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Gardner

[11] **3,788,284**
[45] **Jan. 29, 1974**

[54] **FEEDBACK MODULATION OF EXHAUST GASES IN INTERNAL COMBUSTION ENGINES**

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[52] **U.S. Cl.** .... **123/119 A**
[51] **Int. Cl.** **F02b 33/00**
[58] **Field of Search** .... 123/119 A

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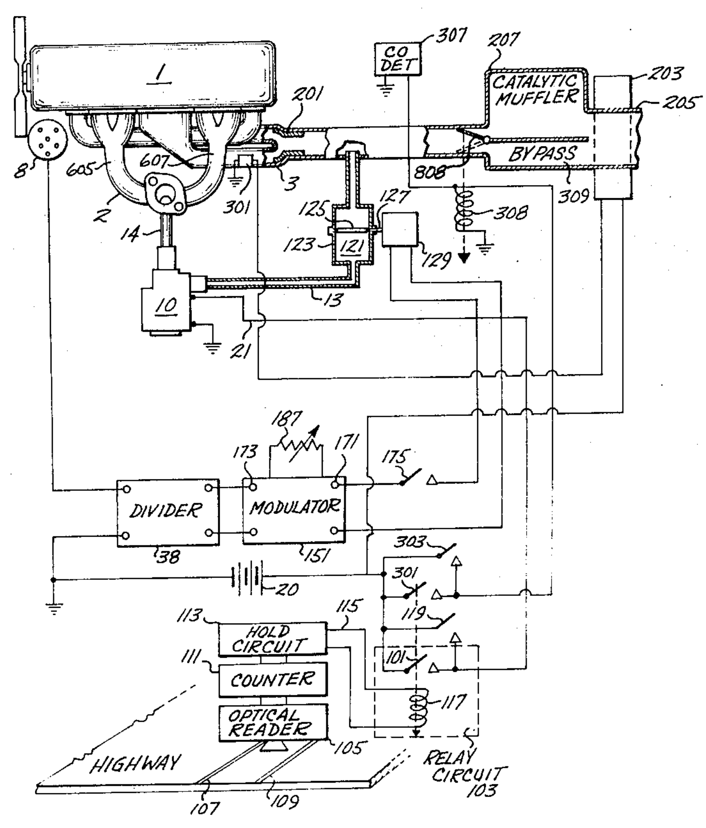
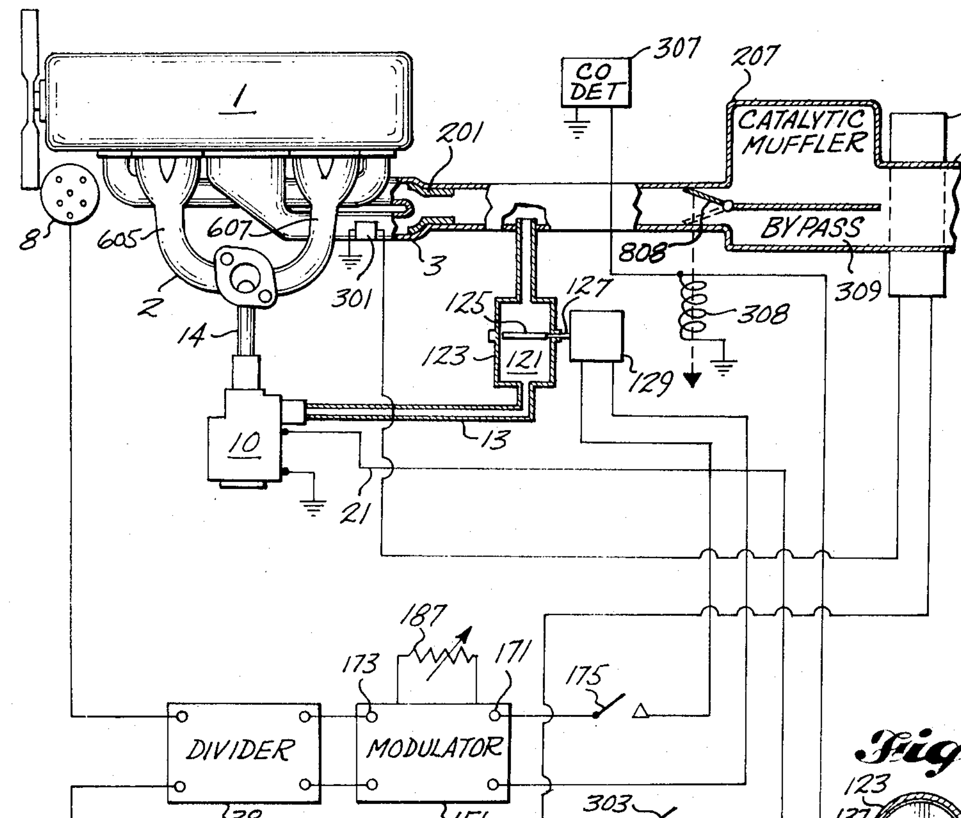
[57] **ABSTRACT**

A system for modulation of the amplitude of engine exhaust feedback to the engine induction system during engine operation. The modulation system includes means for varying the amplitude of exhaust feedback in periodic manner at a frequency which is substantially constant or which may vary as a function of an engine operating parameter. The amplitude may vary as a step function between predetermined levels or continuously and may have a duty cycle (length of time at a predetermined level) which varies as a function of an engine operating parameter, e.g. exhaust manifold temperature. The modulation envelope is controlled by a modulator circuit controlling a valve position in the feedback path. The frequency of modulation is controlled by a divider or multiplier type circuit coupled between a pulse source e.g. the distributor and the modulator circuit.

18 Claims, 6 Drawing Figures





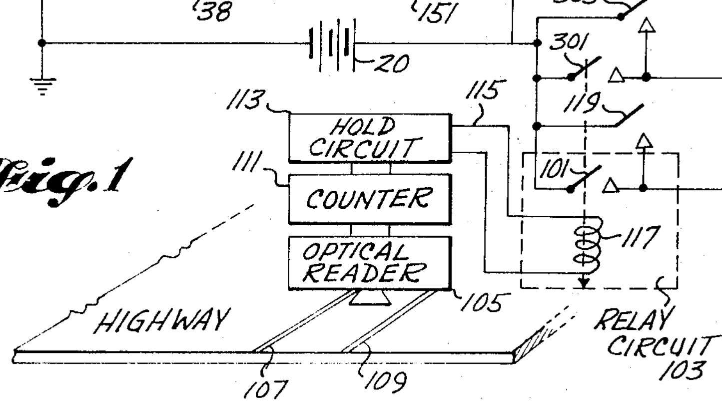


Fig. 1

Fig. 2

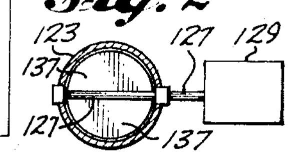


Fig. 3

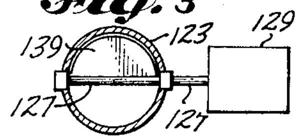
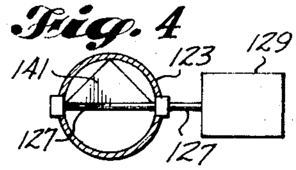


Fig. 4



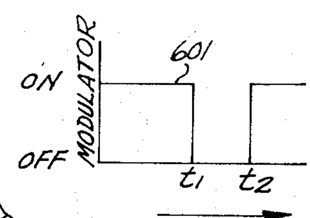
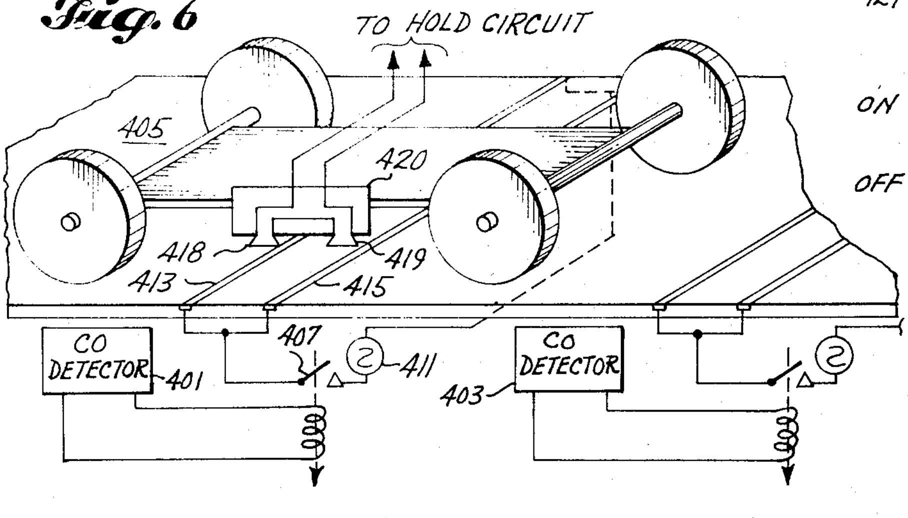


Fig. 5

Fig. 6



FEEDBACK MODULATION OF EXHAUST GASES IN INTERNAL COMBUSTION ENGINES

This invention relates to internal combustion engines in motor vehicles and more particularly to exhaust feedback or recirculation systems in these engines in which exhaust gas is coupled back to the engine induction system.

Prior systems as shown for example in U.S. Pat. No. 3,636,934; 3,641, 989; 3,641,767; and, 3,643,640 are representative of the more recent state of the art recirculating systems and are all ON-OFF systems which are adapted to provide a given level of feedback of engine exhaust.

It is known that the increase above a certain level in the amount of feedback results in the deterioration in engine performance. It is further known that while higher temperature of exhaust manifold operation results in increased conversion rates of carbon monoxide to carbon dioxide, exhaust pipe pressure increases and so higher temperature operation has not been deemed possible and has been limited in the prior art, e.g. in U.S. Pat. No. 3,643,640 means are shown for reducing and preventing the undesired temperature build up.

It is accordingly an object of this invention to provide means utilizing high temperature exhaust manifold operation in the reactor mode whereby high rates of carbon monoxide to carbon dioxide conversion are maintained and catalytic converter means are arranged by direct coupling to the exhaust volume present in the exhaust manifold so that the catalytic converter means may also utilize increased exhaust temperatures for higher efficiency operation.

It is a further object of this invention to provide means for varying the amplitude of exhaust feedback between predetermined levels in a repetitive manner during normal engine operation.

It is yet another object of this invention to provide means for varying amplitude modulation characteristics of feedback exhaust during engine operation.

It is another object of this invention to provide means for controlling pollution control characteristics of an engine in response to ambient pollution levels surrounding the vehicle powered by the engine.

It is another object of this invention to provide means for controlling the amplitude of exhaust feedback in a motor vehicle powered by an internal combustion engine as a function of frequency.

Further objects and advantages arising from the various features of the present invention will become apparent from the following description and drawings in which:

FIG. 1 is a system embodiment of the present invention showing partially in block diagram the feedback modulation system for engine exhaust;

FIG. 2 is an arrangement for providing 0 to 100 percent amplitude modulation of exhaust feedback in the system of FIG. 1;

FIG. 3 is an arrangement for providing 0 to 50 percent amplitude modulation of exhaust feedback in the system of FIG. 1;

FIG. 4 is an arrangment for providing from 0 to less than 50 percent amplitude modulation of exhaust feedback in the system of FIG. 1;

FIG. 5 is a waveshape representative of the periodic control signals generated by the modulator circuit of FIG. 1 to control the valve means comprising the motor

driven arrangements shown in FIGS. 1,2,3, and 4; and,

FIG. 6 is an alternate control arrangement for initiating exhaust feedback in the system of FIG. 1 automatically in response to ambient level pollution detection means however independent of the motor vehicle.

Turning now to FIG. 1 there is seen a system in accordance with an embodiment of the invention wherein the numeral 1 designates the usual internal combustion engine 1 having an intake manifold 2 and exhaust manifold 3. An exhaust recirculation control valve 10 is utilized which is a solenoid valve with a solenoid coil having an input terminal 21 which when connected through switching means closing the circuit path to source of power 20 causes coupling of exhaust (feedback) from exhaust manifold 3 to intake manifold 2. The preceeding feedback path components are known and shown (with the same numerals) in FIG. 5 of U.S. Pat. No. 3,636,934. The following description now concerns features of the present feedback modulation system and other features of the present system which are novel with respect to the prior art.

In FIG. 1, recirculation conduit 13 providing the exhaust feedback path includes a solenoid valve 10 having a terminal 21 which is energized by potential 20 upon the closing of the circuit path including switch 101. Switch 101 is closed upon energization of relay circuit 103 thereby closing switch 101 when optical reading means 105 detects a pair of consecutive spaced apart reflective stripes 107 and 109 in the highway surface beneath the vehicle powered by internal combustion engine 1. Counter means 111 coupled to optical reader 105 upon a coincidence of two pulses counted, energizes hold circuit 113 which remains energized thereafter for a predetermined period of time e.g. 5 minutes during which time an output control signal 115 maintains relay coil 117 energized so as to keep switch 101 closed. After the predetermined time period of hold circuit 113 has expired, control signal 115 is cut off and relay coil 117 becomes deenergized whereby switch 101 opens and source potential 20 is no longer coupled to input terminal 21 of recirculation control valve 10 whereby feedback of exhaust gases ceases. Unless a second pair of stripes subsequent to stripes 107 and 109 is detected in a similar manner within the above predermined time period of hold circuit 113, there is no pollution reduction by exhaust gas recirculation. As a consequence efficiency of engine performance without feedback may be caused to increase in open country where pollution levels are not a problem and increased engine efficiency enjoyed and where therefore no stripes are disposed in the highway surface. In effect this feature of automatic control of pollution reducing means providing 2 modes of engine operation viz. with or without feedback permits increased engine efficiency in one mode while permitting pollution control in a further mode which might not be tolerable technically or economically during all periods of engine operation. Switch 119 is connected in parallel with switch 101 and permits closing manually the circuit including source potential 20 to energize terminal 21 and thereby energize recirculation valve 10 to provide exhaust feedback. Valve means 121 includes a chamber of circular cross section having a wall 123 and a plate member 125 supported by a pin member 127 wherein the pin member bisects the circular cross section of chamber 121 and permits plate member 125 to rotate about the axis of pin member 127 thereby varying the cross sectional area available for passage of and affecting the percentage of exhaust gas which can be fed back through valve means **121.** A stepping motor **129** is coupled to pin member **127** to rotate plate member **125** from an initial first step where the plane of plate **125** is parallel to the path of exhaust flow (0 percent modulation of the feedback path) to a further position where the plane of plate **125** is perpendicular to the path of exhaust flow (modulating the path at a maximum percentage level which equals the ratio of cross sectional area of plate **125** to cross sectional area of the chamber **121** surrounded by wall **123** times 100 percent). Stepping motor **129** when in the initial position not energized retains plate **125** in a plane parallel to the path of exhaust flow (0 percent modulation of the feedback path) and the exhaust recirculation path remains unimpeded or unmodulated by valve means **121.** Plate **125** may comprise a circular shaped plate **137** having a circular cross section as shown in FIG. **2** where the cross section is slightly less than the circular flow path cross section formed by the valve wall **123** (to permit free rotation) so that 100 percent modulation (complete shutoff of valve **121**) can occur when stepping motor **129** has been actuated causing pin **127** to rotate plate **137** to oppose the flow of exhaust. Without a signal output from modulator **151** (between time $t=t_1$ and $t=t_2$) stepping motor **129** returns plate **137** to the position in a plane parallel to the exhaust flow path and there is no resistance to exhaust flow because valve means **121** is fully open so that there is 0 percent modulation of exhaust flow. Thus it can be seen that the arrangement of FIG. **2** when incorporated in the feedback path **13** provides 0 and 100 percent modulation control of the exhaust coupled back through the feedback path. It should be noted that since the stepping motor **129** turning the plate **137** does not respond instantaneously to the modulator control waveshape shown in FIG. **5** due to lag time of the motor in starting and other inertia factors, there is actually a continuous change in modulation from 0 to 100 percent and back to 0 percent which can affect a system where nearly instantaneous changes from 0 to 100 percent are desired in very fast times e.g. over a few engine cycle time periods or over less than an engine cycle time period in which case faster acting or higher response valve means may be utilized in place of the specific type of valve means **121** shown. The several valve structures shown herein are utilized since they are illustrative of the varieties of types of modulation of the exhaust flow path that can be achieved with simple modulator circuit and valve structure configuration. Modulator circuit means **151** comprising a monostable multivibrator circuit provides a periodic output control signal at output terminal **171** having the waveshape **601** shown in FIG. **5** in response to periodic pulses from divider circuit **38** are applied to input terminal **173.** Each pulse from divider circuit **38** triggers modulator circuit means **151** to the ON condition for the portion of the period **0** to t_1 during which time stepping motor **129** holds plate **137** in the 100 percent modulation position as shown in FIG. **2.** Modulator circuit means **151** returns to the OFF state during the remainder of the modulation cycle t_1 to t_2 since the monostable multivibrator circuit has returned to its stable or relaxed state. As mentioned previously the modulation duty cycle may be increased by adjusting the time constant of monostable multivibrator circuit **151,** this being accomplished by varying resistance **187** to either lengthen or shorten the period **0** to t_1 with respect to the modulation period **0** to t_2. Timing means or clocking means for determining the modulation period is provided by a pulse source comprising divider circuit **38** coupled to distributor **8.** The number of distrbutor pulses divided by the ratio of divider circuit **38** gives the modulation time period in seconds, e.g. number of distributor pulses per second divided by a ratio of divider circuit **38** of **20** will provide a modulation period extending over a plurality of engine cycles whereas a ratio of **1** will not divide down but make the modulation cycle vary with each distributor pulse and thereby provide feedback modulation over **1** engine cycle.

While plate **137** shown in FIG. **2** provides 0 and 100 percent modulation, the characteristics of motor **129** may be varied from stepping from 0 to 100 percent to continuous variation from 0 to 100 percent by substitution of a motor providing continuous rotation of plate **137** during a modulation period for the stepping motor. Variation between different amplitude levels of modulation may be set by valve design, here more specifically by change in plate cross section area with respect to the flow path cross section **123.** Modulation between amplitude levels of 50 and 0 percent and less than 50 percent and 0 percent are given herein as examples in plates **139** (semi cicular cross section) or **141** (triangular cross section) shown respectively in FIGS. **3** and **4.**

In the preceding, a timing means for determining modulation period was shown which varied as a function of engine speed. However modulation period can be made to vary as a function of some other engine operating parameter such as exhaust temperature where the pulse source instead of distributor pulses comprises an exhaust temperature sensor having an output frequency which is proportional to exhaust temperature. The turning means utilized herein while utilized to control feedback modulation time periods may also be utilized as a clock or pulse source to control engine inputs such as fuel mixture or air input modulation with respect to time in a predetermined relationship (phase and amplitude) with respect to the herein described feedback modulation of exhaust.

The following example of application of the present feedback modulation control to a present state of the art system is illustrative of the wide range of applicability of the present control loop and is exemplary of its use as a powerful tool in overcoming present problems in the art. In the following it will also be noted how much flexibility exists in the present loop for achieving variation in modulation characteristics. In the preceding it was seen that feedback systems of the prior art were ON -OFF control, and that the only variation in exhaust gas recylce was between idle throttle and full throttle. In order to achieve gradual increase and decrease of the quantity of exhaust gas recycled as desired in the prior art, a mechanical linkage between throttle and variable resistor **187** may be made to vary the resistance value of resistor **187** to gradually increase and decrease the resistance in a manner which decreases modulation duty cycle (allows more feedback of exhaust) and increases modulation duty cycle (allows less feedback of exhaust) between idle throttle and full throttle. Resistor **187** may be placed in the exhaust manifold where the resistor **187** is a temperature sensitive type as temperature sensor **301** where it is desired to vary modulation duty cycle in response to manifold temperature. Where secondary air and rich exhaust combinations are desired for effective utilization of the exhaust manifold in the reactor mode, programmed control of these and the exhaust may be afforded since complete control over exhaust may also be had by the present modulation system. It should be recognized by those skilled in the art that while a single feedback path 13 to intake manifold 2 is shown herein being modulated that a plurality of input ports 605 and 607 and a plurality of reactors (V8 engine) not shown permits modulation in one or more paths between input and output and where a plurality of feedback paths are utilized the modulation in accordance with the teachings of this invention may be in or out of phase with the modulation in another path, the modulation phase relationship being obtained by utilization of a phase control circuit between modulator circuits.

A further feature of this invention includes the disposition of known catalytic conversion material 201 over at least a portion of the inner wall of exhaust manifold 3 (shown here as at least over the inner wall portion surrounding the outlet portion of manifold 3). When the exhaust manifold is operated at higher temperatures (above 1,800° F.) so that high temperature exhaust processing by catalytic conversion material 201 is also afforded, exhaust pipe pressures increase and in accordance with a feature of the present invention, temperature detector 301 positioned in a wall of the exhaust manifold 3 is responsive to temperature (and pressure) increase above desired levels to control cooling means 203 surrounding exhaust pipe 205. Cooling means 203 comprises a cooling coil energized by battery 20 as shown in FIG. 1 but may however comprise other cooling device such as radiator water circulation or some other form of heat sink or dissipation. In the preceding description, normally catalytic muffler 207 would not be coupled downstream of exhaust manifold 3 in the exhaust path since as described previously, manifold 3 would employ catalytic material 201 of the type used in a state of the art muffler 207. However in normal state of the art low temperature exhaust manifold temperature operation where catalytic converter 201 and cooling means 203 are not utilized, catalytic muffler 207 would be utilized as shown and switched into the exhaust stream for exhaust processing under automatic control of optical reader 105 activating switch 301, or under manual control of the operator closing switch 303 or thirdly in the alternative by automatic detection of ambient pollution levels surrounding the vehicle by energization of threshold level CO detector 307 mounted on the vehicle. When any of the preceding three circuit paths are closed, solenoid coil 308 is energized by the potential applied thereto thereby causing closing of bypass passage 309 by valve 808 (as shown in phantom by the dotted line) and processing of exhaust by catalytic muffler 207.

a further example of ambient pollution level detection systems for remotely operating or controlling motor vehicle exhaust pollution control apparatus is shown in FIG. 6 wherein CO detectors 401 and 403 sense dangerous levels above a predetermined level and are actuated (threshold level detectors) when motor vehicles as 405 cause the dangerous level to be exceeded. If detector 401 becomes energized indicating a dangerous level of CO above the highway at the location of detector 401 positioned in the highway surface, relay switch 407 is closed completing the circuit path through a. c. potential source 411 thereby causing lighting of lighting strips 413 and 415 (which may comprise strips of electroluminescent material disposed across the highway below gratings for protection). Photodetector elements 418 and 419 are both energized in their support 420 supported beneath vehicle 405 and hold circuit 113 is thereby actuated with the system of FIG. 1 thereby functioning in the manner previously described when holding circuit 113 became energized. If holding circuit 113 does not become energized again by dectector 403 down the highway within the predetermined time period of holding circuit 113, then the exhaust pollution control means does not remain activated since the pollution level down the highway at location of detector 403 has not indicated that the threshold danger level of CO has been reached at that point along the highway.

While solenoid actuated switching circuits have been shown herein it will be recognized that other switching circuits for switching and applying potentials to activate the various elements may be used.

It should be recognized by those skilled in the art reading this specification that while a divider circuit is coupled to the pulse source, the timing chain shown herein utilized as a time base for the modulator circuit may utilize a multiplier circuit where it is desired to shorten the length of the modulation cycle with respect to the pulse source (here distributor pulses) instead of lengthen it as by division.

The present modulation techniques and features provided are illustrative of the manner of providing feedback control of exhaust in engine design and may be utilized in various optimum relationships with other engine design considerations merely alluded to briefly herein but known to those skilled in the art. While a system shown herein is illustrative of the various kinds of modulation possible in exhaust feedback paths it should be recognized that actual valve means, modulator circuit, and timing reference source will depend for design upon response times inherent in these elements of the system and be determined by modulation period selected, frequency of timing speeds, and character of the modulation envelope desired for a particular feedback application.

Where the valve means coupled to and driven by the modulator circuit comprises a stepping motor driven plate or diaphragm to achieve step function like changes between predetermined modulation levels, modulation cycle periods are limited timewise by stepping motor speed characteristics to time periods in the 100 millisecond range or greater whereas when modulation amplitude is varied continuously over the modulation cycle time period between predetermined levels as when the plate or diaphragm is driven by motor means causing continuous rotation of the plate or diaphragm, then modulation time periods are limited only by the r.p.m. of the motor and may be less than the 100 millisecond range afforded where discrete changes between modulation levels are required. Modulation in the 100 millisecond cycle time period range can be provided by other valve means such as the well known 2-stage type air valve where the first stage is a pilot valve controlling the second stage.

It will be appreciated that modulation time cycle and modulation amplitude variation can be selected according to the teachings of this invention so that variations in sets of conditions e.g. mixture and temperature in the reactor (exhaust manifold) may be matched with the proper amount of feedback for these varying sets of conditions to acieve continuous optimum performance and not only under certain conditions and then only at a given level of feedback.

Modulation duty cycle in the present system may be decreased and increased (time **0** to t_1 compared to cycle time **0** to t_2 in FIG. **5**) between idle throttle and full throttle to increase and decrease feedback where linkage **15** of U.S. Pat. No. 3,643,640 is suitably coupled to drive variable resistance **187** so that modulator circuit **151** comprising the aforementioned multivibrator has the time constant thereof varied to decrease and increase respectively the ON period of time during the modulation cycle. The present modulation of exhaust feedback can be utilized to prevent continuous high level of suppression of peak flame temperature as would be the case where the highest predetermined level of feedback is continuously maintained since at high levels of modulation in the present system smaller levels of feedback are provide with less suppression of peak flame temperature. Various applications of the present feedback modulation control in different systems will be apparent to those skilled in the art.

What is claimed is:

1. In an internal combustion engine having an intake manifold, and a feedback path coupled between said exhaust manifold and said intake manifold for recirculating exhaust gases from said exhaust manifold to said intake manifold;

- means for modulating the rate of flow of exhaust in said feedback path, said means comprising:
- timing means including a pulse source for generating first control signals;
- modulator circuit means including a multivibrator circuit responsive to said first control signals for providing valve control signals, and,
- valve means disposed in said feedback path and responsive to said valve control signals for modulating the rate of flow of exhaust gases in said feedback path.

2. An internal combustion engine according to claim **1** wherein said first control signals are a function of engine speed.

3. Process for operating an internal combustion engine in a manner to reduce pollutants ejected into the atmosphere which comprises recycling of exhaust gases while modulating the rate of flow of said exhaust gases cyclically during operation of said engine.

4. Process of claim **3** wherein said cyclic variation is over a period of time exceeding about 100 milliseconds.

5. In a motor vehicle powered by an internal combustion engine:

- first means for reducing emission of pollutants by said engine;
- second means coupled to said first means for detecting the level of a pollutant in the ambient air surrounding said vehicle and actuating said first means when said level of a pollutant exceeds a predetermined level.

6. The invention according to claim **5** wherein said second means is positioned on said vehicle.

7. The invention according to claim **5** wherein said first means comprises a feedback path including recirculation control valve means.

8. In an internal combustion engine having a feedback path for recirculating engine exhaust;

- means including electrically controlled valve means disposed in said feedback path and further including a modulator circuit coupled to said electrically controlled valve means for modulating said recirculating engine exhaust between predetermined levels in a cyclical manner.

9. The invention according to claim **8** wherein said predetermined levels are 0 and 100 percent.

10. The invention according to claim **8** wherein said cyclical variation is a function of engine exhaust temperature.

11. The invention according to claim **8** wherein said modulation varies as a function of an engine operating parameter.

12. In combination in a motor vehicle having an internal combustion engine including ignition distributor means, intake manifold, exhaust manifold, and an exhaust passage coupled to said exhaust manifold for exhaust gas flow from said exhaust manifold to the atmosphere, the combination comprising:

- a divider circuit responsive to pulses flowing in said ignition distributor means;
- utilization means disposed in said internal combustion engine; and,
- a modulator circuit responsive to the output of said divider circuit for providing control signals for controlling said utilization means.

13. The combination of claim **12** wherein said modulator circuit comprises a multivibrator circuit.

14. The combination of claim **12** wherein said modulator circuit includes means responsive to an engine operating parameter for varying the characteristics of said control signals.

15. In the method of operating an internal combustion engine, the steps of providing an exhaust flow path for recycling exhaust flow from said engine, and

- applying periodic modulation to the exhaust flow in said exhaust flow path to control the peak flame temperature.

16. In the method according to claim **15**, said step of applying periodic modulation comprising applying said modulation as a function of an engine operating parameter.

17. In the method according to claim **15**, the additional step of varying the duty cycle of said periodic modulation.

18. In combination in an internal combustion engine having an intake manifold, and a feedback path coupled between said exhaust manifold and said intake manifold for recirculating exhaust gases from said exhaust manifold to said intake manifold;

- electrically controlled valve means disposed in said feedback path for modulating the rate of flow of exhaust gases in said feedback path;
- a modulator circuit coupled to said electrically controlled valve means; and
- means coupled to said modulator circuit for causing modulation of said modulator circuit to vary as a function of an engine operating parameter.

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REEXAMINATION CERTIFICATE (175th)

United States Patent [19]

[11] **B1 3,788,284**

Gardner

[45] Certificate Issued **Mar. 20, 1984**

[54] **FEEDBACK MODULATION OF EXHAUST GASES IN INTERNAL COMBUSTION ENGINES**

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Filed:	**May 22, 1972**

[51] **Int. Cl.**³ **F02B 33/00**; F02M 25/06

[52] **U.S. Cl.** **123/571**; 123/474; 123/478; 123/484; 123/494

[58] **Field of Search** 123/571, 568, 570, 474, 123/478, 484, 494

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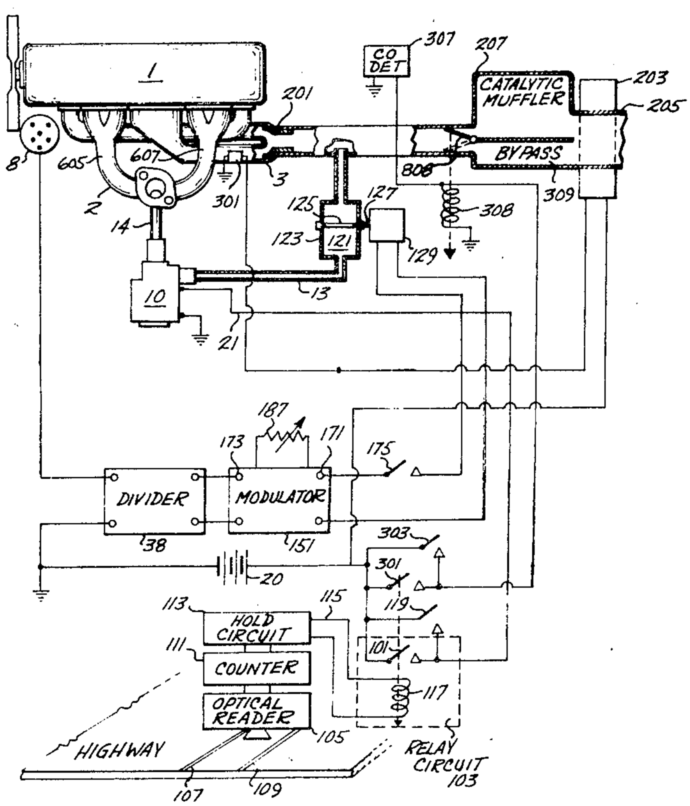
Primary Examiner—Wendell E. Burns

[57] **ABSTRACT**

A system for modulation of the amplitude of engine exhaust feedback to the engine induction system during engine operation. The modulation system includes means for varying the amplitude of exhaust feedback in periodic manner at a frequency which is substantially constant or which may vary as a function of an engine operating parameter. The amplitude may vary as a step function between predetermined levels or continuously and may have a duty cycle (length of time at a predetermined level) which varies as a function of an engine operating parameter, e.g. exhaust manifold temperature. The modulation envelope is controlled by a modulator circuit controlling a valve position in the feedback path. The frequency of modulation is controlled by a divider or multiplier type circuit coupled between a pulse source e.g. the distributor and the modulator circuit.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307.

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **1–11** and **15–18** is confirmed.

Claim **12** is determined to be patentable as amended:

Claims **13** and **14**, dependent on amended claims, are determined to be patentable.

12. In combination in a motor vehicle having an internal combustion engine including ignition distributor means, intake manifold, exhaust manifold, and an exhaust passage coupled to said exhaust manifold for exhaust gas flow from said exhaust manifold to the atmosphere, the combination comprising:

a divider circuit responsive to pulses flowing in said ignition distributor means;

utilization means disposed in said internal combustion engine; [and,]

a modulator circuit responsive to the output of said divider circuit for providing control signals for controlling said utilization means[.]*; and*

wherein the modulation time period of said modulator circuit equals the number of pulses flowing in said ignition distributor means divided by the ratio of said divider circuit.

* * * * *