 may be replaced by virtually any suitable indicator such as a meter, a buzzer, or the like. Moreover, if an indication of the stuck open failure mode of the recirculation valve 26 is not desired, the switches 58 and 84 may be merely eliminated.

Alternately, the indicator circuit may take the form shown in FIG. 2 where like numerals are used to denote like elements. In FIG. 2, one telltale lamp 112 is connected in series with the switches 56 and 82 and another telltale lamp 114 is connected in series with the switches 58 and 84. On the one hand, the emission of light from the lamp 112 indicates that the recirculation valve 26 is stuck closed. On the other hand, the emis-

sion of light from the lamp 114 indicates that the recirculation valve 26 is stuck open. To aid in distinguishing the lamps 112 and 114 from one another, they may be of different colors.

It will now be appreciated that the illustrated embodiment of the invention is presented for demonstrative purposes only and that various alterations and modifications may be made to the illustrated embodiment without departing from the spirit and scope of the invention.

What is claimed is:

1. In an internal combustion engine, the combination comprising: means including an intake passage through which ambient air is drawn into the engine from the surrounding atmosphere; means including an exhaust passage through which exhaust gases are forced from the engine into the surrounding atmosphere; means responsive to the operation of the engine for developing an input signal pressure which differs from the atmospheric pressure by more than a first predetermined amount when the recirculation of exhaust gases from the exhaust passage to the intake passage is desired and which differs from the atmospheric pressure by less than the first predetermined amount when the recirculation of exhaust gases from the exhaust passage to the intake passage is not desired; means including a recirculation valve responsive to the input signal pressure and coupled between the exhaust passage and the intake passage for opening to permit the recirculation of exhaust gases from the exhaust passage to the intake passage through the valve when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount and for closing to prohibit the recirculation of exhaust gases from the exhaust passage to the intake passage through the valve when the input signal pressure differs from the atmospheric pressure by less than the first predetermined amount; means responsive to operation of the recirculation valve for developing an output signal pressure which differs from the atmospheric pressure by more than a second predetermined amount when the recirculation valve is closed and which differs from the atmospheric pressure by less than the second predetermined amount when the recirculation valve is open; and means responsive to the input and output signal pressures for indicating that the recirculation valve is stuck closed when the input signal pressure differs from the atmospheric pressure by more than the first predetermined amount and the output signal pressure differs from the atmospheric pressure by more than the second predetermined amount or for indicating that the recirculation valve is stuck open when the input signal pressure differs from the atmospheric pressure by less than the first predetermined amount and the output signal pressure differs from the atmospheric pressure by less than the second predetermined amount.

2. In an internal combustion engine, the combination comprising: means including an intake passage through which ambient air is drawn into the engine from the surrounding atmosphere due to the difference between the atmospheric pressure outside of the passage and an intake pressure inside of the passage which is substantially less than the atmospheric pressure, the intake passage including a recirculation outlet port located within the passage such that the outlet port is exposed to the intake pressure and including an input signal port located within the passage such that the signal port is exposed to an input signal pressure; means including an

exhaust passage through which exhaust gases are forced from the engine into the surrounding atmosphere due to the difference between the atmospheric pressure outside of the passage and an exhaust pressure inside the passage which is substantially greater than the atmospheric pressure, the exhaust passage including a recirculation inlet port located within the passage such that the inlet port is exposed to the exhaust pressure; a throttle mounted within the intake passage for movement between a fully closed position and a fully open position to regulate the flow of air through the passage, the throttle located relative to the input signal port such that the input signal pressure is below the atmospheric pressure by at least a first predetermined amount when the throttle is between the fully closed position and the fully open position in which event exhaust gas recirculation is desired and such that the input signal pressure is not below the atmospheric pressure by at least the first predetermined amount when the throttle is in either the fully closed position or the fully open position in which event exhaust gas recirculation is not desired; means including a recirculation passage connected between the recirculation inlet port of the exhaust passage and the recirculation outlet port of the intake passage for conducting the recirculation of exhaust gases from the exhaust passage to the intake passage due to the difference between the exhaust pressure and the intake pressure, the recirculation passage including an output signal port located within the passage such that the signal port is exposed to an output signal pressure; means including a recirculation valve disposed within the recirculation passage for permitting the recirculation of exhaust gases when the valve is open and for prohibiting the recirculation of exhaust gases when the valve is closed, the recirculation valve located relative to the output signal port such that the output signal pressure is below the atmospheric pressure by at least a second predetermined amount when the valve is closed and is not below the atmospheric pressure by at least the second predetermined amount when the valve is open; means including a valve actuator connected to the recirculation valve and coupled to the input signal port of the intake passage for opening the recirculation valve when the input signal pressure is below the atmospheric pressure by at least the first predetermined amount and for closing the recirculation valve when the input signal pressure is not below the atmospheric pressure by at least the first predetermined amount; means including a first switch actuator connected to the first switching device and coupled to the input signal port of the intake passage for shifting the first switching device from the first state to the second state when the input signal pressure is below the atmospheric pressure by at least the first predetermined amount and for shifting the first switching device from the second state to the first state when the input signal pressure is not below the atmospheric pressure by at least the first predetermined amount; means including a second switch actuator connected to the second switching device and coupled to the output signal port of the recirculation passage for shifting the second switching device from the second state to the first state when the output signal pressure is below the atmospheric pressure by at least the second predetermined amount and for shifting the second switching device from the first state to the second state when the output signal pressure is not below the atmospheric pressure by at least the second predetermined amount; and

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means for providing a perceptible indication when the first switching device is in the second state and the second switching device is in the first state in which event the recirculation valve is stuck closed or when the first

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switching device is in the first state and the second switching device is in the second state in which event the recirculation valve is stuck open.

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