

[54] EXHAUST GAS RECIRCULATION SYSTEM
WITH HIGH RATE VALVE[75] Inventor: Donald J. Pozniak, Sterling Heights,
Mich.[73] Assignee: General Motors Corporation,
Detroit, Mich.

[22] Filed: July 23, 1973

[21] Appl. No.: 381,754

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

[51] Int. Cl.² F02M 25/06

[58] Field of Search 123/119 A

[56] References Cited

UNITED STATES PATENTS

2,317,582	4/1943	Bicknell	123/119 A
2,408,846	10/1946	Golden et al.	123/119 A
2,543,194	2/1951	Paris, Jr.	123/119 A
3,605,710	9/1971	Helwig	123/119 A
3,626,913	12/1971	Sarto	123/119 A
3,643,640	2/1972	Kraus et al.	123/119 A
3,827,414	8/1974	Sarto	123/119 A

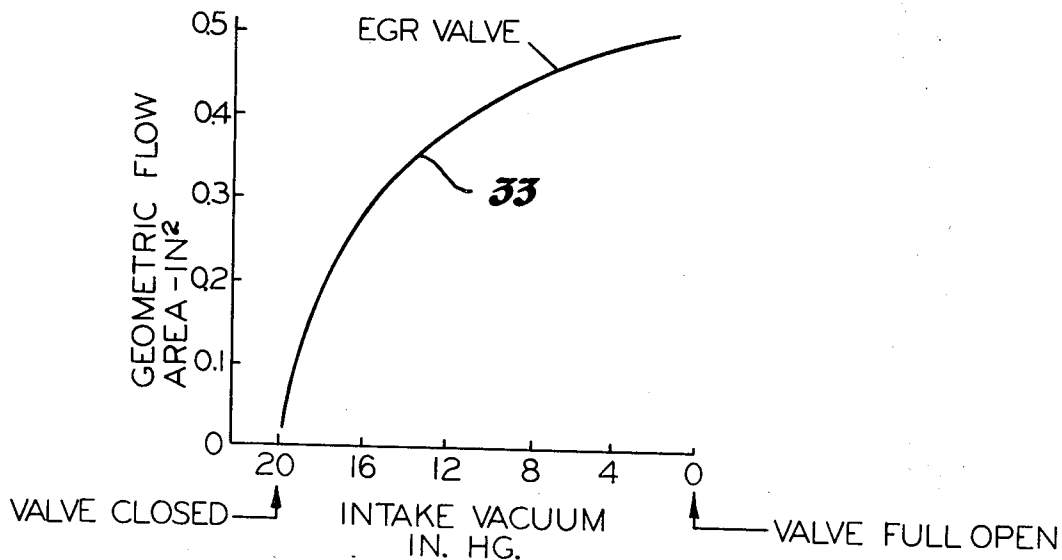
Primary Examiner—Charles J. Myhre
Assistant Examiner—Sheldon Richter
Attorney, Agent, or Firm—J. C. Evans

[57]

ABSTRACT

An exhaust gas recirculation system for an internal combustion engine with a carburetor and a throttle for controlling air-fuel flow to the intake manifold of the vehicle; an exhaust gas recirculation conduit is connected between the vehicle exhaust and an induction passageway between the carburetor and the throttle. Valve means are operated in accordance with the intake manifold pressure to vary the amount of exhaust gas recirculation into the induction manifold, the valve having a high rate flow area scheduled to produce an increasing ratio of exhaust gas recirculation to intake air flow so as to continually increase the exhaust gas recirculation on increasing engine load thereby to maintain reduced vehicle NO_x emissions during all operating conditions.

3 Claims, 11 Drawing Figures



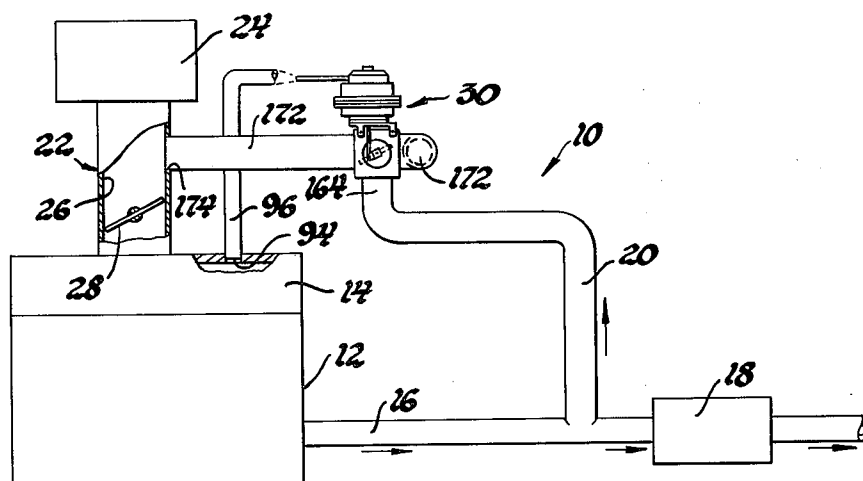


Fig. 1

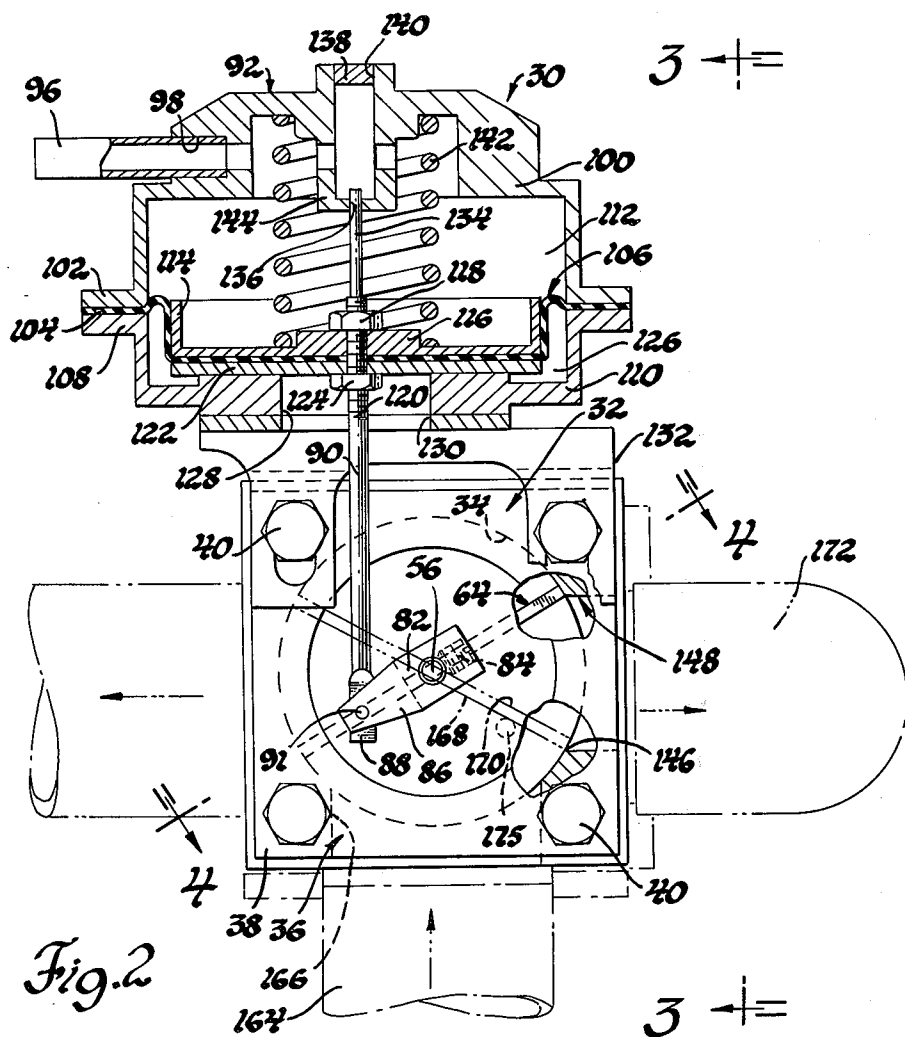
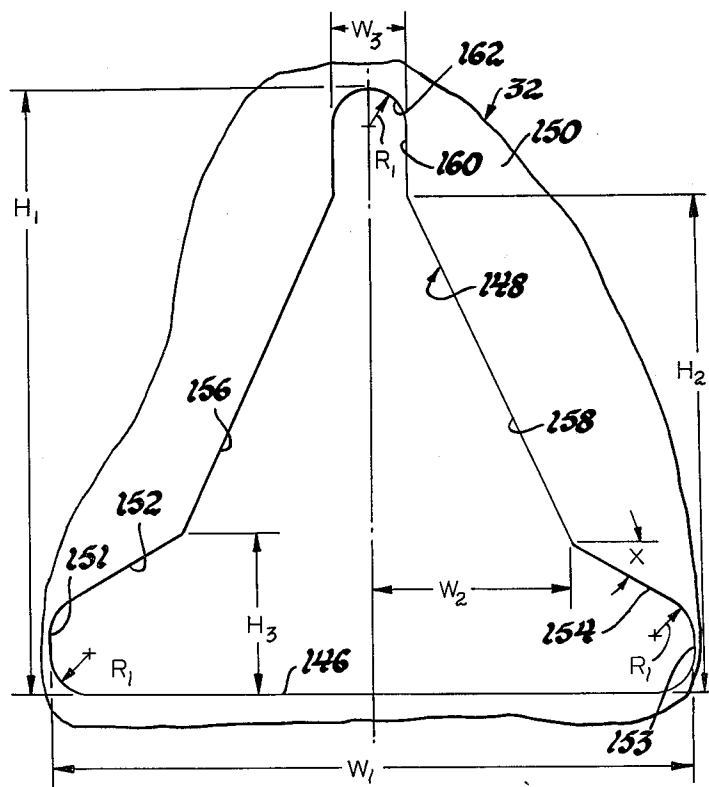
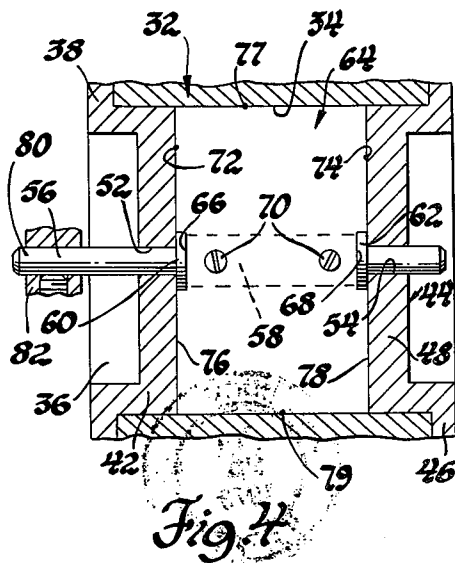
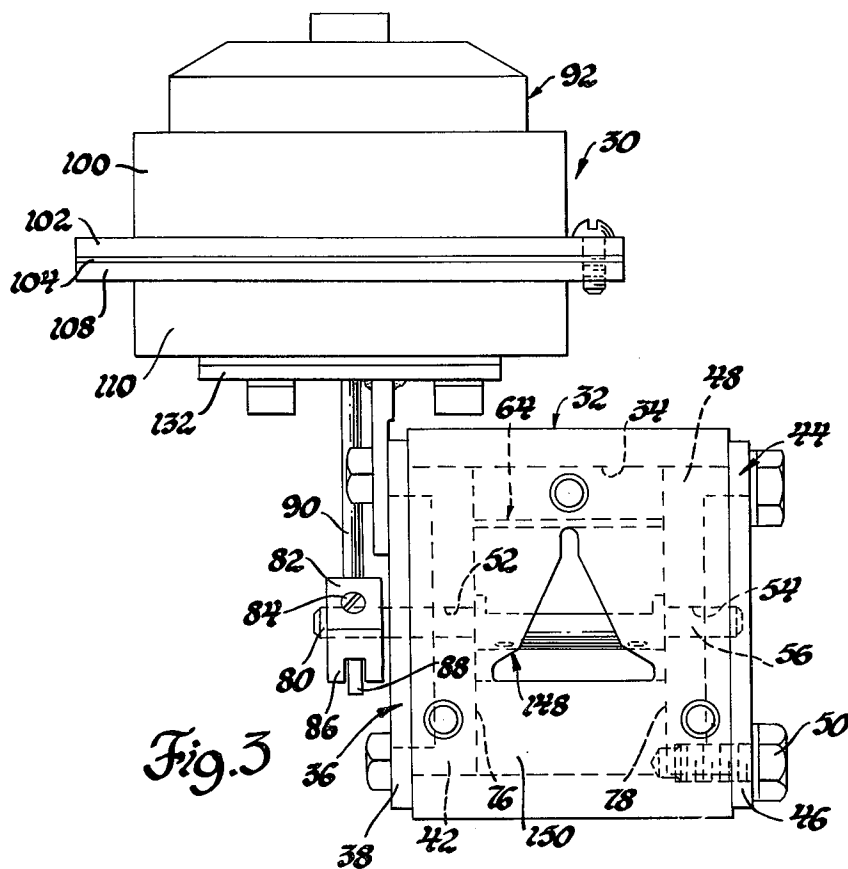


Fig. 2



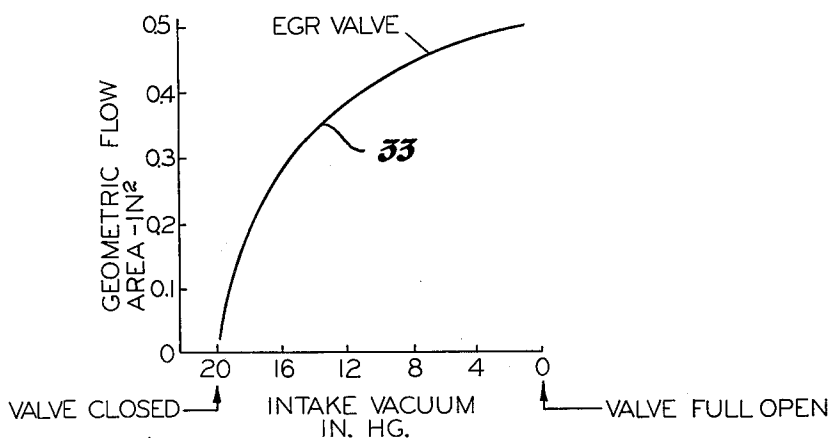


Fig. 6

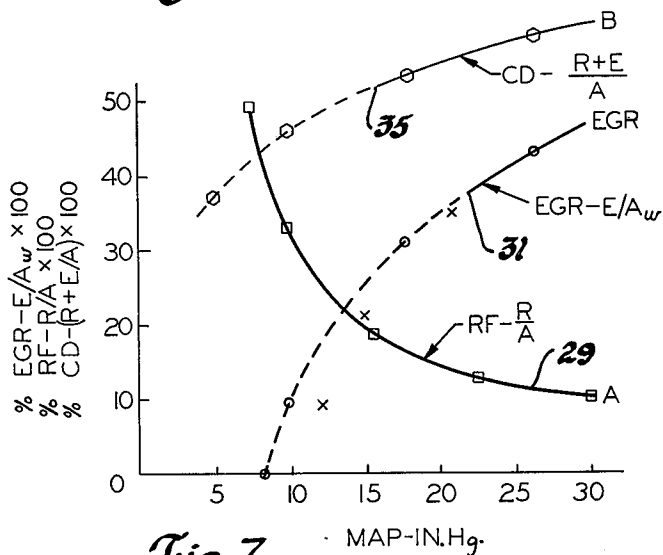


Fig. 7

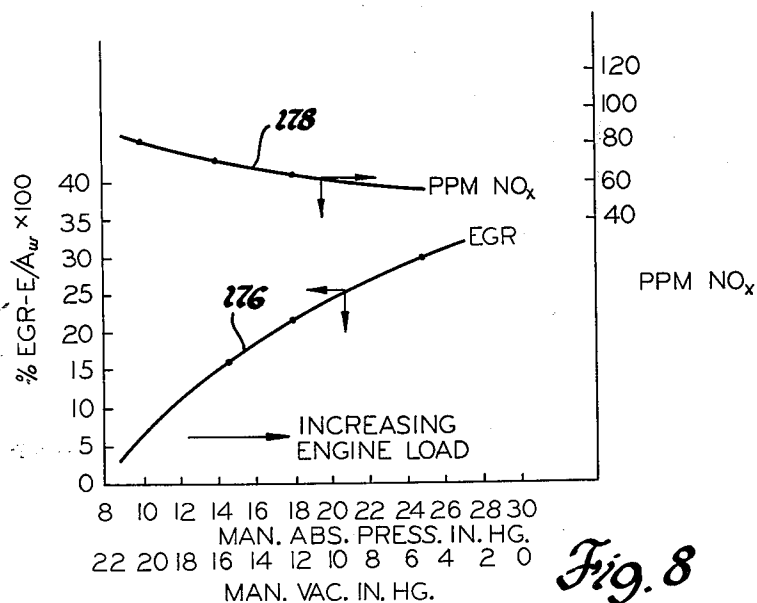


Fig. 8

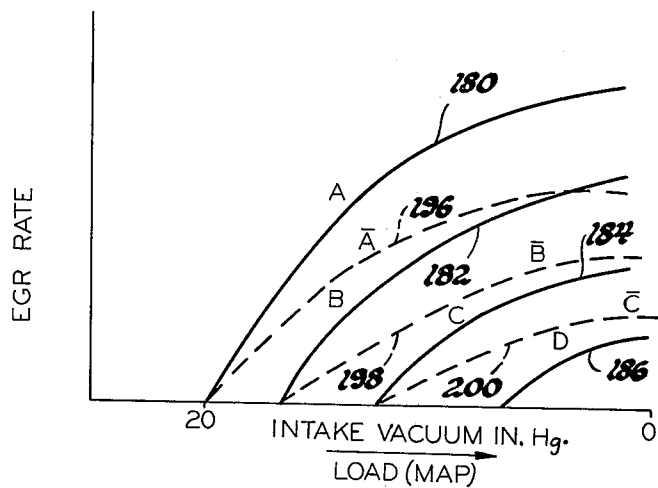


Fig. 9

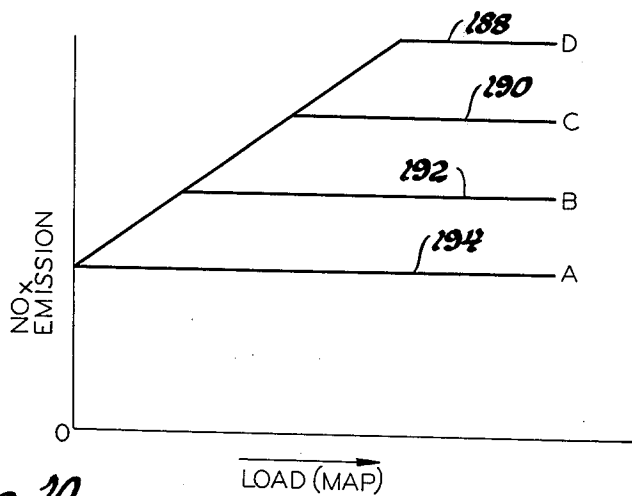


Fig. 10

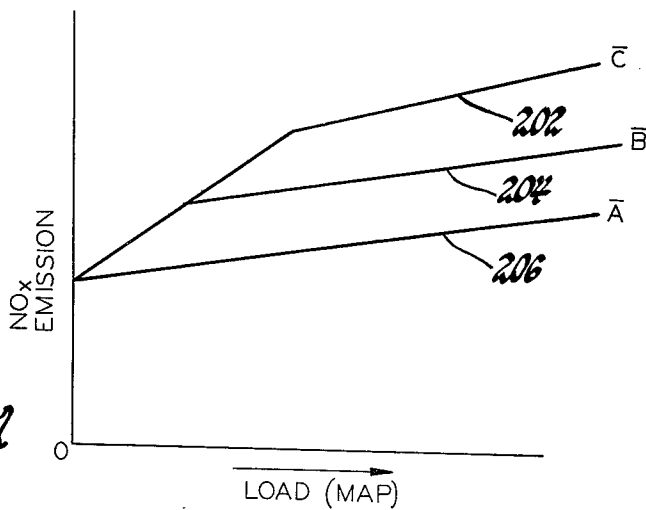


Fig. 11

EXHAUST GAS RECIRCULATION SYSTEM WITH HIGH RATE VALVE

This invention relates to exhaust gas recirculation systems for controlling emissions in vehicles and more particularly to such systems wherein valve means regulate the flow of exhaust gas recirculation from the exhaust manifold to the intake manifold in accordance with vehicle load changes.

Under very light engine loading, those cases where engine operation is under highly throttled conditions, a significant amount of exhaust gas is retained in the combustion chamber of the vehicle. This is due to both the throttling effect and the fact that there is a clearance volume effect in all internal combustion engines. The high throttle condition and the presence of a clearance volume at the end of a piston stroke causes retention of exhaust gas within the cylinder hereafter referred to as internal exhaust gas recirculation or residual fraction. Since the exhaust gas fraction of the combustion chamber mixture is large during highly throttled engine operation, the formation of NO_x in the combustion chamber is severely inhibited. On the other hand, in internal combustion systems utilizing exhaust gas recirculation for control of emissions, under highly loaded engine operation the clearance volume effect and throttling effect is reduced because of the increased intake manifold pressure and open throttle position. This causes the residual fraction to be quite small as compared to the residual fraction during operation of the engine under light load conditions. Accordingly, internal combustion gasoline engines are characterized by significantly more NO_x emissions during high load operation, for example, under conditions where the vehicle is accelerated, than during light load conditions as for example, when it is operating at idle.

In order to optimize the exhaust gas recirculation rate to maintain reduced vehicle NO_x emissions during all operating conditions, the combustion chamber exhaust gas residual fraction or internal EGR should be maintained as substantial as possible but slightly less than that cylinder dilution or combustion chamber dilution that will result in engine misfire. In a typical internal combustion engine, the engine residual fraction, the ratio of residual exhaust gases in the combustion chamber and the air intake into the cylinder will be substantial at idle conditions and will decrease to a relatively reduced level at low inlet manifold vacuums. To optimize operation of the exhaust gas recirculation rate, the total charge dilution of a combustion chamber mixture should be that which will produce minimum NO_x emissions for different intake manifold vacuums. The difference between the desired total dilution and the internal EGR or residual fraction is the amount of exhaust gas recirculation that is required for minimum NO_x emissions.

The exhaust gas retained in the combustion chamber after each exhaust event is the result of both the clearance volume in the combustion chamber and a reflection of the degree of throttling of the engine. For example, a low compression ratio engine has a larger clearance volume to piston displacement ratio than a high compression ratio engine. Hence, the percentage of exhaust gas retained in the combustion chamber after the exhaust event is larger in the case of the low compression engine than in the case of a high compression engine. Throttling of the internal combustion engine results in a condition such that the combustion chamber

does not receive a full charge of intake air-fuel mixture. As the engine becomes more severely throttled, the ratio between the amount of retained exhaust gas and the intake air-fuel mixture increases. Hence, under highly throttled conditions, the percentage of exhaust gas contained in the combustion chamber is high and it has been observed that under these conditions, engine NO_x emissions are quite low. On the other hand, where the engine is only slightly throttled, as under high engine load conditions, the percentage of exhaust gas contained in the combustion chamber is small. It is observed that under these conditions, the engine NO_x emissions are high.

An object of the present invention is to minimize NO_x emissions from an internal combustion engine by the provision of exhaust gas recirculation valve means operated in accordance with changes in intake manifold vacuum and including a scheduled flow area there-through to produce an increasing ratio of exhaust gas recirculation to intake air flow which increases in accordance with increasing engine load as reflected by the absolute pressure in the intake manifold of the engine.

Another object of the present invention is to improve the control of exhaust gas emissions in an internal combustion engine by the method of determining the residual fraction of exhaust in the combustion chamber of the vehicle at different intake manifold pressure conditions; determining the desired total charge dilution in the combustion chamber at which NO_x emissions are minimized without effecting engine performance; selecting a scheduled flow area in an exhaust gas recirculation control valve and selectively opening the scheduled flow area to produce an increasing exhaust gas to inlet air ratio that will combine with the residual fraction in the combustion chamber to produce the desired combustion chamber dilution.

yet another object of the present invention is to provide an improved exhaust gas control system for an internal combustion engine having an air-fuel supply carburetor and a carburetor induction passage including a throttle therein for controlling air-fuel supply into the intake manifold of the vehicle in response to load and wherein an exhaust gas recirculation conduit is connected between the engine exhaust and the induction passageway at a point between the carburetor and the throttle; an exhaust gas recirculation valve controlling recirculation through the conduit in accordance with changes in the intake manifold pressure, the valve including a flow area scheduled to produce a recirculation of exhaust gas from the exhaust to the induction passage to increase the ratio of exhaust gas recirculation to inlet air as the engine load increases thereby to produce a resultant decrease of NO_x emissions throughout the full range of increasing engine load conditions.

These and other objects of the present invention are attained in one working embodiment that produces optimization of the exhaust gas recirculation rate schedules so that minimum nitrogen oxides are emitted from the engine for all engine operating conditions.

The system includes a diaphragm actuated valve that varies the size of an opening with a scheduled flow area located in the exhaust gas recirculation line between the vehicle exhaust system and the point at which the exhaust gas recirculation flow is introduced into the engine intake system. In the system, the exhaust gas recir-

culution flow is introduced between the engine throttle and the carburetor.

The valve actuator includes a housing and a diaphragm forming a vacuum enclosure in communication with engine intake manifold. Accordingly, increases in engine load that reduce the engine intake manifold vacuum will work on the diaphragm against a bias spring so that the valve opening is decreased as the engine intake manifold vacuum is increased. Proper selection of the exhaust gas recirculation line size, the vacuum operator diaphragm area, bias spring size and valve flow area schedule can result in an exhaust gas control rate which produces an increasing ratio of exhaust gas recirculation to intake air flow as engine load increases (intake vacuum manifold decreases) or in other words, the exhaust gas recirculation control rate is maintained always slightly less than the amount that would cause engine misfire because of excessive combustion chamber dilution.

The method of the present invention is established in accordance with the following procedure. First, the engine residual fraction (fraction of exhaust gas in the combustion chamber prior to ignition) is determined for various intake manifold vacuums. This data is then plotted as a residual fraction curve. This curve is dependent primarily on manifold absolute pressure with engine speed having little effect. The desired total dilution which is the exhaust gas recirculation rate provided by the control valve of the system and the previously determined residual fraction in the cylinder is then determined by operating the engine on a dynamometer and determining what level of exhaust dilution in the combustion chamber will cause misfire. The desired total dilution is then plotted.

Then, a control valve is utilized to regulate the exhaust gas recirculation to produce an increasing ratio of exhaust gas recirculation to inlet air flow so that this control of exhaust gas recirculation and the existing residual exhaust within the combustion chamber for different engine loads will combine to produce a total dilution equal to that dilution which will produce a reduced NO_x emission control while maintaining engine performance as the engine load increases.

Further objects and advantages of the present invention will be apparent from the following description, reference being had to the accompanying drawings wherein a preferred embodiment of the present invention is clearly shown.

In the Drawings:

FIG. 1 is a diagrammatic view of an exhaust gas recirculation system including the present invention;

FIG. 2 is a view partially in section and partially in elevation of a vacuum controlled exhaust gas recirculation valve with a scheduled flow area in accordance with the present invention;

FIG. 3 is a side elevational view from the line 3—3 of FIG. 2 looking in the direction of the arrow;

FIG. 4 is a fragmentary sectional view taken along the line 4—4 of FIG. 2;

FIG. 5 is an enlarged fragmentary elevational view showing a contoured hole defining a scheduled flow area for use in the present invention;

FIG. 6 is a graph showing the relationship between the flow area of the valve in FIGS. 1 through 5 and intake manifold vacuum;

FIG. 7 is a graph showing the relationship of the residual fraction, combustion chamber dilution and the

exhaust gas recirculation rate for a typical system using the present invention;

FIG. 8 is a graph showing the relationship between exhaust gas recirculation rate and increasing engine load in the present invention and the effect on NO_x emissions;

FIG. 9 is a graph showing a family of curves of exhaust gas recirculation scheduled in accordance with changes in engine load;

FIG. 10 is a graph of a family of curves showing NO_x emission in accordance with load changes produced by the schedules in FIG. 9; and

FIG. 11 is a graph showing a second family of curves of NO_x emissions produced by other schedules in FIG. 9.

Referring now to the drawings, in FIG. 1 an exhaust gas recirculation system 10 is illustrated. It is associated with an internal combustion engine 12. The engine 12 has an intake manifold 14 and an exhaust including a pipe 16. The exhaust gas is taken from the vehicle exhaust pipe 16 upstream of a muffler 18 and is recirculated through a conduit 20 from the exhaust 16 to the engine induction system 22. The induction system 22 includes a carburetor 24 for directing air and fuel into a bore 26 in the induction system 22. The carburetor 24 is the type presently used on vehicles including means to supply an air-fuel mixture across a load responsive throttle 28 in bore 26 between carburetor 24 and manifold 14.

As shown in FIG. 7, the engine 12 has a residual exhaust fraction in its combustion chamber which varies in accordance with engine load as shown by curve 29. The residual fraction or RF is equal to the ratio of residual exhaust or R in the combustion chamber to the intake air flow A at different engine loads. In accordance with the present invention, the residual fraction or internal exhaust gas within engine 12 is supplemented by the exhaust gas recirculation control of a vacuum operated valve controller 30 which is constructed so that a flow area opening therein increases with decreasing intake manifold vacuum. The controller 30 flow rate area is scheduled to produce an exhaust gas recirculation rate shown by curve 31 in FIG. 7 as a percentage figure plotted versus manifold absolute pressure, MAP in inches of mercury.

As shown by curve 33 in FIG. 6, the controller 30 has a valve opening therein continuously varied in accordance with intake manifold vacuum or intake manifold absolute pressure in such a way that the valve opening increases as the intake manifold vacuum decreases. Since the valve flow area opening is variable as shown in FIG. 6, the engine total charge dilution which includes residual fraction at a given intake manifold vacuum plus the exhaust gas recirculation flow for a particular intake manifold vacuum, produces a resultant curve shown at 35 in FIG. 7 reflecting the total charge dilution in the combustion chamber or chambers of engine 12.

Referring now more particularly to FIG. 2, the controller 30 includes a valve housing 32 having a central bore 34 therethrough which is closed at one end thereof by a valve housing cover 36 with an external flange 38 thereon secured by means of screws 40 to the housing 32. The cover 36 includes a cylindrical portion 42 thereon which fits in one end of the bore 34 to close the housing 32 on one end thereof. The housing is closed at the opposite end of the bore 34 by means of

a valve housing cover 44 like cover 36. Thus, it includes a flange 46 engaging one outer end of the housing 32 and a cylindrical portion 48 thereon directed internally of the bore 34 as seen in FIG. 3 to close the opposite end thereof. A plurality of screws 50, secure the housing cover 44 in place on the housing 32.

The housing covers 36, 44 have central bores 52, 54 respectively that receive opposite ends of a valve shaft 56. As best seen in FIG. 4, the shaft includes a flat surface portion 58 thereon with a pair of spaced apart shoulders 60, 62 thereon to supportingly receive a rectangular valve plate 64 having side notches 66, 68 thereon fit with respect to the shoulders 60, 62 and a central portion thereon seated against the flat surface 58 and secured thereto by means of screws 70.

The valve plate 64 has side edges 72, 74 thereon located in sliding sealing engagement with the inner surfaces 76, 78 on the housing covers 36, 44 respectively. The plate 64 further includes end edges 77, 79 thereon that are located in sliding engagement with the inner surface of the bore 34 between the housing covers 36, 44.

An outboard end 80 of the shaft 56 is connected to one end of a lever arm 82 by means of a set screw 84. A bifurcated end 86 of the lever 82 is secured to a flat end 88 of a diaphragm piston rod 90 by means of a pin 91.

The diaphragm piston rod 90 is connected to a vacuum operator 92 of the controller 30 that is connected to a vacuum port 94 in the intake manifold 14 by a vacuum line 96 having one end connected to the vacuum port 94 and having the opposite end thereof connected to an inlet port 98 formed in a diaphragm cover 100. The diaphragm cover 100 more particularly includes a flange portion 102 thereon in engagement with the periphery 104 of a diaphragm element 106, a Bellofram type class 4-C dynamic linear seal. Element 106 is supportingly received at the periphery thereof by a flange 108 on a diaphragm base 110.

The element 106 is sealed with respect to the cover 100 to form a vacuum chamber 112 on one side of a diaphragm piston 114 that is fit within the upper surface of the diaphragm 106. It has a cup-shaped configuration with a base portion 116 secured to the diaphragm 106 by means of a nut 118 threadably received on a threaded portion 120 of the piston rod 90 in an air tight engagement with piston 114. The opposite side of the diaphragm is supported by a plate 122 secured thereagainst by means of a nut 124 on the threaded portion 120 in air tight engagement with plate 122.

The diaphragm 106 and the diaphragm base 110 define an atmospheric chamber 126 that is in communication with ambient pressure through a bore 128 in the base 110 thence through an opening 130 in an adjustment bracket 132 that serves to adjustably secure the vacuum operator 92 to the valve housing 32.

In the illustrated arrangement, the upper end of the piston rod 90 has a small diameter extension 134 thereon supportingly received within a guide opening 136 in a plug housing 144. A plug 138 is sealingly located within a central opening 140 within the diaphragm cover 100. Additionally, the controller includes a spring 142 therein having one end thereof in engagement with the cover 100 around a plug housing 144. The opposite end of the compression spring is supportingly received by the piston 114 around the piston base portion 116.

Accordingly, the spring 142 will bias the piston 114 and the piston rod 90 connected thereto downward as viewed in FIG. 2 to cause counterclockwise rotation of the lever 82 to move the valve plate 64 between a dotted line valve closed position as shown in FIG. 2 to a solid line valve open position shown therein. The extent of travel of the valve plate 64 between open and closed positions is 60° in one working embodiment. When the valve is in its dotted line closed position the edge 79 thereon will overlap the lower edge 146 of a contoured outlet opening 148 in housing 32 by .004 inches.

Referring now to FIG. 5, the contoured hole 148 is formed in wall 150 of valve housing 32 to define a scheduled flow area for producing an increasing ratio of exhaust gas recirculation to inlet air upon increases in engine load to minimize NO_x emissions. The rate of the scheduled area is selected to produce an exhaust gas recirculation that combined with residual fractions in the combustion chamber of the engine will produce a maximum amount of dilution in the combustion chamber without undesirable engine misfire.

More particularly, in the illustrated arrangement the contoured opening 148 is formed from the base edge 146 thereof to have curve sides 151, 153 thereon merging with gradually inclined edge portions 152, 154 respectively. The inclined edge portions 152, 154 are formed somewhat parallel to the edge 146 and they each merge with a more vertically inclined edge 156, 158 in the contoured opening 148. At the upper end of the contoured opening 148, the edges 156, 158 merge with a slot 160 of a reduced width and having an upper curved edge 162 thereon. The contoured opening 148 is formed symmetrically with respect to the longitudinal axis of the valve plate 64 and the edge 79 of the valve plate 64 cooperates therewith to define a variable area opening between an inlet conduit 164 that is in communication with a circular inlet port 166 of the opening which leads to the upstream surface 168 of the valve plate 64. The downstream surface 170 of the valve plate faces toward the contoured opening 148 which is in communication with an outlet segment 172 of the exhaust gas recirculation conduit 20. Segment 172 is connected at an inlet port 174 in the induction passage 26 downstream of the carburetor 24 and upstream of the throttle 28.

In one working embodiment of the present invention, the mechanical components have the following operating characteristics.

Item	Rating
Diaphragm 106	2.44 inches I.D. 2.75 inches O.D.
Piston 114	2.44 inches O.D. 2.30 inches I.D.
Compression spring 142	93.3 lbs. per inch S.R.
Contoured opening 148	
W ₁	1.08 inches
W ₂	0.34 inches
W ₃	0.125 inches
H ₁	1.0 inches
H ₂	0.82 inches
H ₃	0.24 inches
Angle X	30°
R ₁	0.0625 inches

The valve plate 64 is calibrated by imposing a vacuum signal of 20 inches of mercury in the vacuum chamber 112 and the bracket 132 is adjusted with re-

spect to screws 40 until the valve plate 64 contacts a stop pin 175 on housing cover 36 under no load conditions.

The stop position is represented in FIG. 6 as a valve closed position at an intake vacuum of 20 inches of mercury. It represents a valve control position when the engine load is low, as for example, under engine idle conditions.

As shown in FIG. 7, internal combustion engines are characterized by having a relatively great percentage of residual combustion products, RF, in the combustion chamber under such conditions. This is due to the fact that the engine is throttled at the idle conditions and the combustion chamber will have a clearance volume that will produce a percentage of exhaust gas in the chamber under idle conditions that is relatively great. Under such conditions, NO_x emissions are effectively controlled.

In the present invention, as the engine load increases, the throttle 28 opens to cause a greater amount of intake air to flow into the combustion chamber of the engine 12. At the same time, however, a reduced intake vacuum is produced and a reduced vacuum will occur in the chamber 112 thereby causing the bias spring 142 to move the piston 114 along with the piston rod 90 downwardly. This causes the lever 82 to rotate counterclockwise from the closed position. Immediately, the edge 79 of the valve plate 64 will move upwardly from the edge 146 of the scheduled opening 148 to present an abruptly increased flow area for the recirculation of exhaust gas from the exhaust pipe 16 back to the induction system 22 between the carburetor 24 and the throttle 28. The abruptness of the increase in flow area is defined by the curve 33 in FIG. 6. For example, when the control vacuum level is at twenty inches of mercury there is no exhaust gas recirculation. As soon as the load increases to a point where the intake vacuum is reduced to 16 inches of mercury, the flow area through the contoured opening 148 will be opened to approximately one half of the flow area. Thereafter, upon further increases in load the opening will continue to increase in area up to a maximum at the valve full open position. The illustrated slope of the geometric flow area shown in FIG. 6 and the diaphragm area and spring size will establish an exhaust gas recirculation rate which will continually increase the ratio of exhaust gas recirculation to the inlet air as the engine load increases. This results in an exhaust gas recirculation rate that is always slightly less than the amount that will cause engine misfire and thereby maintain a maximum combustion chamber dilution that will minimize engine nitric oxide emissions.

To determine the actual schedule of the contoured opening 148 and the size of the piston 114 and the force of the compression spring 142, the following procedure is used. First, the engine residual fraction (fraction of exhaust gas in the combustion chamber prior to ignition) is determined for various intake manifold vacuums. This data is then plotted as curve 29 in FIG. 7. Typically, the curve 29 is dependent primarily on the manifold absolute pressure with engine speed having little effect. The desired total dilution (exhaust gas recirculation plus the residual fraction in the combustion chamber) is then determined by running the system on an engine dynamometer to determine maximum dilution without engine misfire. This total dilution curve is plotted as a curve 35 as shown in FIG. 7.

The contoured opening 148 and the characteristics of the valve control components are then selected to produce a flow area and an EGR or exhaust gas recirculation rate which will have a profile like curves 33 and 31, FIGS. 6 and 7 respectively.

In existing exhaust gas recirculation systems, the control signal for exhaust gas recirculation control valves is often an orifice located between the exhaust gas recirculation supply and the intake manifold. In such cases, a full rate to the orifice in the control valve is a combination of a function of a manifold vacuum signal and also a function of the difference between the exhaust back pressure (a measure of engine air flow) and intake manifold vacuum. In such systems, increased vacuum signals to the valve open the valve and thus allow higher exhaust gas recirculation control rates at lower engine loads.

A preferred approach, in accordance with the present invention, is to provide exhaust gas recirculation in a manner such that the percentage (or fraction) of exhaust gas contained in the combustion chamber just prior to ignition corresponds to curves of the type shown in FIG. 6 and FIG. 7 at 33 and 31 respectively. The resultant control of NO_x emissions is shown in FIG. 8 wherein curve 176 represents the ratio of exhaust gas recirculation to intake air and curve 178 represents NO_x in parts per million. The curve 178 shows a continual reduction in NO_x as engine load increases.

Considering the operation of the afordescribed system, the total system includes a carburetor 24 which takes in air and fuel in the normal manner. In the present invention, the exhaust gas recirculation is mixed with the air fuel stream upstream of the engine throttle. Exhaust gas is taken from the vehicle exhaust pipe or a point upstream of the muffler in the system and is recirculated through the exhaust gas recirculation valve 32 into the engine induction system 22 upstream of the engine throttle 28 and downstream of the carburetor 24. The exhaust gas recirculation valve 32 is constructed so its valve opening increases continually upon decreases in intake manifold vacuum (increased engine load) as compared to existing systems which will have a reduced exhaust gas recirculation at high intake manifold vacuums, thereafter will peak to a maximum exhaust gas recirculation flow rate and then will taper off to have a minimum exhaust gas recirculation rate at reduced intake vacuum manifold pressures as produced upon increases in engine load. Such systems are effective to produce reduction in NO_x emissions through a mid range of engine loads but are not as effective in reducing NO_x emissions at increased engine loads as compared to the present invention.

An advantage of the present invention is that proper scheduling of the contoured opening 148 to produce an increasing ratio of exhaust gas recirculation to intake air is that it serves somewhat the same function as vacuum spark advance on present vehicles. Such a vacuum spark advance is included in present systems to compensate for changes in MBT spark timing caused by changes in the percentage of exhaust gas contained in the combustion chamber (due to throttling and in clearance volume effects) prior to ignition. Since the percentage of exhaust gas contained in the combustion chamber prior to ignition, by virtue of the present invention, can be nearly constant, the need for vacuum spark advance might be eliminated.

Furthermore, the present invention incorporates a "fail-worse" feature. If the vacuum signal to the valve 30 becomes disconnected or is removed, the valve 30 will be conditioned to assume a wide open position and produce excessive exhaust gas recirculation at light engine loads. This excessive exhaust gas recirculation will cause poor engine performance to warn the vehicle operator that the emission control system is not functioning properly.

Another advantage of the present invention is that the contoured opening 148 can be altered to vary the flow characteristics of valve 32 to improve engine performance while retaining desired reduction of nitric oxide emissions under increasing engine load operation.

Thus, as shown in FIG. 9 a family of curves 180, 182, 184, 186 are shown in solid line. Curve 180 represents the limit of exhaust gas recirculation in a control system of the present invention at which engine misfire will occur. In the present case, the misfire rate is representatively selected as a combustion chamber dilution which will produce in the order of one misfire for each 300 revolutions of engine operation. Engine misfire in excess of this rate is considered unsatisfactory.

Each of the curves 180, 182, 184, 186 will minimize nitric oxide emissions to a specified level. Curve 180 represents the optimum exhaust gas recirculation schedule for minimum nitric oxide emissions as shown in FIG. 10 by curve 194. Where an increased level of NO_x is permitted, the contoured opening 148 in the valve 32 is modified to produce a resultant increase in exhaust gas recirculation rate which is less than that produced by the optimum curve 180 but nevertheless, will maintain an increasing ratio of exhaust gas recirculation to the intake air resulting in a NO_x emission control as shown by curve 192 in FIG. 10. Likewise, further modification of the contoured opening will produce curves like 184, 186 in FIG. 9 with resultant NO_x emission controls as shown at curves 190, 188 in FIG. 10.

Alternative curves 196, 198, 200 are shown in dotted lines in FIG. 9. These curves will produce an increasing exhaust gas recirculation rate in accordance with increases in engine load but the rate of increase will be less than the family of curves represented by 180 thru 186.

The resultant NO_x emission controls for valves contoured as shown in curves 196, 198, 200 are shown by curves 206, 204, 202 in FIG. 11. These alternative curves will give better vehicle acceleration at some sacrifice in nitric oxide emission control as shown in FIG. 11. This control, however, may be satisfactory depending upon emission control standards required for particular internal combustion engines.

One important point in the present invention is that if the exhaust gas recirculation is scheduled according to any of the above curves as set forth in FIGS. 9 thru 11, both vehicle fuel consumption and performance can be further improved by use of a high compression engine with a compression ratio in the order of 10:1 instead of the present compression ratios of 8:1. Such high compression engine applications can use no lead fuel in the order of 91 octane. This is because the exhaust gas recirculation rate in accordance with the present invention effectively increases the octane number of the fuel. The increased combustion chamber dilution as produced by an increasing ratio of exhaust gas

recirculation to intake air will modify the combustion characteristics in the chamber so as to produce this result.

While the embodiments of the present invention, as herein disclosed, constitute a preferred form, it is to be understood that other forms might be adopted.

What is claimed is as follows:

1. An exhaust gas recirculation system for an internal combustion engine having a carburetor for air fuel supply at one end of an engine induction passage with an unrestricted segment, a throttle valve in said induction passage at the other end thereof for controlling air-fuel flow therethrough to an intake manifold in communication with combustion chambers, and an exhaust passage for exhaust gas flow from the engine comprising: an exhaust gas recirculation line connected between the exhaust passage and a point in the unrestricted segment of the induction passage upstream of said throttle valve and downstream of the carburetor, valve means for controlling exhaust gas recirculation through said recirculation line in accordance with changes in intake manifold pressure, said valve means including means responsive to intake manifold pressure for selectively opening and closing said valve means throughout a throttle position range from idle to wide open throttle, said valve means including a variable geometry flow path therethrough scheduled to open so as to produce a ratio of exhaust gas recirculation to inlet air flow which continually increases as engine load increases thereby to maximize the exhaust gas recirculation to a point slightly less than will produce misfire in the combustion chambers because of charge dilution of the air fuel charge by recirculation of exhaust gas from the exhaust passage to the induction passage.

2. A method for operating an internal combustion engine having a carburetor and an engine throttle for supplying air-fuel mixture to an intake manifold and a combustion chamber and wherein exhaust means are provided to direct combustion products from the combustion chamber comprising:

providing a quantity of air-fuel mixture for supply to the combustion chamber in proportion to engine load and speed,

providing a control of exhaust gas recirculation from the exhaust manifold into the combustion chamber to maintain a charge dilution therein which increases as engine load increases,

the charge dilution being produced by directing exhaust gas recirculation from the exhaust means to the combustion chamber in a controlled schedule to produce an initial abrupt influx of exhaust gas recirculation at engine idle and thereafter an increasing ratio of the exhaust gas recirculation to the inlet air flow with the ratio continually increasing in accordance with increases in intake manifold pressure throughout a throttle position range from throttle idle operation to wide open throttle operation.

3. An exhaust gas recirculation control system for use in an internal combustion engine having a carburetor at one end of an induction passage with an unrestricted segment for air flow to the engine, a throttle in the other end of said induction passage controlling air flow therethrough to produce a quantity of air-fuel mixture proportional to engine load and speed, and a combus-

tion chamber along with an exhaust passage for exhaust gas flow from the engine comprising:

means defining an exhaust gas recirculation introduction port in the unrestricted segment of the induction passage between the carburetor and engine throttle valve,

an exhaust gas recirculation line connected between the exhaust passage and the introduction port,

valve means in said exhaust gas recirculation line movable between closed and opened positions for controlling exhaust gas recirculation flow, said valve means having an opening therein contoured to progressively increase valve flow area at a continuously positive rate from said closed position to said open position with the positive rate being greatest at the initial opening movement and least at the final opening movement,

a valve operator including a movable diaphragm and housing means forming an enclosure,

a vacuum signal line connected between the intake

manifold of the engine and the enclosure for biasing said diaphragm in accordance with changes in intake manifold pressure produced by increases in engine load,

spring means within said enclosure for opposing the biasing action of said vacuum signal,

actuator means coupling said diaphragm to said valve means for causing said valve means opening to progressively move into a more open position in accordance with engine load to continually increase the ratio of exhaust gas recirculation flow to air flow through the induction passage as engine load increases through a throttle range from throttle idle operation to wide open throttle operation,

said spring means returning said valve means to full open position upon vacuum signal failure to produce maximum exhaust gas recirculation at reduced engine loads thereby to reduce engine performance so as to indicate system malfunction.

* * * * *

25

30

35

40

45

50

55

60

65