United States Patent

McJones

[15] **3,650,254**

[45] **Mar. 21, 1972**

[54] METHOD AND APPARATUS FOR RAPIDLY CHANGING THE AIR-FUEL RATIO OF AN INTERNAL COMBUSTION ENGINE FROM A LEAN CONDITION TO A RICH CONDITION

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[22] Filed: **Mar. 16, 1970**

[21] Appl. No.: **19,884**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 858,816, Sept. 17, 1969.

[52] **U.S. Cl.** .....**123/120,** 48/184, 123/179 G

[51] **Int. Cl.**.....**F02m 21/02,** F02n 17/00

[58] **Field of Search**.....123/120, 179, 179 G; 48/184

[56] **References Cited**

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[57] **ABSTRACT**

A regulator in the fuel system of a vehicle's internal combustion engine regulates the fuel pressure of a gaseous fuel, such as natural gas, to a fuel-air mixer. The regulator maintains a predetermined fuel pressure for idle and cruise conditions and increases fuel pressure to effect an enriching of the air-fuel ratio for full throttle conditions. The degree of enriching is sufficient to pass through a region where there is a threat of exhaust valve burning and where the maximum amount of the oxides of nitrogen are produced. The change in air-fuel ratio is extremely rapid to avoid operation for any material amount of time in this region. The regulator also effects a change from a rich air-fuel ratio to a lean one at a predetermined point in throttle setting below the point at which enriching occurs.

31 Claims, 4 Drawing Figures

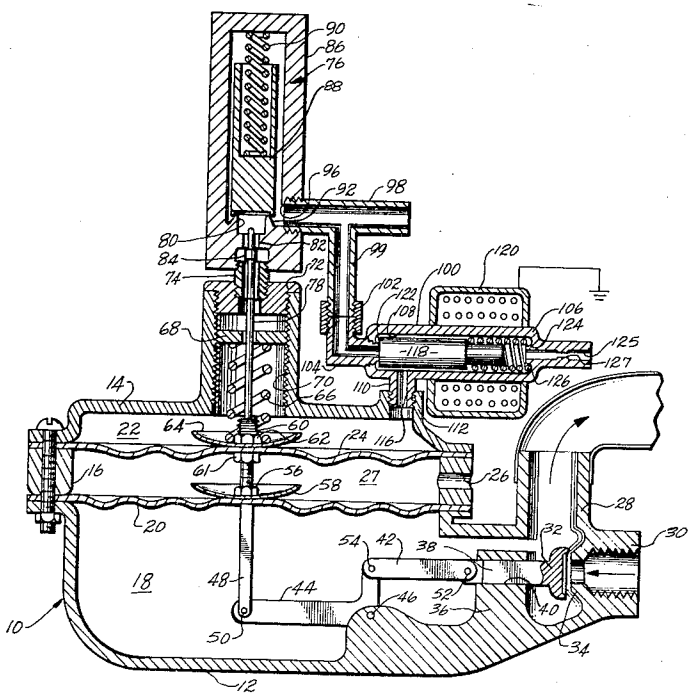


FIG. 1

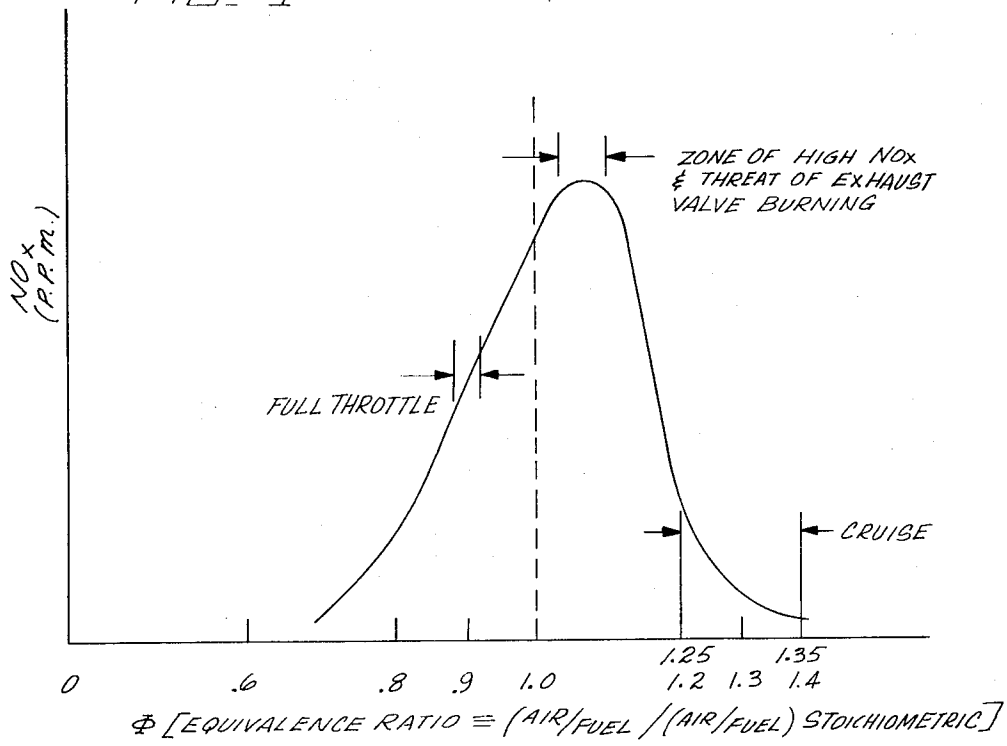
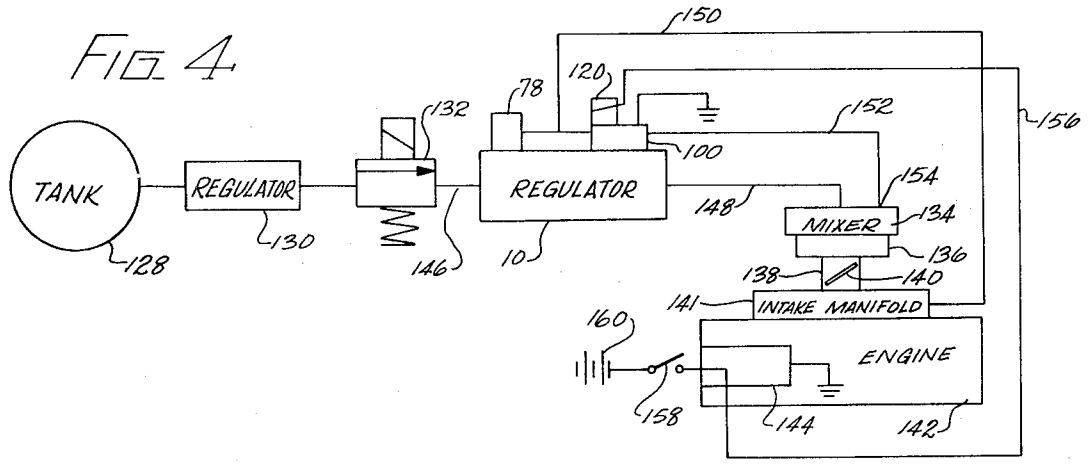


FIG 4



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FIG. 3

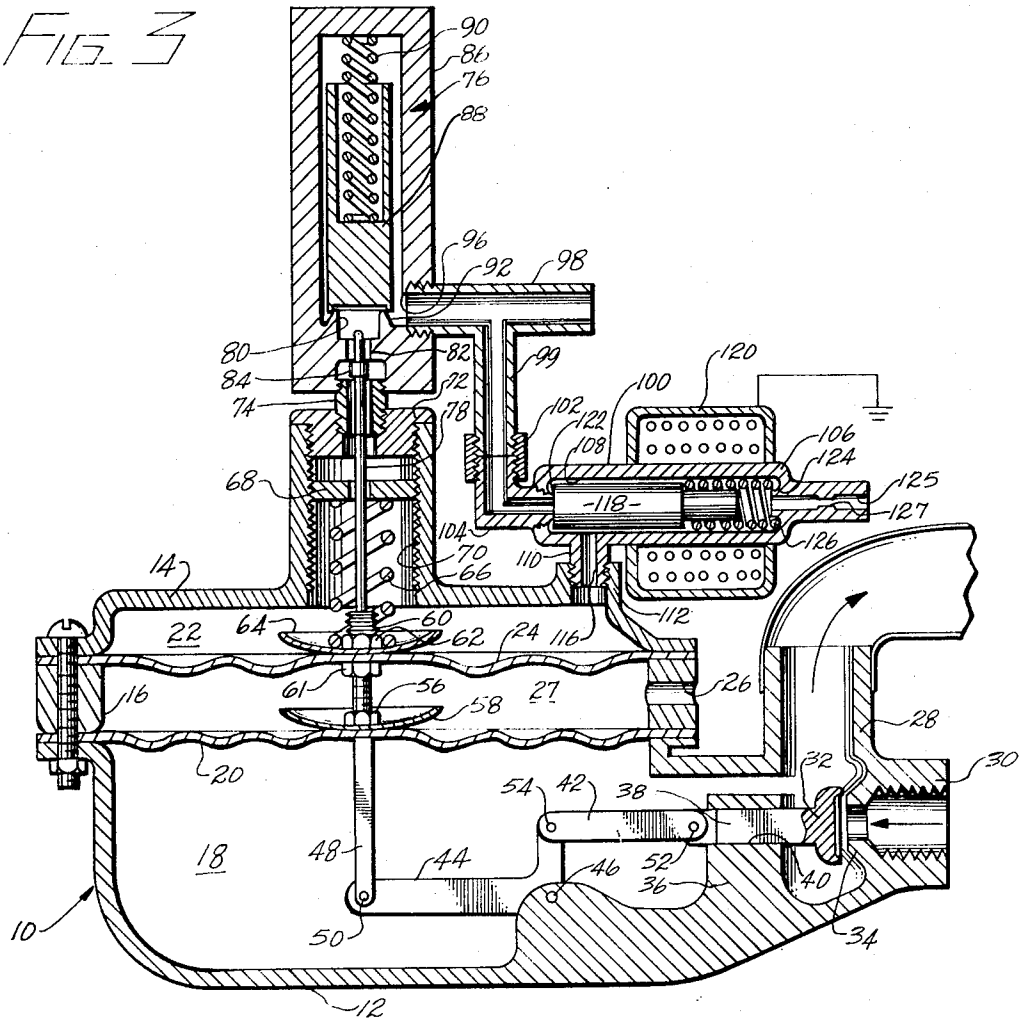
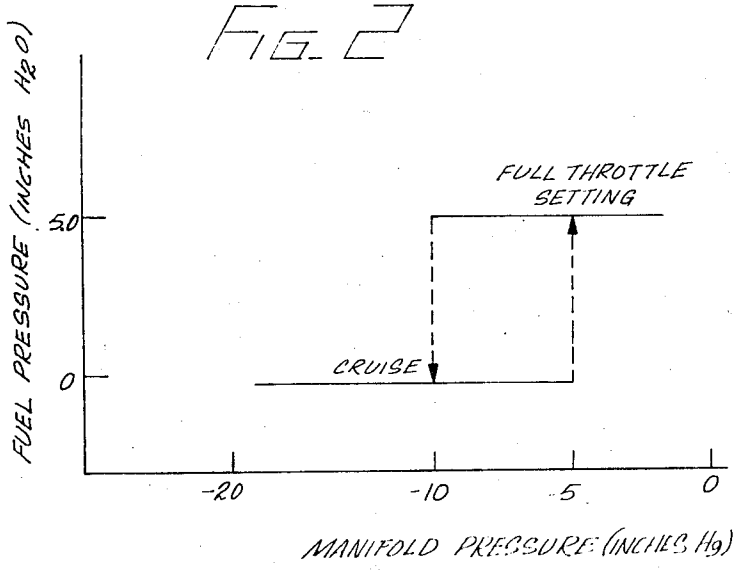

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127
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118
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70
66
110
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14
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20
32
30
54
42
38
18
48
44
46
52
36
40
10
50
34
12

FIG. 2


FUEL PRESSURE (INCHES H2O)
50
0
FULL THROTTLE SETTING
CRUISE
-20
-10
-5
0
MANIFOLD PRESSURE (INCHES Hg)

METHOD AND APPARATUS FOR RAPIDLY CHANGING THE AIR-FUEL RATIO OF AN INTERNAL COMBUSTION ENGINE FROM A LEAN CONDITION TO A RICH CONDITION

REFERENCE TO RELATED APPLICATION

This is a continuation-in-part of application Ser. No. 858,816, filed Sept. 17, 1969.

BACKGROUND OF THE INVENTION

In general, the present invention relates to fuel systems for internal combustion engines typically used in motor vehicles and, more in particular, to a regulator and method for effecting a rapid transition from a fuel-lean condition to a fuel-rich condition for full power operation of a vehicle.

Considerable attention is being given to the problem of air pollution generated by internal combustion engine powered motor vehicles. Several approaches to the problem of exhaust gas emissions from an internal combustion engine have been taken. The pernicious exhaust gas emissions which are being given most attention are the oxides of nitrogen, unburned hydrocarbons and carbon monoxide. Presently much of the effort to reduce exhaust gas emissions is being directed to engine operation with a relatively lean air-to-fuel ratio. One of the problems with lean operation is that while unburned hydrocarbon emissions are reduced, the amount of oxides of nitrogen (NO_x) increases over that experienced with richer engine operation.

However, with very lean operation the oxides of nitrogen once again are reduced to acceptable levels. In short, the oxides of nitrogen being admitted to the atmosphere reach a maximum slightly on the lean side of stoichiometric.

One of the problems with operating an engine with a very lean air-to-fuel ratio is that many fuels do not operate at all or are highly unsatisfactory in ultralean mixtures with air. Gasoline is an example of such a fuel.

Recently the feasibility of vehicle operation on natural gas as a fuel has been demonstrated. One of the advantages of natural gas powered vehicles is in the ability to run the vehicle with an extremely lean fuel-to-air ratio. With this lean operation, once again, the emissions of oxides of nitrogen are well within acceptable standards. Moreover, with the lean operation the emissions of unburned hydrocarbons and carbon monoxide are very low.

It has been found, however, that a relatively rich air-to-fuel ratio is required with operations of natural gas for full power conditions. Specifically, operation just on the rich side of stoichiometric is required. This means that a transition must be made between full power operation and cruise operation which passes through the zone of maximum NO_x emission. Moreover, the richer the air-to-fuel ratio becomes from the very lean condition to the zone of maximum NO_x emission, the more NO_x there is in a vehicle's exhaust. In addition, it has been found that operation in the zone of maximum NO_x emission also corresponds to the highest combustion chamber temperatures. With sustained operation in the zone of maximum NO_x emission and because there is too little fuel to combine with all the available oxygen, there is a distinct possibility of exhaust valve burning.

Therefore, there is a need for a method and apparatus for rapidly changing the air-to-fuel ratio in a gaseous fuel powered engine from a very lean condition to a relatively richer condition in order to pass through the zone of maximum NO_x emission without the risk of engine damage by, for example, exhaust valve burning.

SUMMARY OF THE INVENTION

The present invention provides a method and a regulator adapted for rapidly changing the air-fuel ratio of an internal combustion engine from a very lean, low exhaust pollutant emission condition to a relatively richer condition on the rich side of stoichiometric and past the zone of maximum NO_x generation. In preferred form, the present invention provides

a method and a regulator adapted for effecting stable operation when changing the air-fuel ratio from rich to lean, or conversely, by effecting a different point in throttle setting or manifold pressure for return to lean operation from that point where rich operation begins.

While the present invention includes a regulator as such, the regulator can best be understood in its use in the fuel system of a motor vehicle. A specific form of the regulator is operative to deliver a gaseous fuel, such as natural gas or propane, to a fuel-air mixer at a predetermined fuel pressure of, say, zero inches of water for normal cruise operation of a vehicle. The regulator is operative, however, to rapidly change the gaseous fuel pressure to the fuel-air mixer at a predetermined higher pressure of, say, 5 inches of water at full or near full throttle conditions. To prevent instability in the operation of the regulator, means are preferably provided to return from the full throttle condition to the normal cruise condition at a lower throttle setting than was required to change from the cruise condition to the fuel-rich condition. In terms of manifold pressure, the change from cruise to full throttle setting may occur at about 5 inches of mercury below atmospheric, while the return from the full throttle setting to the cruise condition might occur at, say, 10 inches of mercury below atmospheric.

In greater detail, the regulator contemplated by the present invention includes a regulator body having means for separating an interior thereof into two mutually isolated chambers. Such means preferably include two spaced-apart diaphragms, each being positionally responsive to pressure differentials across them. The first of these chambers may be a fuel chamber. The second chamber has means for communicating with a pressure source such as the intake manifold of the engine used with the regulator. As such, the second chamber may be regarded as a low pressure chamber. Means are provided to effect pressure differentials across both diaphragms, such as a third chamber between the diaphragms which is open to atmosphere. A valve element of the regulator is coupled to the diaphragm bounding the fuel chamber to admit gaseous fuel into the fuel chamber from, for example, a first regulator stage. Outlet means are provided from the fuel chamber to pass fuel at regulated pressure to a fuel-air mixer of the engine. At part throttle, the diaphragms are not coupled together and atmospheric pressure on the fuel chamber diaphragm keeps the valve element in position to maintain the pressure in the fuel chamber at zero inches of water (gauge), the fuel pressure corresponding to the lean operating condition. Other pressures than zero inches of water may be used to effect the desired lean operation condition, in which case the fuel chamber diaphragm can be made additionally responsive to a biasing spring. Selectively actuatable means is provided to effect a second and different predetermined pressure differential across the fuel chamber diaphragm at full throttle conditions. Such means is responsive to movement of the low pressure chamber diaphragm to a full throttle position in response to a predetermined pressure differential across the low pressure diaphragm determined by an intake manifold pressure of a given value. The second predetermined fuel pressure in the fuel chamber may be, say, 5 inches of water (gauge). The selectively actuatable means may be in the form of a spring urging against the low pressure chamber diaphragm. The spring constant is chosen to effect the desired second predetermined pressure differential of 5 inches of water pressure in the fuel chamber, and is coupled to the fuel chamber diaphragm during full throttle operation such that the fuel chamber diaphragm is resisted by the spring. During cruise conditions, however, the relatively low pressure in the low pressure chamber and atmospheric pressure on the low pressure chamber diaphragm overcome the spring to maintain both diaphragms uncoupled.

To effect the steplike, rapid change from a fuel-lean to a fuel-rich full throttle condition, the pressure in the low pressure chamber together with the biasing means cooperate to overcome atmospheric pressure in the third chamber to move the low pressure diaphragm in a sense required to couple the biasing spring and the fuel chamber diaphragm together.

It is important to maintain fuel pressure at the fuel-rich condition constant to avoid operation in the zone of maximum NO_x generation. It is also important to avoid instability of regulated fuel pressure where there is the change from fuel-lean operation to fuel-rich operation. To satisfy these two requirements, a pilot valve couple to the low pressure chamber diaphragm is provided between the low pressure chamber and the intake manifold to prevent communication between the two until a predetermined return manifold pressure is reached, at which point the pilot valve is operative to reestablish this communication. This predetermined manifold pressure is lower than the threshold manifold pressure required to initiate fuel-rich operation in the first place.

It has been found that the fuel-rich condition is not satisfactory for engine startup conditions. To maintain fuel pressure to the fuel-air mixer at its lean value until the engine starts, means is provided to circumvent or bypass the pilot valve and communicate the low pressure chamber with intake manifold pressure.

It is also preferred to attenuate the pressure in the low pressure chamber relative to intake manifold pressure so that the biasing means on the low pressure chamber diaphragm can overcome the resistance of atmospheric pressure on the diaphragm at the desired time. The attenuating means may include first and second orifices into the low pressure chamber from the intake manifold and a reference pressure source which may be essentially atmospheric. To develop a quick response of the low pressure diaphragm in returning from the fuel-rich to the fuel-lean condition, the orifice to the intake manifold is preferably enlarged until the diaphragm is in its fuel-lean position.

These and other features, aspects and advantages of the present invention will become more apparent from the following description, appended claims and drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a plot of NO_x emission versus air-to-fuel ratio which facilitates an understanding of the operation and problems solved by the present invention;

FIG. 2 is a plot of fuel pressure versus manifold pressure to illustrate the operation of the present invention;

FIG. 3 is an elevational half-sectional view of the regulator of the present invention; and

FIG. 4 is a schematic line diagram showing the regulator of the present invention as it is used in the fuel system for an engine of an internal combustion engine.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. 1, the nature of the operation of the present invention will be described. As previously mentioned, fuels such as natural gas admit to very lean operation. As is readily seen from FIG. 1, operation at an equivalence ratio of from between about 1.25 to about 1.35 results in a substantial reduction in the amount of oxides of nitrogen over that which would be experienced at richer practical air-to-fuel ratios. (Equivalence ratio is defined by the actual air-to-fuel ratio divided by the air-to-fuel ratio at stoichiometric.) Operation at such lean values of air-to-fuel ratios is very satisfactory for cruise conditions; however, it is not satisfactory when full power is required. For effective full throttle operation, a slightly fuel-rich condition should be used, say, at an equivalence ratio of about 0.9. Between an equivalence ratio of 0.9 and one of between about 1.25 and about 1.35 is a zone of high NO_x emission. This zone occurs at an equivalence ratio of around 1.05. Inasmuch as this zone also corresponds to the zone of maximum combustion chamber temperatures and is on the lean side of stoichiometric, a condition exists where the oxygen in the combustion air can attack and burn exhaust valves since this oxygen is not being used to burn fuel.

Thus it is highly advantageous to shift from the cruise equivalence ratios to the full throttle equivalence ratios as rapidly as possible.

With reference to FIG. 2, a plot of fuel pressure versus manifold pressure is presented. The fuel pressure is the pressure leaving the regulator of the present invention. The lean cruise condition is shown at a fuel pressure of zero inches of water. The full throttle position is shown as plus 5 inches of water. It can be seen from the plot that cruising with greater and greater throttle opening until full throttle is approached, the fuel pressure will remain at zero inches of water. As a consequence, operation will be in the lean range shown in FIG. 1. Ultimately, however, at about full throttle, say, at a manifold vacuum of 5 inches of mercury, the regulator is operative to switch to its full throttle setting. For full throttle and for a range of down to, say, 10 inches mercury manifold vacuum, the engine will operate in the full throttle range shown in FIG. 2. The transition from cruise to full throttle is shown by the vertical dashed arrow on the right side of FIG. 2, while the transition from full throttle setting to cruise is shown by the vertical dashed arrow on the left side of the plot. It should be noted here that full throttle operation setting over an extended range of manifold pressures avoids instability in fuel pressure occasioned by switching fuel pressures back and forth at a fixed manifold pressure, but that full throttle setting operation occurs only after leaving the cruise setting.

With specific reference to FIG. 3, the regulator of the present invention will be described. The regulator is indicated in general by reference numeral **10**. The regulator has a body which is divided into a bottom **12**, a cover **14** and a spacer **16**. A fuel pressure chamber **18** is defined by the inner walls of the bottom and by the lower surface of a fuel pressure chamber diaphragm **20**. A low pressure chamber **22** is defined by the inner walls of cover **14** and the upper wall of low pressure chamber diaphragm **24**. Spacer **16** has a vent **26** to ensure that atmospheric pressure always exists in a third chamber **27**, defined by both diaphragms and the spacer, by allowing air to pass in either direction through the vent with positional changes of the diaphragms. The regulator has an outlet **28** for gas to pass to a fuel-air mixer of the vehicle using the regulator.

A gas inlet **30** of the regulator is adapted for connection to a fuel line from a first stage regulator for the passage of gas into fuel pressure chamber **18**. A valve element **32** is adapted to cooperate with a seat **34** of bottom **12** to meter the flow of gas into fuel pressure chamber **18**. Valve element **32** is supported for longitudinal movement by a boss **36** of bottom **12** through sliding support of a shank **38** of the valve element in a cooperating passage **40** in the boss. A link **42** connects the shank of the valve element to a bellcrank **44** which in turn is pivotally connected to the bottom at **46** and to a shaft **48** at **50**. Movement of shaft **48** vertically towards the top of the Figure forces valve element **32** towards seat **34**. Valve element **32** is pivotally connected to link **42** as is bellcrank **44** at **52** and **54**, respectively, to accommodate the rotational movement of the bellcrank.

Shaft **48** is carried by diaphragm **20** through a nut **56** threaded onto the shaft. A washer **58** between nut **56** and diaphragm **20** provides for load distribution to the diaphragm. A threaded fitting **60** passes through diaphragm **24** and has a head **61**. A nut **62** is threaded on the threads of the threaded fitting for holding, in cooperation with head **61**, a second washer **64** in place against this diaphragm. The second washer provides for load distribution to the second diaphragm. A biasing spring **66** engages diaphragm **24** at one of its ends, through washer **64**, and a threaded washer **68** at its other end. Washer **68** is threaded into a threaded bore **70** of cover **14**. The compressive force of spring **66** on diaphragm **24** can readily be adjusted by adjusting the position of washer **68** in bore **70**.

In the full throttle position shown in FIG. 3, head **61** of fitting **60** bears on the end of shaft **48** to couple spring **66** and diaphragm **20** together. The spring constant of spring **66** is chosen to effect the desired 5 inches of water pressure in chamber **18**. At the full throttle setting, atmospheric pressure exists in both chambers **22** and **27**; therefore spring **66** reacts

solely against fuel pressure in chamber 18 acting on diaphragm 20. The resultant position of diaphragm 20 determines the position of valve element 32 to effect desired regulated pressure; in the specific embodiment described here 5 inches of water (gauge). However, when fuel chamber diaphragm 24 is lifted to its cruise position, head 61 of fitting 60 is raised considerably away from the top of shaft 48. As a consequence, during cruise conditions diaphragm 20 finds a position where the pressure on both of its sides is the same. This position seeking assures that the pressure in chamber 18, during cruise, is always the zero inches of water required to effect operation at the desired fuel-to-air ratio of between about 1.25 and about 1.35 on an equivalence basis.

A threaded cap 72 is threaded into threaded bore 70 and receives a threaded nipple 74. A pilot valve 76 is mounted on this nipple. A pin 78 is carried by fitting 60 and extends all the way through the nipple and into a bore 80 of pilot valve 76. An orifice 82 in bore 80 also receives pin 78. Pin 78 has an enlarged diameter portion 84 which is outside of orifice 82 when low pressure chamber diaphragm 24 is in its lower fuel-rich position. This provides a large passage through which manifold vacuum effects a rapid transition from a fuel-rich to a fuel-lean condition.

Pilot valve 76 has a housing 86. A valving element 88 is disposed for longitudinal movement within the housing. A spring 90 is disposed between an upper wall of the housing and the valving element to bias the valving element towards its closed position, blocking the outlet of bore 80 by residing against a seat 92. The seat cooperates in sealing relationship with the walls of a recess 94 of the valving element when the valving element is in its closed position.

An intake manifold pressure passage 96 in housing 86 is in open communication with the interior of the housing, but is prevented from communication with bore 80 by valving element 88 when the latter is in its closed position. A tee fitting 98 between inlet manifold passage 96 and the inlet manifold itself has one of its branches 99 connected directly to a bypass valve 100 through a coupling 102 and an el 104.

Bypass valve 100 includes a housing 106 which defines a bore 108. A threaded boss 110 is threadedly engaged in a cooperating boss 112 of cover 14. A passage 116 in boss 110 leads from low pressure chamber 22 into the hollow interior of the bypass valve. A valving element 118 is disposed for movement back and forth in the interior of the housing. A solenoid 120 is disposed about the housing. Valving element 118 is the armature of the solenoid. A seat 122 defined by an end of el 104 is disposed to be engaged by valving element 118 to prevent pressure communication between the intake manifold and chamber 22 through the bypass valve when the solenoid is not actuated. Similarly, a valve seat 124 on the right side of the housing is disposed to be engaged by the valving element to prevent communication between chamber 33 and an air cleaner reference pressure tap through a passage 125 when the solenoid is actuated, the valving element admitting to such communication otherwise. A biasing spring 126 maintains the valving element in position to close branch 99.

An orifice 127 is provided in passage 125 to effect a pressure drop between the air cleaner reference tap and chamber 22. Orifice 127 and orifice 82 cooperate to limit the amplitude of the negative pressure within chamber 22 to 5 inches of water at the intake manifold pressure where the regulator changes from its cruise to its full throttle settings. This is necessary because spring 66 has a relatively low spring constant to effect a regulated fuel pressure of 5 inches of water for full throttle operation, and the pressure in chamber 22 without limitation would be at intake manifold vacuum of, say, five inches of mercury for the change from cruise to full throttle operation.

With reference to FIG. 4, a schematic section of a typical fuel system employing the principles of the present invention is shown. A tank 128 for a fuel such as natural gas or propane is provided. The tank is in fuel communication with a first stage regulator 130 of standard construction. This first stage regulator is designed for dropping the fuel pressure from, say about 2,250 p.s.i. for natural gas to, say, about 50 to 60 p.s.i. A normally closed solenoid valve 132 is disposed between regulator 130 and regulator 10. This solenoid-actuated valve is actuated to its open position by the ignition circuit of the vehicle. A fuel-air mixer 134 is mounted on top of a carburetor 136. The fuel-air mixer is preferably of the type disclosed in my copending application Ser. No. 858,816, filed Sept. 17, 1969. A throttle body 138 of carburetor 136 is shown exaggerated for the purpose of illustration. The throttle butterfly valve is indicated by reference numeral 140. Carburetor 136 is mounted on an intake manifold 141 of an engine 142 in a standard manner. A starter 144 of the engine is also shown schematically for purposes to be described subsequently.

A line 146 between solenoid valve 132 and regulator 10 represents the input to fuel pressure chamber 18 of the regulator. Line 148 represents outlet from fuel chamber 18 of regulator 10 and it runs directly between the regulator and fuel-air mixer 134. A line 150 extends from between pilot valve 76 and bypass valve 100 to intake manifold 141 for the sensing of intake manifold pressure. A line 152 extends from bypass valve 100 to a reference pressure tap 154 of essentially atmospheric pressure disposed in the air cleaner of mixer 134. Solenoid 120 is in circuit through conductor 156 with starter 144. An ignition switch 158 is disposed between a battery 160 and the starter and solenoid circuits. When the ignition switch is energized to energize the starter circuit, the solenoid is also energized to force its armature or valving element 118 to open line 150 for pressure communication between the intake manifold and chamber 22 of regulator 10.

The operation will now be described.

To start engine 142, the starter circuit is energized through the closing of ignition switch 158. While the engine is cranking, solenoid 120 is energized. Valving element 118 will close the air cleaner reference tap by closing on valve seat 124. Low pressure chamber 22 of regulator 10 will then be in communication with the intake manifold through passage 116 and branch 99 of tee 98. While the engine is cranking, a slight vacuum exists in the intake manifold. This vacuum is sufficient to overcome the effect of spring 66 and force low pressure diaphragm 24 upwardly in FIG. 3. Valve element 32 will then respond to movement of fuel chamber diaphragm 20 to effect a fuel pressure in chamber 18 of zero inches of water, for diaphragm 20 seeks a position where there is atmospheric pressure on each of its sides.

Once in a raised position, as determined by the raised positions of diaphragm 24, pin 78 maintains valving element 88 of pilot valve 76 away from seat 92 to communicate low pressure chamber 22 of regulator 10 with the intake manifold of engine 142 through bore 80, tee 98 and line 150.

Once the engine begins to run, solenoid valve 120 is deenergized and valving element 118 is returned to its normal position by spring 126 to prevent direct intake manifold communication with chamber 22 through branch 99. While the engine is running, the negative pressure within chamber 22 is attenuated from that existing in the intake manifold by virtue of the communication of the air cleaner reference tap with the chamber through bypass valve 100.

Over a range of engine operation from idle to almost full throttle, say, five inches of mercury manifold vacuum, diaphragm 24 will be raised to maintain spring 66 uncoupled from diaphragm 20 to allow this diaphragm to position valve element 32 relative to seat 34 and to maintain the pressure in fuel chamber 18 at essentially zero inches of water. When manifold vacuum falls to this predetermined value, the force of spring 66 will move diaphragm 24 downwardly in FIG. 3 and couple the spring to diaphragm 20 for the creation of a fuel pressure within chamber 18 of five inches of water, the position of diaphragm 20 and its controlled valve element 32 now being determined by spring 66. At this point there has been a rapid step shift in the air-fuel ratio of from between about 1.25 and about 1.35 to about 0.9 on an equivalence ratio basis, as shown in FIG. 1. Once this full throttle condition

has been achieved, pilot valve **76** closes to prevent communication between chamber **22** and the intake manifold. At the full throttle setting, the pressure within chamber **22** will be the pressure at reference pressure tap **154**, essentially atmospheric.

At a predetermined lower throttle setting corresponding to a manifold vacuum of, say 10 inches of mercury, the vacuum within the pilot valve will be sufficient in conjunction with the pressure exerted on the walls of recess **94** to raise valving element **88** and reestablish communication between chamber **22** and the intake manifold. Enlarged portion **84** of pin **78** is disposed to reside within orifice **82** when valving element **88** of pilot valve **76** rises to its fully open position to cooperate with orifice **127** to assure the proper pressure in chamber **22**. Before the enlarged portion is disposed within the orifice, the orifice admits to the rapid sensing of intake manifold vacuum within chamber **22** for the rapid raising of diaphragm **24** to its cruise position.

The present invention, then, provides a means for rapidly changing from a fuel-lean condition to a fuel-rich condition for full power operations. The changeover is sufficiently rapid that no substantial amount of operation in the zone of maximum NO_x production exists. Moreover, because the time at which an engine operates within this zone is very small, there is no risk of burning valves. The invention also provides means to prevent unstable operation between the full throttle setting and the cruise setting by effecting return to the cruise setting at a manifold pressure substantially below that required to go from the cruise setting to the full throttle setting. In addition, the present invention provides means for bypassing the pilot valve while starting the engine in order to initiate operation at the cruise setting.

The present invention has been described with reference to a certain preferred embodiment. The spirit and scope of the appended claims should not, however, necessarily be limited to the foregoing description.

I claim:

1. A regulator capable of use in regulating fuel pressure to a fuel-air mixer of gaseous fueled internal combustion engine between a lean and a rich mixture comprising:

a. a body having a hollow interior;

b. first separating means within the hollow interior for defining a first pressure chamber, the first separating means being positionally responsive to a pressure differential across it;

c. gas inlet means into the first pressure chamber;

d. valve means for the inlet means coupled to the first separating means so that the gas flow through the inlet means is a function of the position of the separating means:

e. gas outlet means from the first pressure chamber;

f. means for effecting a first predetermined pressure differential across the first separating means to effect a first predetermined pressure in the first pressure chamber;

g. selectively actuatable means for effecting a second predetermined pressure differential across the first separating means to effect a second predetermined pressure in the first pressure chamber;

h. second separating means within the hollow interior defining a second pressure chamber, the second separating means being positionally responsive to a pressure differential across it;

i. means for effecting a pressure differential across the second separating means including means for communicating the second pressure chamber with a variable pressure source;

j. the second separating means being operable upon the occurrence of a predetermined threshold pressure at the variable pressure source to be displaced to a coupling position from an uncoupled position and actuate the selectively actuatable means to effect the predetermined second pressure in the first pressure chamber; and

k. means for preventing pressure communication between the second pressure chamber and the variable pressure source when the second separating means is in its coupling position until a predetermined return pressure at the variable pressure source exists.

2. The regulator claimed in claim **1** including bypass valve means for selectively communicating the second pressure chamber with the pressure source independently of the preventing means.

3. The regulator claimed in claim **1** wherein the preventing means includes a pilot valve having a valving element in pressure communication with the second pressure chamber and adapted for pressure communication with the variable pressure source, the pilot valve having biasing means for urging its valving element into a closed position where it terminates pressure communication between the variable pressure source and the second pressure chamber, the pilot valve being operative upon the presence of the return pressure therein to displace its valving element against the biasing means to an open position and establish pressure communication between the second pressure chamber and the variable pressure source to enable the return of the second separating means to its uncoupled position, and means is included coupled to the second separating means to maintain the valving element of the pilot valve in its open position when the second separating means is in its uncoupled position.

4. The regulator claimed in claim **3** wherein:

selectively actuatable bypass valve means is included for selectively communicating the second pressure chamber with the variable pressure source independently of the preventing means, the bypass valve means being adapted for pressure communication with a reference pressure source and being in communication with the second pressure chamber, the bypass valve means having a valving element normally in position to communicate the reference pressure source with the second pressure chamber and to prevent pressure communication between the second pressure chamber and the variable pressure source, the valving element of the bypass valve upon actuation of the bypass valve being in a position to prevent pressure communication between the reference pressure source and second pressure chamber and to establish pressure communication between the second pressure chamber and the variable pressure source.

5. The regulator claimed in claim **4** wherein:

means are provided to attenuate the pressure in the second pressure chamber relative to that of the variable pressure source.

6. The regulator claimed in claim **5** wherein:

the attenuating means includes an orifice between the variable pressure source and the second pressure chamber and a second orifice between the reference pressure source and the second pressure chamber.

7. The regulator claimed in claim **6** wherein:

means are provided to increase the effective area of the orifice between the variable pressure source and the second pressure chamber during the opening of the valving element of the pilot valve.

8. A regulator capable of use in regulating fuel pressure to a fuel-air mixer of gaseous fueled internal combustion engine between a lean and a rich mixture comprising:

a. a body having a hollow interior;

b. a first pressure responsive diaphragm within the hollow interior defining a first pressure chamber;

c. a second pressure responsive diaphragm within the hollow interior defining a second pressure chamber, the first and second diaphragms being spaced apart to define a third pressure chamber;

d. gas inlet means into the first pressure chamber;

e. valve means for the inlet means coupled to the first diaphragm to meter gas flow through the inlet means as a function of the pressure response of the first diaphragm;

f. gas outlet means from the first pressure chamber;

g. means including the first and third pressure chambers for establishing a first predetermined pressure differential across the first diaphragm to effect a first predetermined pressure in the first pressure chamber;

h. spring means urging the second diaphragm towards the first diaphragm;

i. means including the spring means, the second pressure chamber and the third pressure chamber for effecting a pressure differential across the second diaphragm;

j. means for communicating the second pressure chamber with a variable pressure source;

k. the second diaphragm being operable upon the occurrence of a predetermined threshold pressure differential across it determined by a threshold pressure at the variable pressure source to be displaced from an uncoupled position to a coupling position wherein the spring means is coupled to the first diaphragm for effecting a second predetermined pressure differential across the first diaphragm; and

l. a pilot valve disposed to control communication between the second pressure chamber and the variable pressure source, the pilot valve having a valving element in pressure communication with the second pressure chamber and adapted for pressure communication with the variable pressure source, and biasing means for urging the valving element into a closed position where it presents pressure communication between the variable pressure source and the second pressure chamber, the valving element being responsive to a predetermined return pressure of the variable pressure source to be displaced to an open position and establish pressure communication between the second pressure chamber and the variable pressure source to enable the return of the second diaphragm to its uncoupled position, and means is included to maintain the valving element in its open position when the second diaphragm is in its uncoupled position.

9. The regulator claimed in claim **8** wherein:

selectively actuatable bypass valve means is included for selectively communicating the second pressure chamber with the variable pressure source independently of the preventing means, the bypass valve means being adapted for pressure communication with a reference pressure source and being in communication with the second pressure chamber, the bypass valve means having a valving element normally in position to communicate the reference pressure source with the second pressure chamber and to prevent pressure communication between the second pressure chamber and the variable pressure source, the valving element of the bypass valve upon actuation of the bypass valve being in a position to prevent pressure communication between the reference pressure source and second pressure chamber and to establish pressure communication between the second pressure chamber and the variable pressure source.

10. A regulator for use in regulating fuel pressure to a fuel-air mixer of a gaseous fueled internal combustion engine between a lean and a rich mixture comprising:

a. a body having a hollow interior;

b. means separating the hollow interior into a fuel chamber and a low pressure chamber, the separating means being displaceable between a first fuel-lean position and a second fuel-rich position;

c. a fuel inlet into the fuel chamber adapted to be connected in the fuel system of the internal combustion engine;

d. a fuel outlet from the fuel chamber adapted to be connected to the fuel-air mixer;

e. a displaceable valve for the fuel inlet;

f. means coupling the displaceable valve to the separating means to effect a predetermined low pressure and a predetermined high pressure in the fuel chamber when the separating means is in its first and its second position, respectively;

g. port means for pressure communicating the low pressure chamber with the inlet manifold of the internal combustion engine; and

h. biasing means for urging the separating means into its second position, the biasing means being operable upon the presence of a predetermined threshold intake manifold pressure in the low pressure chamber and the predetermined low pressure in the fuel chamber to be overcome by the resulting pressure differential such that the separating means is displaced to its second position in a step shift for effecting the predetermined high pressure in the fuel chamber.

11. The regulator claimed in claim **10** wherein:

a pilot valve controlling the port means is included, the pilot valve being adapted for pressure communication with intake manifold and being operative to prevent communication between the low pressure chamber and the inlet manifold when the separating means is in its second position and to reestablish such communication upon the sensing of a predetermined return intake manifold pressure lower than the threshold pressure.

12. The regulator claimed in claim **11** wherein:

a bypass valve is included, the bypass valve having an inlet in pressure communication with the low pressure chamber, an outlet adapted for pressure communication with the intake manifold, and means operative by the starter circuit of the internal combustion engine to open the bypass valve to establish communication between its inlet and outlet during engine starting.

13. The regulator claimed in claim **11** wherein the separating means includes a diaphragm between the fuel and low pressure chambers, and means is provided to attenuate the pressure in the fuel chamber relative to the intake manifold pressure.

14. The regulator claimed in claim **13** including a two-position bypass valve, the bypass valve having an inlet in pressure communication with the low pressure chamber, a first outlet adapted for pressure communication with the intake manifold, a second outlet adapted for pressure communication with a reference pressure source of essentially atmospheric pressure, and means operative by the starter circuit of the internal combustion engine to actuate the bypass valve to a first position establishing pressure communication between the inlet and the first outlet while preventing pressure communication between the second outlet and the inlet, the bypass valve in its second position preventing pressure communication between the inlet and first outlet and establishing pressure communication between the second outlet and the inlet, the attenuating means including an orifice in the second outlet.

15. The regulator claimed in claim **14** wherein the attenuating means includes a second orifice in fluid circuit with the port means and controlled by the pilot valve in the same manner as the port means.

16. The regulator claimed in claim **14** wherein the attenuating means includes a second orifice between the pilot valve and the port means, and means controlled by the separating means is included to decrease the effective area of the second orifice after the pilot valve senses the return pressure and the separating means is in its first position.

17. In combination with an internal combustion engine having a fuel-air mixer for mixing a gaseous fuel with air, the fuel-air mixer being in communication with the intake manifold of the engine to supply the engine with a fuel-air mixture, an improved regulator for use in regulating fuel pressure to the fuel-air mixer between a lean and a rich mixture, the regulator comprising:

a. a body having a hollow interior;

b. means separating the hollow interior into a fuel chamber and a low pressure chamber, the separating means being displaceable between a first fuel-lean position and a second fuel-rich position;

c. a fuel inlet into the fuel chamber adapted to be connected in the fuel system of the internal combustion engine;

d. a fuel outlet from the fuel chamber coupled to the fuel-air mixer for supplying fuel thereto;
e. a displaceable valve for the fuel inlet;
f. means coupling the displaceable valve to the separating means to effect a predetermined low pressure and a predetermined high pressure in the fuel chamber when the separating means is in its first and its second position, respectively;
g. port means pressure communicating the low pressure chamber with the inlet manifold of the internal combustion engine; and
h. biasing means for urging the separating means into its second position, the biasing means being operable upon the presence of a predetermined threshold intake manifold pressure in the low pressure chamber and the predetermined low pressure in the fuel chamber to be overcome by the resulting pressure differential such that the separating means is displaced in a step shift to its second position for effecting the predetermined high pressure in the fuel chamber.

18. The regulator claimed in claim **17** wherein:

a pilot valve controlling the port means is included, the pilot valve being adapted for pressure communication with the intake manifold and being operative to prevent communication between the low pressure chamber and the inlet manifold when the separating means is in its second position and to reestablish such communication upon the sensing of a predetermined return intake manifold pressure lower than the threshold pressure.

19. The regulator claimed in claim **18** wherein:

a bypass valve is included, the bypass valve having an inlet in pressure communication with the intake manifold, and means operative by the starter circuit of the internal combustion engine to open the bypass valve to establish communication between its inlet and outlet during engine starting.

20. The regulator claimed in claim **18** wherein the separating means includes a diaphragm between the fuel and low pressure chambers, and means is provided to attenuate the pressure in the fuel chamber relative to the intake manifold pressure.

21. The regulator claimed in claim **20** including a two-position bypass valve, the bypass valve having an inlet in pressure communication with the low pressure chamber, a first outlet adapted for pressure communication with the intake manifold, a second outlet adapted for pressure communication with a reference pressure source of essentially atmospheric pressure, and means operative by the starter circuit of the internal combustion engine to actuate the bypass valve to a first position establishing pressure communication between the inlet and the first outlet while preventing pressure communication between the second outlet and the inlet, the bypass valve in its second position preventing pressure communication between the inlet and first outlet and establishing pressure communication between the second outlet and the inlet, the attenuating means including an orifice in the second outlet.

22. The regulator claimed in claim **21** wherein the attenuating means includes a second orifice between the pilot valve and the port means, and means controlled by the separating means is included to decrease the effective area of the second orifice after the pilot valve senses the return pressure, and the separating means is in its first position.

23. The regulator claimed in claim **17** wherein the predetermined low pressure corresponds to a fuel-air ratio of from between about 1.25 to about 1.35 on an equivalence basis and the predetermined high pressure corresponds to a fuel-air ratio of about 0.9.

24. A method for reducing the amount of NO_x in the exhaust gas emissions of an internal combustion engine during normal operating conditions by running the engine with a lean fuel-air ratio and for rapidly increasing the power of the engine at a full throttle operating condition by rapidly shifting to a rich fuel-air ratio, the method comprising the steps of:

a. regulating the pressure of a gaseous fuel to a predetermined first pressure corresponding to a fuel-lean condition leaner than the air-fuel ratio at which maximum NO_x occurs during normal operating conditions;
b. regulating the pressure of the gaseous fuel to a predetermined second pressure during full throttle operating conditions corresponding to a fuel-rich condition richer than the air-fuel ratio at which maximum NO_x occurs by increasing the regulated fuel pressure from the predetermined first pressure in a step shift to the predetermined second pressure at a predetermined intake manifold pressure corresponding to at least nearly full throttle;
c. mixing the gaseous fuel after regulation with air to obtain a fuel-air mixture;
d. introducing the mixture into the combustion chambers of the internal combustion engine for burning therein; and
e. burning the mixture within the combustion chamber to operate the internal combustion engine.

25. The method claimed in claim **24** including the step of returning the regulated pressure in a step shift from the second pressure to the first pressure at an intake manifold pressure below that required to initiate operation at the second pressure.

26. The method claimed in claim **24** wherein the predetermined intake manifold pressure corresponding to at least nearly full throttle is about 29 inches of mercury, and the intake manifold pressure at which the regulated pressure drops from the second pressure to the first pressure is about **20** inches of mercury.

27. The method claimed in claim **26** wherein the fuel-air mixture at the first pressure is at an equivalence ratio of from between about 1.25 to about 1.35 and the fuel-air mixture at the second pressure is at an equivalence ratio slightly less than one.

28. The method claimed in claim **27** wherein the fuel-air mixture at the second pressure is at an equivalence ratio of about 0.9.

29. An improved regulator for use in regulating fuel pressure to a gaseous fuel, fuel-air mixer of an internal combustion engine comprising:

a. means for regulating the pressure of a gaseous fuel to a first pressure corresponding to a fuel-lean condition leaner than the air-fuel ratio at which maximum NO_x occurs during normal operating conditions of the engine over a range of operating conditions including a cruise condition to at least nearly a fully throttle condition;
b. pressure increasing means responsive to intake manifold pressure for changing the regulated pressure of the gaseous fuel to a second pressure higher than the first pressure at an intake manifold pressure corresponding at least to about the full throttle operating conditions, the second pressure corresponding to a fuel-rich condition richer than the air-fuel ratio at which maximum NO_x occurs; and
c. return means responsive to intake manifold pressure for returning to the first pressure from the second pressure at an intake manifold pressure below that required to initiate operation at the second pressure.

30. The improved regulator claimed in claim **29** wherein each of the pressure increasing means and the return means effects its change in pressure between the first pressure and the second pressure in step shift.

31. The improved regulator claimed in claim **30** including means for maintaining the first pressure during engine startup.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,650,254 Dated March 21, 1972

Inventor(s) Robert W. McJones

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the specification: Column 5, line 54, "33" should be --22--.

In the claims: Claim 1, column 7, line 71, after "pressure" insert --differential across it determined by a threshold pressure--. Claim 29, column 12, line 50 "fully" should be --full--.

Signed and sealed this 19th day of December 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents