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Wertheimer

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[54] **EXHAUST GAS RECIRCULATION FLOW CONTROL SYSTEM**

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[52] **U.S. Cl.** ..... **123/119 A**

[51] **Int. Cl.²** **F07M 25/06**

[58] **Field of Search** ..... 123/119 A

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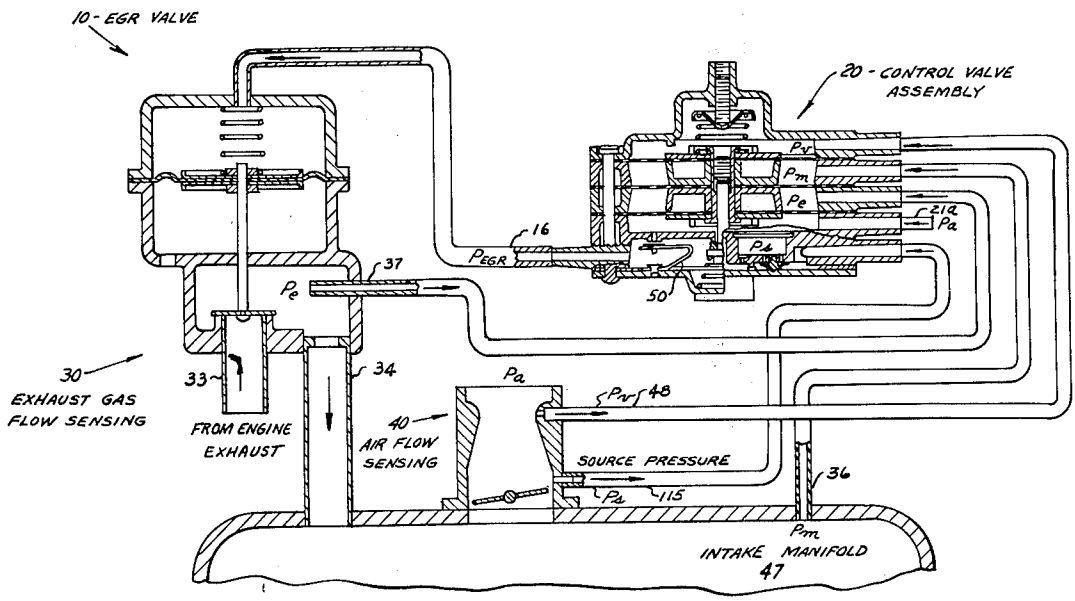
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Assistant Examiner—David D. Reynolds
Attorney, Agent, or Firm—Remy J. Vanophem

[57] **ABSTRACT**

The present invention relates in general to reducing the internal combustion engine exhaust emission polutants. More specifically, it relates to a control device that regulates the amount of exhaust gas being recirculated into the intake manifold of an internal combustion engine such that the exhaust gas recirculation flow is nearly proportional to engine air flow, and is a controlled function of intake manifold vacuum. The flow may be completely inhibited at low engine temperatures and also at times of low manifold vacuum and high engine air flow in order to maintain acceptable driveability.

30 Claims, 6 Drawing Figures



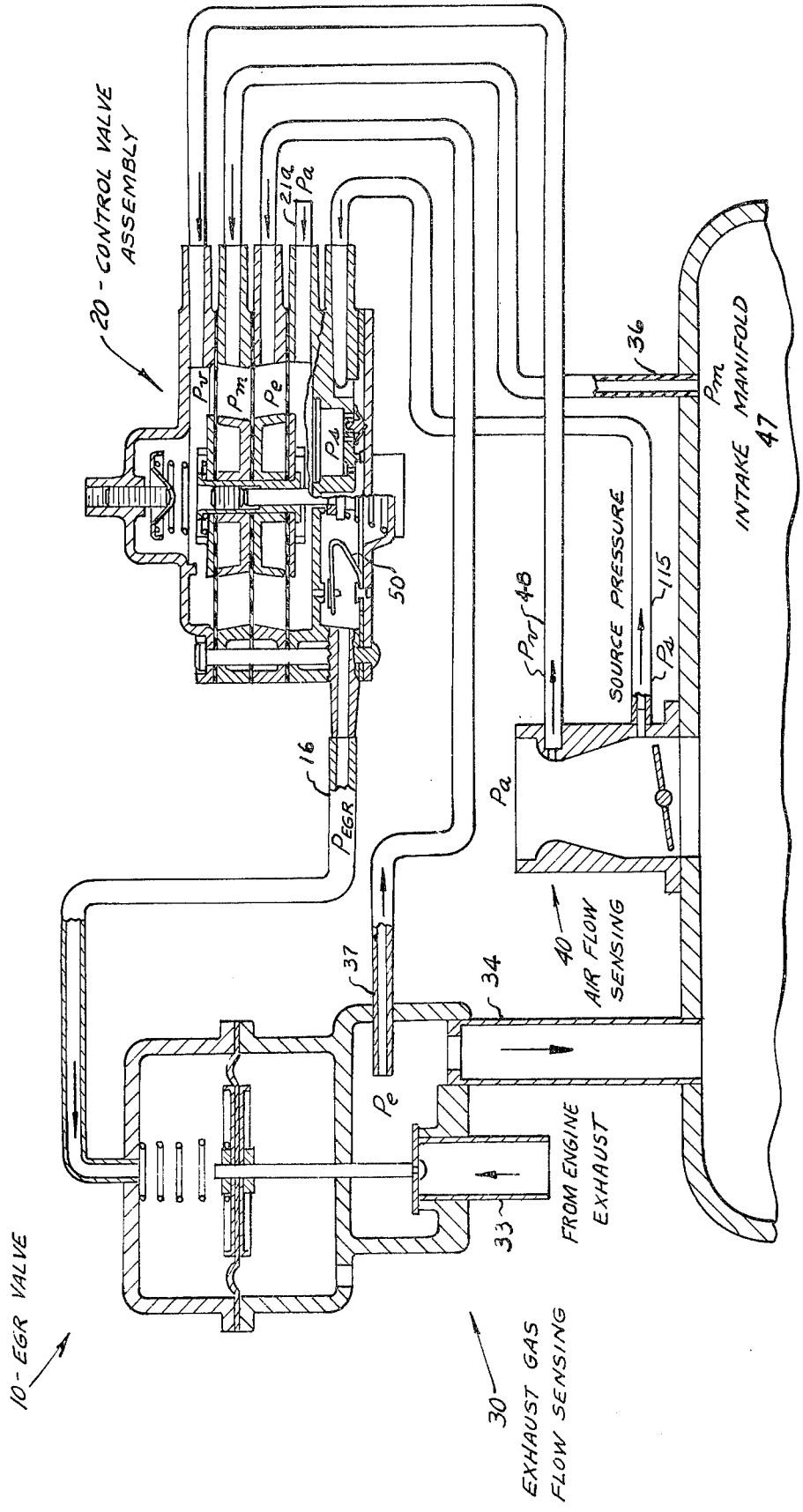

20 - CONTROL VALVE ASSEMBLY
21a
Pa
Pr
Pm
Pe
Pd
50
16
PEGR
37
34
Pe
40
AIR FLOW SENSING
Pa
Pr
48
SOURCE PRESSURE
115
Pa
36
Pm
INTAKE MANIFOLD
47
33
FROM ENGINE EXHAUST
30
EXHAUST GAS FLOW SENSING
10 - EGR VALVE

FIG. 1

FIG. 2

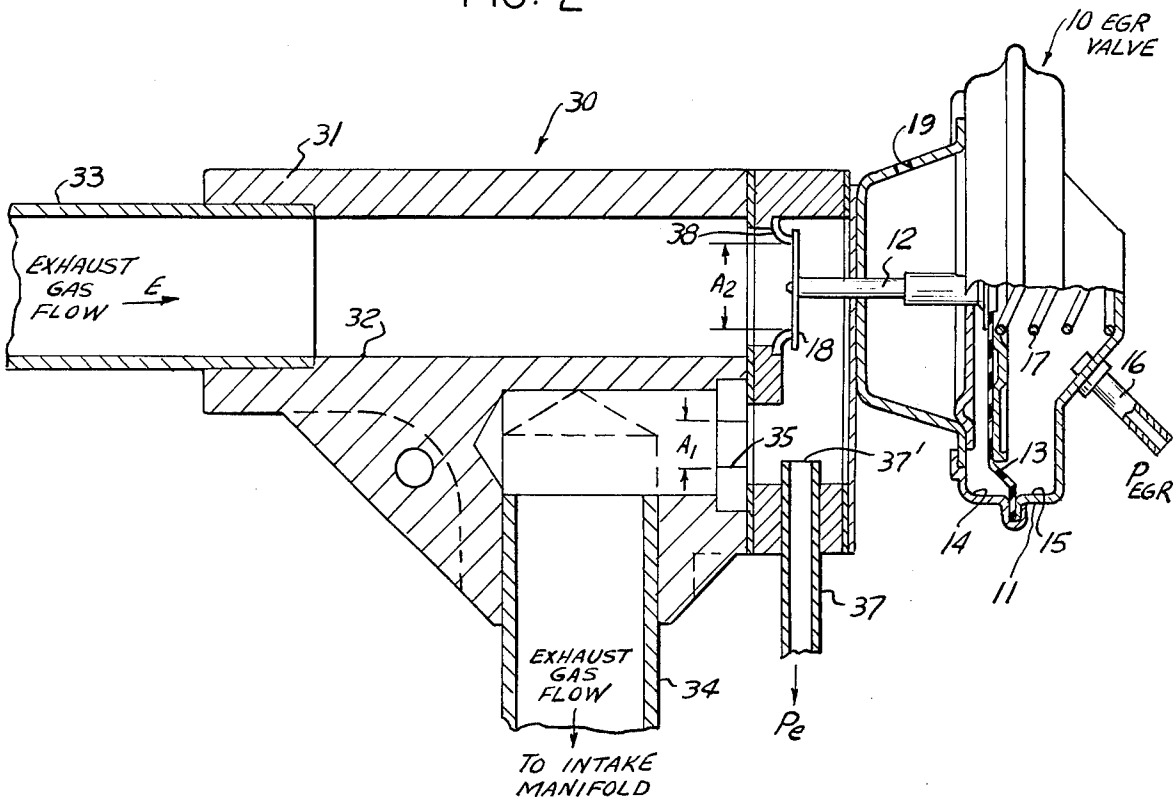

10 EGR VALVE
30
31
33
19
38
12
EXHAUST GAS FLOW
E
A_2
32
18
17
16
A_1
35
37'
13
P_{EGR}
14
15
11
37
EXHAUST GAS FLOW
34
P_e
TO INTAKE MANIFOLD

FIG. 3

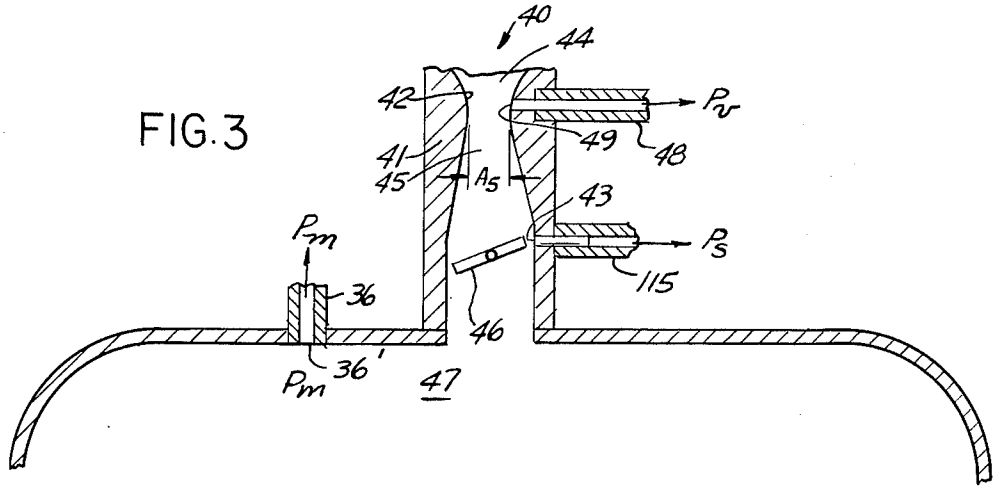

40
44
42
P_v
49
48
41
45
A_s
43
P_m
P_s
115
36
46
P_m
36'
47

FIG. 4

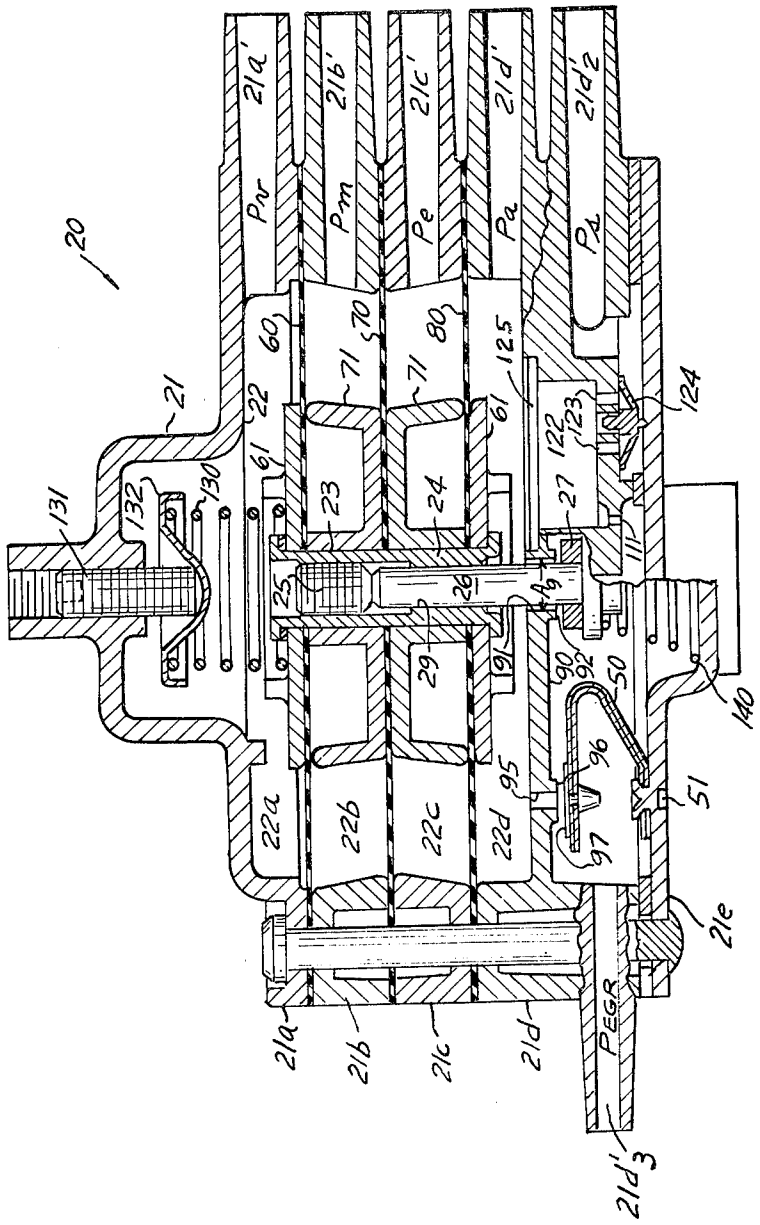
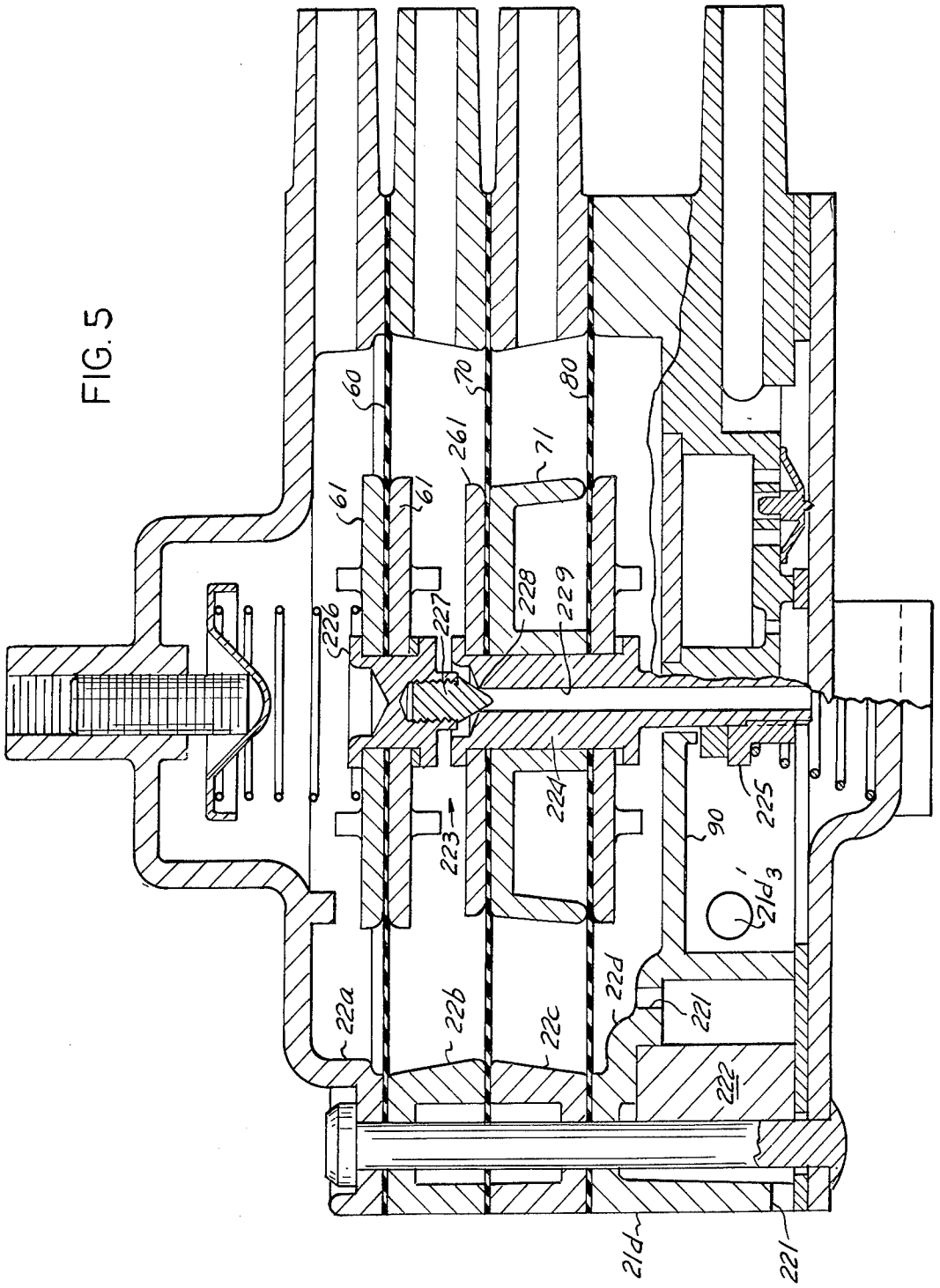

20
21
21a'
21b'
21c'
21d'
21d'2
Pr
Pm
Pe
Pa
Pd
60
70
71
80
125
61
22
23
24
27
122
123
124
131
132
130
25
26
29
19
90
92
50
140
95
96
97
51
21e
22a
22b
22c
22d
21a
21b
21c
21d
PEGR
21d'3

FIG. 5


60
70
80
261
71
61
61
228
229
226
227
224
223
225
90
21d3
22a
22b
22c
22d
221
222
21d
221

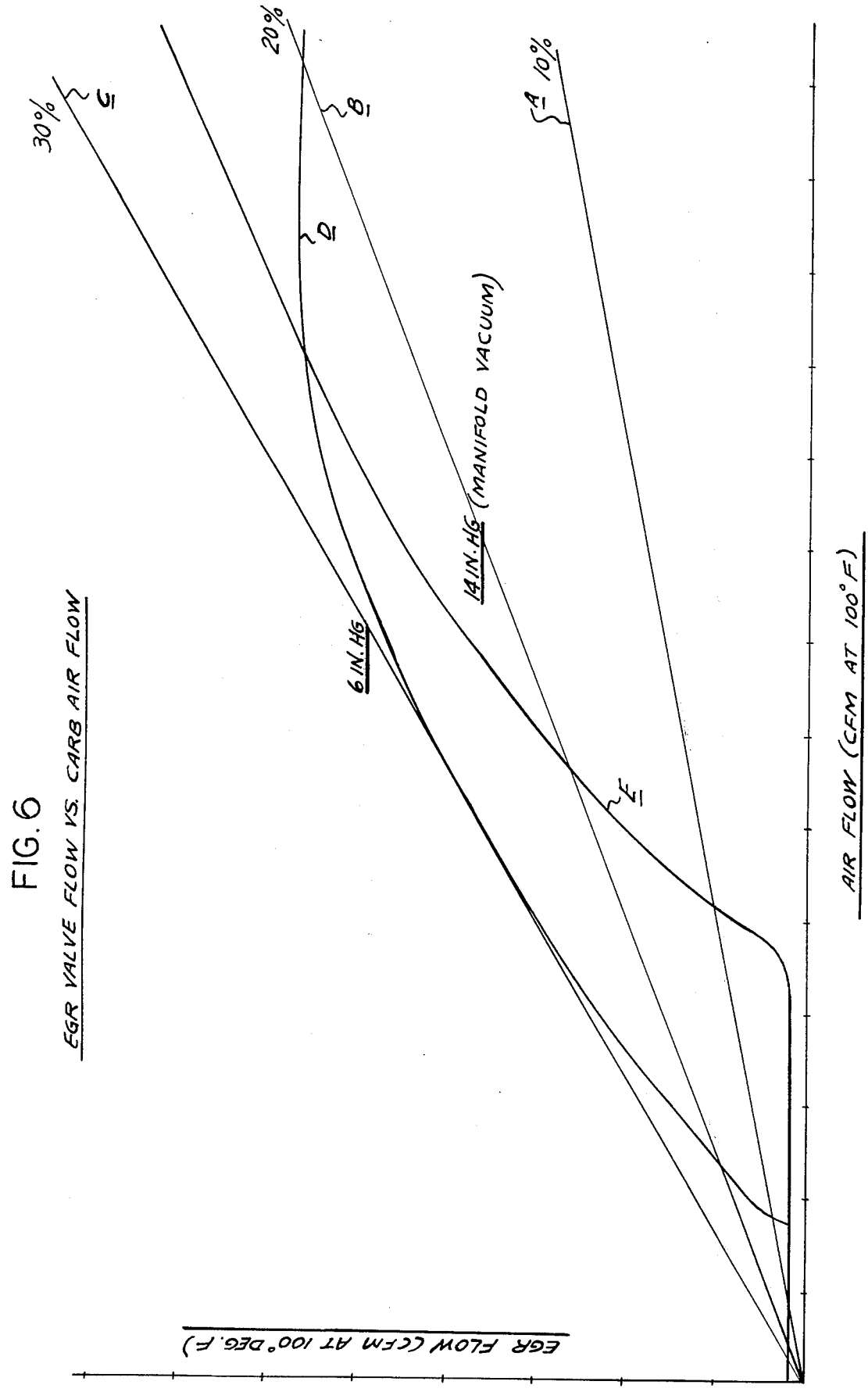


FIG. 6
EGR VALVE FLOW VS. CARB AIR FLOW

EXHAUST GAS RECIRCULATION FLOW CONTROL SYSTEM

CROSS REFERENCES TO RELATED APPLICATIONS

The present invention is an improvement over the exhaust gas recirculation control system described in co-pending, commonly assigned U.S. patent application Ser. No. 318,150, now U.S. Pat. No. 3,814,070, entitled "Exhaust Gas Recirculation Flow Control System" filed Dec. 26, 1972.

BACKGROUND OF THE INVENTION

A major source of atmospheric air pollution is the exhaust gas from automobile engines. A present approach to control this general problem is to modify engine operation parameters through spark timing controls systems to alter combustion in conjunction with the addition of an exhaust gas treating device to minimize the output of undesirable exhaust gas pollutants.

To reduce emission of oxides of nitrogen, one of several gaseous emissions considered harmful, several controlled approaches which operate to lower peak combustion temperatures have been used. Of these approaches, one in which a portion of the engine exhaust is recirculated into the combustion chamber along with the fuel charge, has been found effective and has gained favor with those versed in the art.

Exhaust gas recirculation (EGR) is the process by which a portion of the exhaust gases are recirculated to the intake manifold primarily for the purpose of reducing the oxides of nitrogen to a level which is acceptable per federal and some state exhaust emissions standards. Prior art EGR has been implemented using controls ranging in sophistication from a simple on-off control to a closed loop control system which achieves optimum control of exhaust gas recirculation for maximum effectiveness at minimum loss in vehicle driveability. With the simple on-off control, the amount of exhaust gas recirculated increases with increasing intake manifold vacuum and is not correlative to air flow into the engine. This type of system is not necessarily the most desirable, in that, exhaust gas recirculation rates, which increase with intake manifold vacuum will not permit a good compromise between driveability and economy on one hand and oxides of nitrogen on the other. This would necessitate a need for larger engines and higher fuel consumption to get the same performance characteristics as was obtainable before utilizing EGR to control pollutants. Therefore, it was determined that for maximum effectiveness of pollutant control, consistent with acceptable vehicle driveability and economy requirements, the EGR flow should be maintained as a relative constant percentage of the engine's air flow, and further, EGR should be inhibited at low ambient or engine temperatures as well as at low and high engine air flows. These parameters are consistent with driveability, economy and emissions requirements normally associated with high speed operation of the vehicle and with urban driving.

Devices such as the venturi vacuum amplifier, which attempt to maintain a degree of proportionality between the amount of EGR and total engine air flow, are limited in attaining the above objectives in that these devices are sensitive to engine air flow, but there is no "feedback" from the exhaust gas recirculation portion of the EGR system thereby enabling automatic adjustment to be made to the system to compensate for variations between EGR valves. Further, the basic venturi vacuum amplifier system as well as some feedback type systems allow the EGR as a fraction of air flow to increase or at best stay constant as manifold vacuum increases.

The closed loop exhaust gas recirculation control system described in co-pending, commonly assigned U.S. patent application Ser. No. 318,150 achieves optimum control of exhaust gas recirculation for maximum effectiveness of pollutant control and minimum loss in vehicle driveability and economy requirements. This type of EGR control provides a "feedback" from the exhaust gas recirculation flow as well as sensing engine air flow, thereby enabling continuous adjustments to be made within the system to compensate for changes in the sensed engine varibles. In this type of closed loop prior art system, an engine air flow responsive means operative to provide a differential pressure related to engine air flow, and a recirculated exhaust gas flow responsive means operative to provide a differential pressure related to recirculated exhaust gas flow, is communicated to a control valve assembly which through a plurality of diaphragms present therein sums these differential pressures in order to regulate an exhaust gas recirculation valve on a proportional basis. The control valve is biased so as to inhibit EGR flow at low engine air flow, and additional provisions for inhibiting EGR flow at high engine air flow as well as a temperature responsive member to inhibit EGR flow at a predetermined low ambient temperature is included in the closed loop system.

In this type of closed loop system it was initially believed that the exhaust gas flow responsive means should be located in the exhaust gas passage directly ahead (upstream) of the EGR valve, with the independent function of metering the amount of exhaust gas being performed by a limiting orifice located in the exhaust gas passage downstream of the EGR valve. Therefore, the prior art disclosure performs the flow sensing function by sensing the pressure drop across a venturi located upstream of the EGR valve in the recirculation exhaust gas passage. This provides a differential pressure which is a function of exhaust gas flow.

Placing the flow sensing element downstream of the EGR valve was an approach considered less desirable since the intake manifold vacuum would need to be used as a reference point to provide the differential pressure necessary to sense exhaust gas flow. Initial considerations of using intake manifold vacuum to sense exhaust gas flow was negated by the fact that pressure fluxuations in the intake manifold are much greater than the pressure fluxuations in the exhaust manifold. Therefore, placing the flow sensing element downstream of the EGR valve was an approach considered less desirable since the extreme intake manifold vacuum fluxations appeared difficult to handle. Following this analysis, the idea of utilizing intake manifold vacuum as a control function was not pursued.

The problems associated with sensing exhaust gas flow in the exhaust gas passage between the EGR valve and the exhaust manifold were caused by pressure pulsations arising from the cyclic nature of the internal combustion engine. Initially dampening devices were used to attempt to dampen out the pulsations and thereby create some degree of stability in the control system. However, dampening the exhaust pulsations caused limitations in responses of the recirculated ex-

haust gas flow signal. This limitation of response resulted in poor transient behavior of the control system in practice.

BRIEF SUMMARY OF THE INVENTION

The invention is a closed loop exhaust gas recirculation flow control system which provides a means to regulate and control the amount of exhaust gas recirculated to the intake manifold as a function of engine air flow and intake manifold vacuum. The exhaust gas recirculation flow control system disclosed herein is substantially insensitive to exhaust back pressure except when the flow becomes orifice limited. Also, the control system disclosed creates characteristic curves in which the percentage of exhaust gas recirculated is reduced at increased manifold vacuum. This characteristic is compatible with the need to maintain economy and driveability or engine performance while controlling emissions of oxides of nitrogen.

The invention is characterized by an engine air flow responsive means operative to provide a first signal corresponding to engine air flow, a means for generating a second signal in the intake manifold, and a receiving and regulating means which through a plurality of diaphragms sums these signals in order to regulate an exhaust gas recirculation valve on a continuous basis as a function of engine air flow and intake manifold vacuum. The invention is further characterized by an exhaust gas recirculation flow responsive means whereby the flow rate of exhaust gas recirculated is maintained at an established level for a given value of said first and second signal.

It is therefore the primary object of this invention to disclose a closed loop exhaust gas recirculation flow control system which achieves optimum control of exhaust gas recirculation for maximum effectiveness of pollution control and minimum loss in vehicle driveability.

It is a further object of the invention to provide an exhaust gas recirculation flow control system that controls the percentage of exhaust gases recirculated as a function of engine air flow and intake manifold vacuum.

It is a further object of this invention to provide an exhaust gas recirculation flow control system that enables a continuous control of the recirculation of the exhaust gases into the engine's intake manifold by means of a control valve assembly responsive to engine air flow, and intake manifold pressure, said control assembly utilizing a feedback loop in which recirculated exhaust flow is sensed.

Another object of this invention is to provide an exhaust gas recirculation flow control system wherein the amount of exhaust gas recirculated to the engine's intake manifold is inhibited at a predetermined low ambient temperature, inhibited at a low engine air flow, and/or also inhibited at a high engine air flow.

It is still a further object of the present invention to disclose an exhaust gas recirculation flow control system which is designed to be readily adjusted to compensate for tolerance variations of the various components within the control valve assembly. It is still a further object of this invention to disclose an exhaust gas recirculation flow control system that permits automatic compensation for tolerance variation of the EGR valve.

Yet another object of this invention is to provide an exhaust gas recirculation flow control system which may be utilized in combination with presently available exhaust gas recirculation valve and is economical to manufacture.

Other objects and advantages of the invention will become apparent from the description which follows, taken in conjunction with the accompanying drawings which show a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a diagramatic view of the exhaust gas recirculation flow control system.

FIG. **2** is a cross-sectional view of the preferred embodiment of the exhaust gas flow sensing means and its interrelationship with the standard EGR type valve.

FIG. **3** is a schematic view of a carburetor normally associated with an internal combustion engine and illustrating the engine air flow sensing means.

FIG. **4** is a cross-sectional view of the control valve assembly of the preferred embodiment of this invention.

FIG. **5** is a cross-sectional view of the control valve assembly shown in FIG. **1** and illustrating an alternate embodiment of the invention which incorporates a limiting function which cuts off the recirculated exhaust gas when intake manifold vacuum is low and engine air flow is high.

FIG. **6** graphically illustrates the test results of the invention as applied to an existing internal combustion engine.

DETAILED DESCRIPTION OF THE DRAWINGS

The exhaust gas recirculation flow control system according to the invention is shown in FIG. **1.** The control system is comprised of the engine air flow sensing means **40,** the exhaust gas flow sensing means **30,** and the control assembly **20** including the control valve member, and its related structure which controls the exhaust gas recirculation (EGR) valve **10.** An example of the temperature responsive member **50** which may be used in combination with the inventive system is shown in FIG. **1.**

Referring to FIG. **3,** a carburetor **41** of the down draft type is shown having an air-fuel induction passage **45** with an atmospheric air inlet **44** at one end and connected to the engine's intake manifold **47** at the opposite end. Passage **45** contains a fixed area venturi **42** and a throttle valve **46.** The latter is rotatably mounted on a part of the carburetor body across passage **45** in a manner to control the flow of air-fuel mixture into the intake manifold. Fuel is inducted from a nozzle, (not shown) projecting into or adjacent venturi **42.**

Throttle valve **46** is shown in its engine idle speed position essentially closing induction passage **45** and is rotatable to a nearly vertical position essentially unblocking passage **45.** A port or static tap **49** is provided in the throat of the venturi **42** which in combination with the venturi **42** and a conduit passage **48** mounted adjacent to static tap **49** comprises the engine air flow sensing means. The pressure or vacuum level at the static tap **49** is a function of the total air flow passing through venturi **42.** That is, engine air flow is regulated by the relative position of throttle valve **46.** As the throttle valve opens air flow increases which in turn causes the pressure at static tap **49** to decrease with respect to atmospheric pressure, or any pressure at an upstream stagnation point which is not shown. It has been shown that the stagnation point may also be be-

tween the static tap and the throttle plate in an area where the flow stream velocity is near zero. The vacuum or pressure which is created at static tap **49** for purposes of discussion will be labelled as P_v. Pressure signal P_v is communicated to the control valve housing **21** shown in FIG. **1** through conduit member **48.** The cross-sectional area of the throat of the venturi **42** is designated as A_5. The cross-sectional area A_5 is a design parameter which must be known since the disclosed system regulates EGR flow as a partial function of the air flow which passes through this venturi. A conduit passage **36** in the intake manifold **47** communicates the intake manifold pressure P_m sensed at port **36'** to the control valve housing **21.**

A spark port **43** is provided at a point just above the idle position of throttle valve **46,** which is traversed by the throttle valve **46** as it rotates to unblock passage **45.** The vacuum or pressure level at spark port **43** will vary as a function of the rotational movement of the throttle valve, the spark port **43** reflecting essentially atmospheric pressure upon closure of the throttle valve. The vacuum or pressure sensed at port **43** is communicated through conduit passage member **115** to the vacuum source **122** shown in FIG. **4.** With this modification incorporated into the system, exhaust gas recirculation will be inhibited at small throttle openings, as well as at low engine air flow for reasons which will become more apparent from the following description.

Although the engine air flow sensing means **40** as herein described relates to a down draft type carburetor **41,** element **40** can also be referred to more generally as any air throttling body since the disclosed system can be used in combination with any fuel metering system which senses air flow or in which an air flow sensor has been added.

Referring to FIG. **2,** the exhaust flow responsive means **30** is shown. A housing **31** has a passage **32** formed therein to which is connected a pipe **33** from the exhaust manifold and a pipe **34** connected to the intake manifold. Disposed within the passage **32** and fixedly secured thereto is a valve seat **38** having a cross-sectional area A_2. A conduit passage **37** is located between the valve seat **38** and an orifice **35** disposed downstream of valve seat **38.** The orifice **35** has a cross-sectional area A_1. Arrow E shows the direction of recirculated exhaust gas flow.

An EGR valve **10** which is of standard design is fixedly secured to the housing **31** by any conventional means such as bolting. The EGR valve is of the spring biased diaphragm type having a rod **12** fixedly secured to diaphragm **13.** Diaphragm **13** divides the housing **11** of the EGR valve into two separate chambers **14** and **15,** chamber **14** being exposed to ambient air through an opening **19** and chamber **15** communicating with control valve housing **21** (shown in FIG. **1**) through conduit passage **16.** Valve body **18** which is fixedly secured or integrally formed on rod **12** is biased against the valve seat **38** of housing **31** by spring **17** which has a predetermined spring force F_1. It is to be understood that as the pressure varies across the diaphragm **13** the rod and therefore the valve body **18** move towards or away from the valve seat **38** thereby controlling the amount of exhaust gas recirculated through passage **32** into the intake manifold **47.**

Exhaust flow sensing is accomplished by measuring the pressure drop across restriction **35.** Conduit passage member **37** which has an opening **37'** senses the exhaust gas pressure P_e in passage **32,** between EGR valve **10** and restriction **35** and communicates this pressure to control valve housing **21.** As discussed above, a conduit passage member **36** in the intake manifold **47** communicates the intake manifold pressure P_m at opening **36'** to the control valve assembly **21.** The differential pressure established by pressures P_e and P_m increases with the flow rate of exhaust gas passing through orifice **35** in a manner like the differential pressure between atmospheric pressure P_a and venturi pressure P_v increases with the flow rate of air passing through carburetor venturi **42** as described above. Orifice **35** having a cross-sectional area A_1 serves the additional function of limiting the maximum amount of exhaust gas that can be recirculated to the intake manifold. By sensing exhaust gas flow downstream of EGR valve **10** the exhaust gas recirculated to the intake manifold can become a function of not only engine air flow, but also a function of intake manifold vacuum which will become apparent from the description which follows below.

Referring now to FIG. **4,** the control valve assembly **20** of the exhaust gas recirculation flow control system is shown. The control valve housing **21** is of a laminated construction with sections **21***a* and **21***b* retaining a diaphragm **60** and sections **21***b* and **21***c* retaining a diaphragm **70** and sections **21***c* and **21***c* retaining a diaphragm **80** therebetween. These four sections form a cavity **22** which because of the diaphragms **60, 70** and **80** is divided into separate chambers **22***a*, **22***b*, **22***c* and **22***d*. These sections are secured to each other by any suitable means such as riveting, with cover section **21***e* completing the housing assembly. Disposed within cavity **22** and fixedly secured, through the use of distribution members **61** and **71,** to the diaphragm **60, 70** and **80** is a control valve member **23.** The portions of diaphragm **60, 70** and **80** which are included within the cavity **22** have "effective" cross-sectional areas A_6, A_7 and A_8 respectively. The "effective" area of a diaphragm is that area which is defined by the ratio of the resultant force to the applied pressure and therefore, the effective area is a function of both the outside diameter of the diaphragms within cavity **22** and the outside diameter of the pressure distribution members **61** and **71.**

Control valve member **23** is comprised essentially of three main parts, a stem portion **24,** an adjustment member **25** and a piston member **26.** Stem portion **24** is fixedly secured to diaphragms **60, 70** and **80** through distribution members **61** and **71.** Adjustment member **25** is threadably disposed within stem portion **24.** Stem portion **24** has a portion of its inner diameter **29** formed for receiving piston member **26.** Piston **26** is slidably assembled into the formed portion **29** and the disposition of diaphragms **60, 70** and **80** as well as distribution members **61** and **71** within cavity **22** relative to piston member **26** is determined by adjustment member **25.** The lower most extension of piston **26** has a valve **27** fixedly secured thereto. Valve **27** may be integrally formed with piston **26.** Valve **27** is adapted to seat against valve seat **92** as the piston **26** translates within stem portion **24.** The pressure signal P_{EGR} which is communicated from cavity **90** to the EGR valve port **16** is a function of the relative position of valve **27** and may be of a magnitude equal to atmospheric (P_a) or the source pressure (P_s) in cavity **122** or some value in between.

Control valve member **23** is biased by spring members **130** and **140.** Housing cover **21***e* is adapted to

receive spring **140** so that the force generated by spring **140** can act in an axial direction upon piston **26.** Similarly, housing chamber **21***a* is adapted to receive spring member **130** so that an adjustment screw **131** may be threadedly secured to housing cavity **21***a* and through spring retainer member **132** generate a force axially aligned with control valve member **23.** Utilization of the biasing forces generated by spring member **130** and spring member **140** permits adjustment of the complete control valve assembly to compensate for tolerance variations between the subassembly of distribution members **61** and **71,** stem **24** and diaphragms **60, 70** and **80.** Any suitable means biasing the control valve member **23** with an adjustment feature can be utilized to accomplish a similar result.

Housing section **21***a* is adapted to receive pressure signal P_v and by means of passage **21***a'* and conduit passage **48,** chamber **22***a* communicates with static tap **49** in venturi throat **45.** Housing section **21***b* is adapted to receive pressure signal P_m from the intake manifold and through passage **21***b'* and conduit passage **36,** chamber **22***b* communicates with the intake manifold **47.** Housing section **21***c* is adapted to receive pressure signal P_e and chamber **22***c* communicates, through passage **21***c'* and conduit passage **37,** with the exhaust gas passage **32.** Chamber cavity **22***d* is subject to a filtered source of atmospheric pressure P_a communicated to cavity **22***d* through passage **21***d'* formed in housing section **21***d.* Chamber **22***d* is also connected through passage **91** to a second cavity **90** formed in housing section **21***d.* The lower portion of passage **91** forms the valve seat **92** projecting into cavity **90.** Passage **91** has a cross-sectional area designated A_9. Housing cavity **90** communicates with chamber **15** of EGR valve **10** through EGR conduit passage **16** (see FIG. **2**) and housing section **21***d* passage **21***d*$_3$'). Cavity **90** is formed by securing housing section cover **21***e* to section **21***d.*

Cavity **90** has a second passage **95** which communicates with housing chamber **22***d.* The lower portion of this passage terminates in a valve seat **96.** A bimetallic strip **50** is mounted in cavity **90** secured to housing cover **21***e* by any conventional method such as riveting **51.** The bimetallic strip **50** senses temperature in the vicinity of the control valve assembly **20** i.e., the engine compartment temperature, and in response to a predetermined temperature valve member **97** will seat upon valve seat **96** and terminate the communication of pressure signal P_a from chamber **22***d* to cavity **90** through second passage **95.** By terminating pressure signal P_a through passage **95,** the pressure in cavity **90** becomes a function of P_s when valve **27** is closed. This function will be communicated to chamber **15** of EGR valve **10** and generate a force F_2 across diaphragm **13.** When F_2 becomes greater than F_1 (spring force generated by spring **17**) valve **18** will begin to open and exhaust gas will begin to flow through passage **32** into the intake manifold. This will be discussed in more detail in the operational discussion that follows. Other temperature responsive means can also be incorporated in this invention so that the control valve assembly **20** could also be made responsive to such temperature variables, as for example, the temperature of the engine coolant.

The combination of control valve cover **21***e*, housing section **21***d* and cover member **125,** creates a third cavity **122** within housing section **21***d.* Cavity **122** communicates with cavity **90** through orifice **111.** Housing section **21***d* is adapted to receive spark port signal P_s sensed at port **43** of induction passage **45** and cavity **122** communicates with the carburetor's induction passage **45** through housing passage **21***d*$_2$' and conduit passage **115.** A check valve **124** of standard design is disposed about the openings **123** of cavity **122** in order to insure an adequate power signal source regardless of variation in induction passage signal. An alternate source of power can be selected, namely, the intake manifold signal.

Referring to FIG. **5** an alternate embodiment of the invention is shown incorporating a limiting function which terminates EGR flow when intake manifold pressure P_m approaches atmospheric pressure P_a and engine air flow is high. The portions of the control valve assembly **20** which are the same as those shown in FIG. **1** carry the same reference numerals in FIG. **5.** Chamber cavity **22***d* is subject to a filtered source of atmospheric pressure P_a communicated to chamber **22***d* through passages **221** and filter element **222.** For purposes of clarity only that portion of passage **21***d*$_3$' that intersects with cavity **90** is shown. It is understood that as in FIG. **1,** passage **21***d*$_3$' communicates with chamber **15** of the EGR valve.

Control valve member **223** which is an alternate embodiment is referred to as a receiving or summing means and is comprised again essentially of three main parts, a stem portion **224,** an adjustment member **225** and a second stem portion **226** incorporating a valve body **227.** Stem portion **224** is fixedly secured to diaphragms **70** and **80** through distribution members **61, 71** and **261.** Stem portion **226** is secured to diaphragm **60** through distribution member **61** and at its lower extremity incorporates valve body **227.** Adjustment member **225** is threadedly disposed on one end of stem **224.** The opposite end or upper portion of stem **224** includes valve seat **228.** Stem **224** also has a central passage **229** which permits any signal in housing chamber **22***b* to communicate with cavity **90** when valve body **227** is unseated from valve seat **228.** It can readily be understood that when the force generated across diaphragm **60** acts in an upward direction, with a sufficient magnitude to overcome the spring force **130** valve body **227** will unseat from valve seat **228** and permit the signal present and chamber **22***b* P_m to be communicated through passage **229** to cavity **90** and through passage **21***d*$_3$' to chamber **15** of EGR valve **10.**

OPERATION

To simplify the understanding of the operation of the exhaust gas recirculation flow control system, the operation of the system immediately before the EGR flow control valve begins to open will first be considered. From this discussion it will be obvious to one skilled in the art that the amount of EGR recirculated to the intake manifold is a function of both engine air flow and intake manifold pressure. The function related to intake manifold pressure is obtained through controlling the relationship of the effective areas of the diaphragms. Therefore, once EGR begins to flow the overall effect of this function upon the control valve assembly can only be determined by looking at the net forces generated to open or close valve **27.** It will be obvious to those skilled in the art from the discussion that follows as to how the above engine parameters affect the net force generated on the control valve assembly to thereby control the recirculation of exhaust gas into the intake manifold.

For discussion purposes, manifold vacuum, venturi vacuum, etc., will be regarded as pressures, recognizing that they are normally negative with respect to atmospheric pressure.

The control valve assembly serves to regulate the pressure P_{EGR} which controls the opening and closing of the EGR valve. The position of the valve **27** with respect to the valve seat **92** is determined by the summation of forces on valve stem **24.** These forces consist of spring forces **130** and **140,** biasing the valve stem, and forces exerted by the three diaphragms **60, 70** and **80** under the action of the differential pressures across said diaphragms. As indicated above, diaphragm **60** has an effective area equal to A_6, diaphragm **70** has an effective area equal to A_7 and diaphragm **80** has an effective area of A_8.

Carburetor venturi pressure P_v is communicated from the carburetor through conduit passage **48** and housing passage **21***a'* to the top side of diaphragm **60** in chamber **22***a*. The pressure signal P_v decreases as the engine air flow increases through the carburetor. The intake manifold pressure, P_m, is communicated through conduit passage **36** and housing passage **21***b'* to chamber **22***b* and to the underside of diaphragm **60** or top side of diaphragm **70.** A filtered source of atmospheric pressure, P_a, is communicated through passage **21***d'* to chamber **22***d* or to the underside of diaphragm **80.** Recirculated exhaust gas pressure, P_e, is communicated from exhaust gas passage **32** between exhaust gas valve seat **38** and restriction **35,** to the top side of diaphragm **80** in chamber **22***c* through conduit passage **37** and housing passage **21***c'*. A pressure source, normally the spark port pressure, provides pressure signal P_s to chamber **122** through housing passage $21d_2'$ and conduit passage **115.** This pressure source P_s is maintained at the lowest attainable pressure at spark port **43** by check valve **124** which permits air flow only towards the intake manifold.

In the control valve assembly, an orifice **111** separates pressure P_s from chamber **90** and therefore P_{EGR} is some function of P_s, said function being determined by the position of valve **27** relative to valve seat **92,** or the net force on valve stem **24.**

When valve **27** opens fully, P_{EGR} becomes nearly equal to atmospheric pressure P_a. Since the cross-sectional area A_9 of passage **91** is substantially greater than the cross-sectional area of orifice **111,** atmospheric pressure, P_a, is communicated from chamber **22***d* through passage **91** and into cavity **90.** When valve **27** is fully closed, only P_s is communicated to cavity **90** and therefore, P_{EGR} will equal P_s. As pressure signal P_{EGR} decreases and approaches P_s, the force generated across diaphragm **13** of the EGR valve **10** increases sufficiently to overcome the biasing force F_1 due to the spring **17** and the EGR valve will begin to open permitting exhaust gas to be recirculated into the intake manifold. When P_{EGR} equals P_s, the EGR valve will be fully open.

The functional relationship between recirculated exhaust gas flow and air flow through the engine can easily be seen by considering the effect of only air flow on the control valve assembly when the EGR valve is closed. Under this condition, P_e is equal to P_m and the net force generated on control valve member **23** is directly related to the venturi pressure P_v in cavity **22***a* and the atmospheric pressure P_a in cavity **22***d*. The pressure differential $P_a - P_v$ increases with increasing air flow through the carburetor. The effective areas of diaphragms **60** and **80** are essentially equal $A_6 = A_8$ and all three diaphragms act directly on the valve stem. Diaphragm **70** not having a differential pressure across it will therefore not generate a force. Thus, an increase in air flow increases the differential $P_a - P_v$ and causes an increase in the upward force on the valve stem **24,** tending to close valve **27** and thereby start EGR flow by reducing the influence of P_a on P_{EGR}.

When exhaust gas begins to flow in passage **32,** a feedback signal tending to null the effect caused by the air flow through the carburetor is generated. The nulling effect is such that for a given air flow a certain EGR flow will be obtainable regardless of the variations in the EGR valve design parameters. This nulling or feedback effect is illustrated by considering the effect of exhaust gas flow when the EGR valve begins to open. As soon as the EGR valve opens and exhaust gases are permitted to flow in exhaust gas passage **32** past orifice **35,** P_e, the pressure upstream of the metering orifice, no longer equals P_m, the pressure downstream of the metering orifice or intake manifold pressure. This results in a differential pressure $P_e - P_m$ across diaphragm **70.** This differential pressure $P_e - P_m$ relates to EGR flow in the same way that $P_a - P_v$ relates to air flow. The essential difference, however, is that P_e and P_m act not only on diaphragm **70** but also on diaphragms **80** and **60** respectively. Since the effective area of diaphragm **80** is greater than the effective area of diaphragm **70,** an increase in P_e will result in a downward force on valve stem **23** thereby tending to move valve **27** from its valve seat **92** (open) and permit pressure P_a from chamber **22***d* to be communicated to cavity **90** and through passage $21d_3'$ to the EGR valve. The pressure in chamber **15** of the EGR valve will then increase and approach atmospheric pressure which will cause the EGR valve to close. The intake manifold pressure, P_m, in cavity **22***b* has a similar influence across diaphragm **60** but in the opposite direction of the force generated across diaphragm **80.** It can therefore be seen that an increase in EGR flow, which results in an increase in the pressure differential $P_e - P_m$, which in turn will increase the downward force on the control valve member **23** causing valve **27** to move away from valve seat **92** thereby permitting pressure signal P_a to be communicated to chamber **90** resulting in P_{EGR} becoming a greater function of P_a rather than P_s and thereby beginning to close the EGR valve by reducing the force generated across diaphragm **13** in the EGR valve. The above described exhaust gas flow sensing function is referred to as the closed loop control of the exhaust gas flow recirculation system.

An additional function of the restriction **35** in the exhaust gas passage **32** is to limit the maximum amount of exhaust gas recirculated to the intake manifold. When the EGR flow becomes limited by the effect of orifice **35** the pressure differential $P_e - P_m$ remains relatively constant and as a result further increases in air flow increases the closing force on the valve. Under these conditions the spark port pressure will continue to decrease and approach atmospheric pressure. Check valve **124** is designed to maintain P_s at its former level rather than permit it to decrease and approach atmospheric pressure present at the spark port. The effect of check valve **124** maintaining P_s at its former level results in the EGR valve maintaining its former position. Therefore, the combination of reservoir **122** and check valve **124** maintains an adequate pressure source regardless of the variations in engine air flow or engine

manifold pressure when EGR flow is maximized and regardless of whether the reservoir is controlled by spark port pressure or by manifold pressure. The EGR valve is thereby enabled to be operative at very low pressure levels while still having the capability of delivering EGR flow at pressure levels nearly equal to atmospheric pressure.

The functional relationship between recirculated exhaust gas flow and intake manifold pressure is obtained by permitting the effective area of diaphragm **60** to be different than the effective area of diaphragm **80.** This will become clear to one skilled in the art considering a condition where the effective areas of diaphragm **60** and diaphragm **80** have equal effective areas. Under this condition manifold pressure P_m will have little effect on the EGR flow. Before EGR begins to flow P_e equals P_m, and the force contribution of diaphragm **70** to the overall net force on valve stem **23** is zero. If the area of diaphragm **60** is greater than that of diaphragm **80,** an increase in manifold pressure P_m (equal to P_e) will contribute an upward force to the net force on valve stem **23** and assist in closing valve **27** causing EGR to start flowing at a lower air flow. As air flow increases, the effect is for EGR flow to remain higher at high values of intake manifold pressure P_m (low vacuum) than at lower levels of intake manifold pressure.

It can therefore be easily seen that the net force operating on valve stem **23** can be independently controlled by selecting diaphragm **60** to have a larger effective area than diaphragm **80** and thereby cause intake manifold pressure in chamber **22***b* to independently affect the force required to move valve **27** relative to valve seat **92.** This is effectively illustrated in FIG. **6.** Note that at six inches of manifold vacuum represented by curve D the exhaust gas recirculated to the intake manifold begins at a substantially lower air flow than that shown by curve E where the intake manifold vacuum is **14** inches of vacuum. Therefore, the percentage of EGR flow recirculated to the intake manifold is not only a function of air flow as described above, but also a function of intake manifold vacuum.

By modifying and changing the various design parameters shown herein and, for example, by using intake manifold pressure instead of spark port pressure as a source pressure in reservoir **122,** different criteria for affecting "cut in" and "cut off" of EGR flow can be accomplished.

The alternate embodiment of control valve **20** shown in FIG. **6** provides the feature of a complete cut off function when the intake manifold pressure approaches atmospheric pressure and engine air flow is high. This is desirable to permit full utilization of the power potential of the engine which is not normally associated with urban driving. Under these conditions normally the engine air flow is high and the manifold pressure is relatively close to atmospheric pressure. At high engine air flows the pressure signal P_v in chamber **22***a* will be substantially lower than the pressure signal P_m in chamber **22***b*. The net effect of the summation of these two pressure signals will be to cause an upward force on diaphragm **60.** As diaphragm **60** deflects upwards valve **227** is caused to unseat from valve seat **228** thereby uncovering a passage through stem **224** which allows pressure signal P_m to be communicated to chamber **90.** The effect of communicating pressure signal P_m, which is approaching atmospheric pressure, to chamber **90** will cause pressure signal P_{EGR} to become a greater function of P_m. Pressure signal P_{EGR} is communicated to chamber **15** of EGR valve **10** and as P_{EGR} approaches P_m the balance of forces across diaphragm **13** of EGR valve **10** will equalize each other thereby permitting spring **17** to bias valve stem **12** and valve body **18** towards valve seat **38.** The effect of this cut off function is to stop the recirculation of the exhaust gases through exhaust gas passage **32** to the intake manifold when P_m approaches P_a and engine air flow is high. Therefore, under these conditions full utilization of the engine's power potential is available and in effect provide more economical operational characteristics. As the air flow declines, the pressure differential $P_v - P_m$ across diaphragm **60** will be insufficient to keep valve **227** unseated, and therefore valve **227** will seat on valve seat **228** and permit the net forces across the control valve assembly to again be a function of the engine's air flow and intake manifold pressure as earlier discussed.

As was described above, the temperature responsive element **50,** as shown in FIG. **4,** can be caused to react making the control valve responsive to low and/or high ambient or engine compartment temperature in order to inhibit EGR flow when either of these conditions exist. That is, as the engine compartment temperature decreases a predetermined temperature is eventually reached which will cause the bimetal strip to bend downwardly away from valve seat **96,** thereby opening passage **95** to cavity **90** and permitting pressure signal P_a to communicate with the pressure signal P_{EGR} in cavity **90.** This results in P_{EGR} being a greater function of P_a than P_s and since P_{EGR} is communicated through passage $21d_3'$ and passage **16** to chamber **15** of the EGR valve, the EGR valve will begin to close. Temperature element **50** will maintain an open position until ambient temperatures have reached a predetermined level thereby inhibiting EGR flow below this predetermined level.

Whenever valve **27** as well as valve **97** is not in contact with its respective valve seat, there is a continuous flow of fresh air through passage **21***b'*, **91** or **95** into cavity **90** and into cavity **122.** If this fresh air was permitted to continue to travel through passage $21d_2'$ and into the spark port area of the carburetor these large amounts of fresh air would create air fuel ratio errors and adversely affect the operation of the engine. Orifice **111** is designed to serve the function of preventing large amounts of fresh air to flow into the carburetor spark port area. Check valve **124** as shown in FIG. **4,** serves the purpose of preventing the flow of air from the spark port passage or alternately from the intake manifold should the intake manifold be used as a source pressure, to chamber **122.** As earlier discussed, it also serves the function of maintaining P_s at a level different than the spark port pressure.

Referring to FIG. **7,** actual test results are graphically illustrated. Lines A, B and C represents plots of an EGR system designed for EGR flows of exactly **10, 20** and **30** percent of the engine air flow respectively. Line D is a plot of the disclosed system wherein intake manifold vacuum is **6** inches of mercury. Line E is a plot of the exhaust gas recirculated to the intake manifold at a vacuum level of **14** inches of mercury. As discussed above, the curves illustrated indicate the objects of the invention, since EGR is inhibited at low engine air flows and also EGR flow is illustrated as a function of not only engine air flow, but also intake manifold pressure.

Although only one preferred embodiment and an alternate embodiment showing the cut off function has been illustrated in the accompanying figures and description of the foregoing specification, it is especially understood that various changes may be made to the embodiment shown and described without departing from the spirit and scope of the invention as will now be apparent to those skilled in the art. Also, it will be apparent that changes may be made to the invention as set forth in the appended claims and in some instances certain features of the invention may be used to advantage without corresponding use of other features. For example, it was pointed out that the control of the control valve member **23** can be easily modified by changing some of the design parameters, (i.e. size of certain of the pressure sensitive elements contained in the housing **21.** Also, on a qualitative basis, control valve **23** can control the EGR flow directly. However, since the venturi pressure signals are relatively low and since the EGR valve must have a significant cross sectional area, this approach would require very large diaphragms and would thus be impractical. Accordingly, it is intended that the illustrative and descriptive materials herein be used to illustrate the principles of the invention and not to limit the scope thereof.

I claim:

1. In combination with an internal combustion engine of the type having a carburetor with a venturi passage and a spark port, an intake manifold between said carburetor and the engine; a recirculated exhaust gas passage directing a portion of the exhaust gases from the engine to the intake manifold and valve means disposed within said exhaust gas passage for controlling the flow of recirculated exhaust gas to the intake manifold, the improvement comprising:

means for generating a first signal corresponding to engine air flow;

means for generating a second signal corresponding to intake manifold pressure; and

means for receiving said first and second signals, said receiving means operative to control said valve means whereby the flow of exhaust gas recirculated to said intake manifold is a function of engine air flow and intake manifold pressure, said receiving means further including means for receiving a third signal corresponding to recirculated exhaust gas flow, so that said receiving means is operative to maintain the flow through said recirculated exhaust gas passage as a function of said first, second and third signals.

2. The combination as claimed in claim **1** including means for sensing the ambient engine compartment temperature, said sensing means operative to control said valve means independent of said first, second and third signals until the engine compartment temperature has reached a predetermined temperature.

3. The combination as claimed in claim **1** wherein said receiving means includes a source of pressure for operating said valve means.

4. The combination as claimed in claim **1** wherein said receiving means further includes means for terminating the operative effect of said first signal when said second signal has reached a predetermined value.

5. The combination as claimed in claim **1** wherein said means for generating a second signal includes:

a restriction disposed in the recirculated exhaust gas passage between said intake manifold and said valve means, said restriction limiting the maximum flow of exhaust gas into the intake manifold; and

wherein said second and third signal senses the pressures on each side of said restriction whereby said receiving means receives signals corresponding to the differential pressure across said restriction.

6. The combination as claimed in claim **1** including means for sensing the ambient engine compartment temperature, said sensing means operative to control said valve means independent of said first, second and third signals until the engine compartment temperature has reached a predetermined temperature.

7. The combination as claimed in claim **1** wherein said receiving means includes a source of pressure for operating said valve means.

8. The combination as claimed in claim **4** including means for sensing the ambient engine compartment temperature, said sensing means operative to control said valve means independent of said first, second and third signals until the engine compartment temperature has reached a predetermined temperature.

9. The combination as claimed in claim **4** wherein said receiving means includes a source of pressure for operating said valve means.

10. The combination as claimed in claim **8** wherein said receiving means includes a source of pressure for operating said valve means.

11. The combination as claimed in claim **5** wherein said receiving means further includes means for terminating the operative effect of said first signal when said second signal has reached a predetermined value.

12. The combination as claimed in claim **11** including means for sensing the ambient engine compartment temperature, said sensing means operative to control said valve means independent of said first, second and third signals until the engine compartment temperature has reached a predetermined temperature.

13. The combination as claimed in claim **5** including means for sensing the ambient engine compartment temperature, said sensing means operative to control said valve means independent of said first, second and third signals until the engine compartment temperature has reached a predetermined temperature.

14. The combination as claimed in claim **5** wherein said receiving means includes a source of pressure for operating said valve means.

15. The combination as claimed in claim **12** wherein said receiving means includes a source of pressure for operating said valve means.

16. The combination as claimed in claim **1** wherein said receiving means comprises:

a first conduit having one end communicating with said carburetor and adapted to transmit a signal corresponding to air flow through said carburetor, the other end of said first conduit communicating with said receiving means;

a second conduit having one end communicating with said intake manifold and adapted to transmit a signal corresponding to intake manifold pressure, the other end of said second conduit communicating with said receiving means;

a third conduit having one end communicating with said recirculated exhaust gas passage and adapted to transmit a signal corresponding to recirculated exhaust gas pressure, the other end of said third conduit communicating with said receiving means;

a fourth conduit having one end communicating with said carburetor spark port and adapted to transmit

a signal corresponding to spark port pressure, the other end of said fourth conduit communicating with said receiving means;

a fifth conduit adapted to receive an atmospheric pressure signal, one end of said fifth conduit communicating with atmospheric pressure, the other end of said fifth conduit communicating with said receiving means; and

a sixth conduit having one end communicating with said receiving means and the other end communicating with said valve means, said sixth conduit adapted to transmit a signal to said valve means which is a function of said signals transmitted to said receiving means.

17. The combination as claimed in claim **15** wherein said receiving means comprises:

a first conduit having one end communicating with said carburetor and adapted to transmit a signal corresponding to air flow through said carburetor, the other end of said first conduit communicating with said receiving means;

a second conduit having one end communicating with said intake manifold and adapted to transmit a signal corresponding to intake manifold pressure, the other end of said second conduit communicating with said receiving means;

a third conduit having one end communicating with said recirculated exhaust gas passage between said valve means and said restriction and adapted to transmit a signal corresponding to recirculated exhaust gas pressure, the other end of said third conduit communicating with said receiving means;

a fourth conduit having one end communicating with said carburetor spark port and adapted to transmit a signal corresponding to spark port pressure, the other end of said fourth conduit communicating with said receiving means;

a fifth conduit adapted to receive an atmospheric pressure signal, one end of said fifth conduit communicating with atmospheric pressure, the other end of said fifth conduit communicating with said receiving means; and

a sixth conduit having one end communicating with said receiving means and the other end communicating with said valve means, said sixth conduit adapted to transmit a signal to said valve means which is a function of said signals transmitted to said receiving means.

18. In combination with an internal combustion engine of the type having a carburetor with a venturi passage and a spark port, an intake manifold between said carburetor and the engine; a recirculated exhaust gas passage directing a portion of the exhaust gases from the engine to the intake manifold and valve means disposed within said exhaust gas passage for controlling the flow of recirculated exhaust gas to the intake manifold, the improvement comprising:

means for generating a first signal corresponding to engine air flow;

means for generating a second signal corresponding to intake manifold pressure; and

means for receiving said first and second signals, said receiving means operative to control said valve means whereby the flow of exhaust gas recirculated to said intake manifold is a function of engine air flow and intake manifold pressure, said receiving means including:

a first conduit having one end communicating with said carburetor and adapted to transmit a signal corresponding to air flow through said carburetor, the other end of said first conduit communicating with said receiving means;

a second conduit having one end communicating with said intake manifold and adapted to transmit a signal corresponding to intake manifold pressure, the other end of said second conduit communicating with said receiving means;

a third conduit having one end communicating with said recirculated exhaust gas passage and adapted to transmit a signal corresponding to recirculated exhaust gas pressure, the other end of said third conduit communicating with said receiving means;

a fourth conduit having one end communicating with said carburetor spark port and adapted to transmit a signal corresponding to spark port pressure, the other end of said fourth conduit communicating with said receiving means;

a fifth conduit adapted to receive an atmospheric pressure signal, one end of said fifth conduit communicating with atmospheric pressure, the other end of said fifth conduit communicating with said receiving means; and

a sixth conduit having one end communicating with said receiving means and the other end communicating with said valve means, said sixth conduit adapted to transmit a signal to said valve means which is a function of said signals transmitted to said receiving means.

19. In combination with an internal combustion engine of the type having a carburetor with a venturi passage, an intake manifold between said carburetor and the engine, a recirculated exhaust gas passage connected between said engine intake manifold and to said engine exhaust to direct a portion of the exhaust gas from the engine to the intake manifold, the improvement comprising:

engine air flow sensing means operative to provide a first signal corresponding to air flow through the carburetor;

a first valve means disposed in the exhaust gas passage;

a first control means for receiving said first signal and for controlling said first valve means as a function of air flow through the carburetor, so that said first valve means regulates the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage;

means for sensing engine intake manifold pressure and providing a second signal corresponding to intake manifold pressure; and

a second control means for receiving said second signal and for controlling said first valve means as a function of engine intake manifold pressure, so that the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage is a function of air flow through the carburetor and intake manifold pressure, said first and second control means including second valve means which controls said first valve means in response to changes in air flow through the carburetor and intake manifold pressure;

means for sensing temperature which is a function of engine temperature and providing a third signal;

means for supplying said third signal to said first valve means so that the flow of recirculated exhaust gas entering the intake manifold is a function of engine temperature;

means for sensing recirculated exhaust gas flow and providing a fourth signal which is a function of exhaust gas flow; and

means for supplying said fourth signal to said second control means so that the flow of exhaust gas entering the intake manifold is a function of air flow through the carburetor, intake manifold pressure, and recirculated exhaust gas flow.

20. In combination with an internal combustion engine of the type having a carburetor with a venturi passage, an intake manifold between said carburetor and the engine, a recirculated exhaust gas passage connected between said engine intake manifold and to said engine exhaust to direct a portion of the exhaust gas from the engine to the intake manifold, the improvement comprising:

engine air flow sensing means operative to provide a first signal corresponding to air flow through the carburetor;

a first valve means disposed in the exhaust gas passage;

means for sensing engine intake manifold pressure and providing a second signal corresponding to intake manifold pressure;

a first control means for receiving said first signal and for controlling said first valve means as a function of air flow through the carburetor, so that said first valve means regulates the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage, said first receiving means further including means for terminating the operative effect of said first signal when said second signal has reached the predetermined value;

a second control means for receiving said second signal and for controlling said first valve means as a function of engine intake manifold pressure, so that the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage is a function of air flow through the carburetor and intake manifold pressure;

means for sensing recirculated exhaust gas flow and providing a fourth signal which is a function of exhaust gas flow; and

means for supplying said fourth signal to said second control means so that the flow of exhaust gas entering the intake manifold is a function of air flow through the carburetor, intake manifold pressure, and recirculated exhaust gas flow.

21. In combination with an internal combustion engine of the type having a carburetor with a venturi passage, an intake manifold between said carburetor and the engine, a recirculated exhaust gas passage connected between said engine intake manifold and to said engine exhaust to direct a portion of the exhaust gas from the engine to the intake manifold, the improvement comprising:

engine air flow sensing means operative to provide a first signal corresponding to air flow through the carburetor;

a first valve means disposed in the exhaust gas passage;

means for sensing engine intake manifold pressure and providing a second signal corresponding to intake manifold pressure;

a first control means for receiving said first signal and for controlling said first valve means as a function of air flow through the carburetor, so that said first valve means regulates the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage;

a second control means for receiving said second signal and for controlling said first valve means as a function of engine intake manifold pressure, so that the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage is a function of air flow through the carburetor and intake manifold pressure, said first and second control means including a source of pressure for operating said valve means;

means for sensing recirculated exhaust gas flow and providing a fourth signal which is a function of exhaust gas flow; and

means for supplying said fourth signal to said second control means so that the flow of exhaust gas entering the intake manifold is a function of air flow through the carburetor, intake manifold pressure, and recirculated exhaust gas flow.

22. In combination with an internal combustion engine of the type having a carburetor with a venturi passage, an intake manifold between said carburetor and the engine, a recirculated exhaust gas passage connected between said engine intake manifold and to said engine exhaust to direct a portion of the exhaust gas from the engine to the intake manifold, the improvement comprising:

engine air flow sensing means operative to provide a first signal corresponding to air flow through the carburetor;

a first valve means disposed in the exhaust gas passage;

means for sensing engine intake manifold pressure and providing a second signal corresponding to intake manifold pressure;

a first control means for receiving said first signal and for controlling said first valve means as a function of air flow through the carburetor, so that said first valve means regulates the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage;

a second control means for receiving said second signal and for controlling said first valve means as a function of engine intake manifold pressure, so that the flow of exhaust gas entering the engine intake manifold through said exhaust gas passage is a function of air flow through the carburetor and intake manifold pressure;

means for sensing recirculated exhaust gas flow and providing a fourth signal which is a function of exhaust gas flow, said means for sensing recirculated exhaust gas flow including:

a restriction disposed in the recirculated exhaust gas passage between said intake manifold and said valve means, said restriction limiting the maximum flow of exhaust gas into the intake manifold, and wherein said second and fourth signal senses the pressures on each side of said restriction whereby said second control means receives signals corresponding to the differential pressure across said restriction; and

means for supplying said fourth signal to said second control means so that the flow of exhaust gas entering the intake manifold is a function of air flow

through the carburetor, intake manifold pressure, and recirculated exhaust gas flow.

23. The combination as claimed in claim **19** wherein said first receiving means further includes means for terminating the operative effect of said first signal when said second signal has reached the predetermined value.

24. The combination as claimed in claim **21** wherein said first receiving means further includes means for terminating the operative effect of said first signal when said second signal has reached the predetermined value.

25. The combination as claimed in claim **27** wherein said first receiving means further includes means for terminating the operative effect of said first signal when said second signal has reached the predetermined value.

26. The combination as claimed in claim **19** wherein said first and second control means includes a source of pressure for operating said valve means.

27. The combination as claimed in claim **20** wherein said first and second control means includes a source of pressure for operating said valve means.

28. The combination as claimed in claim **27** wherein said first and second control means includes a source of pressure for operating said valve means.

29. The combination as claimed in claim **23** wherein said first and second control means includes a source of pressure for operating said valve means.

30. The combination as claimed in claim **25** wherein said first and second control means includes a source of pressure for operating said valve means.

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