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Loos

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[54] **DEVICE FOR CONTROLLING THE AIR-FUEL RATIO λ IN A COMBUSTION ENGINE**

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[63] Continuation of Ser. No. 19,438, March 13, 1970, abandoned.

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[51] **Int. Cl. F02m 7/00,** F02m 13/04, G01n 31/00, G01n 27/42

[58] **Field of Search** .... 123/140 MC, 119 E, 123/119 R, 139 AW; 73/23, 23.1; 324/29, 71

[56] **References Cited**

UNITED STATES PATENTS

2,355,090	8/1944	Love et al.	123/119 E
2,389,797	11/1945	MacNeil et al.	123/119 E
3,464,008	8/1969	Meysson et al.	324/29

FOREIGN PATENTS OR APPLICATIONS

446,197	12/1964	Japan	73/23

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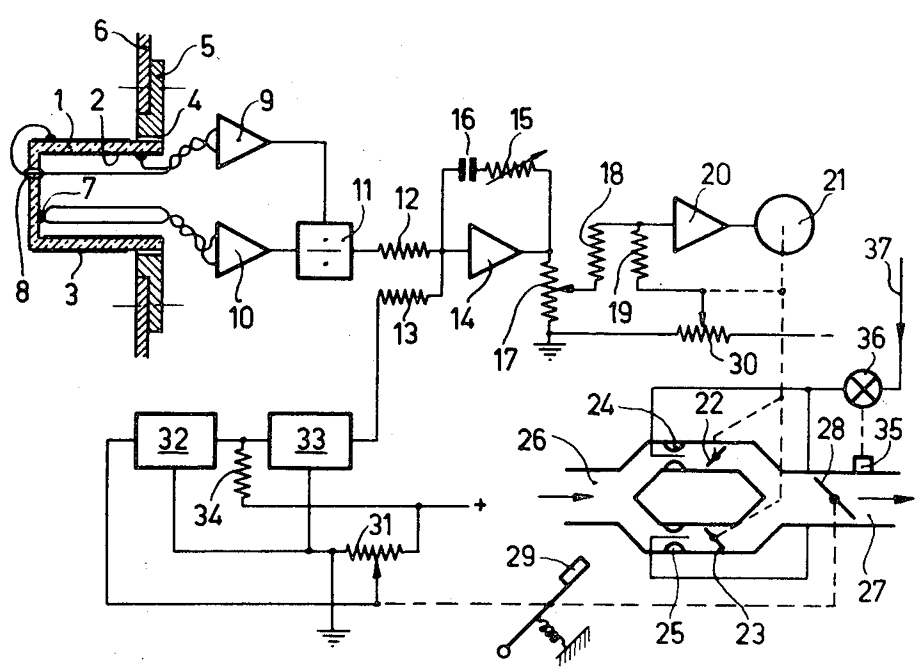
[57] **ABSTRACT**

Device for controlling the air-fuel ratio λ of the mixture supplied to a combustion engine, comprising a pick-up sensitive to the carbon monoxide content of a gas mixture and arranged in an exhaust gas duct of the engine and producing a voltage increasing with said content, a member for controlling the air-fuel ratio λ and a feedback mechanism acting upon said member so that the ratio λ is increased when the voltage produced by the pick-up increases.

8 Claims, 5 Drawing Figures



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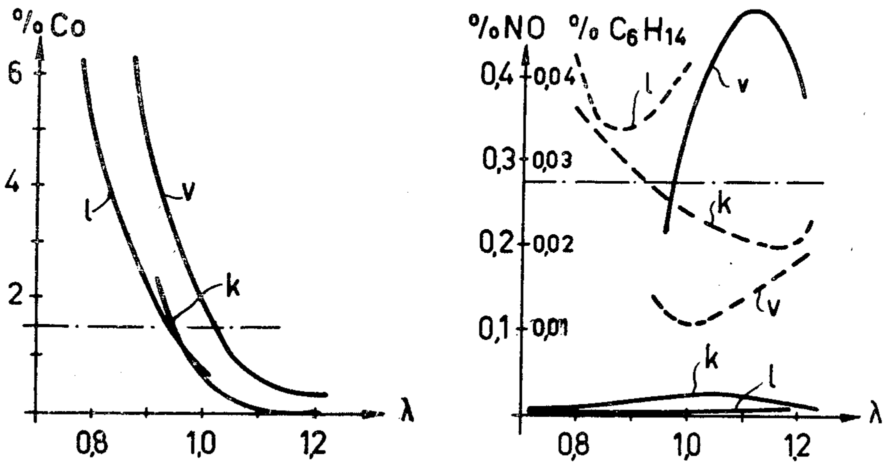

fig.1

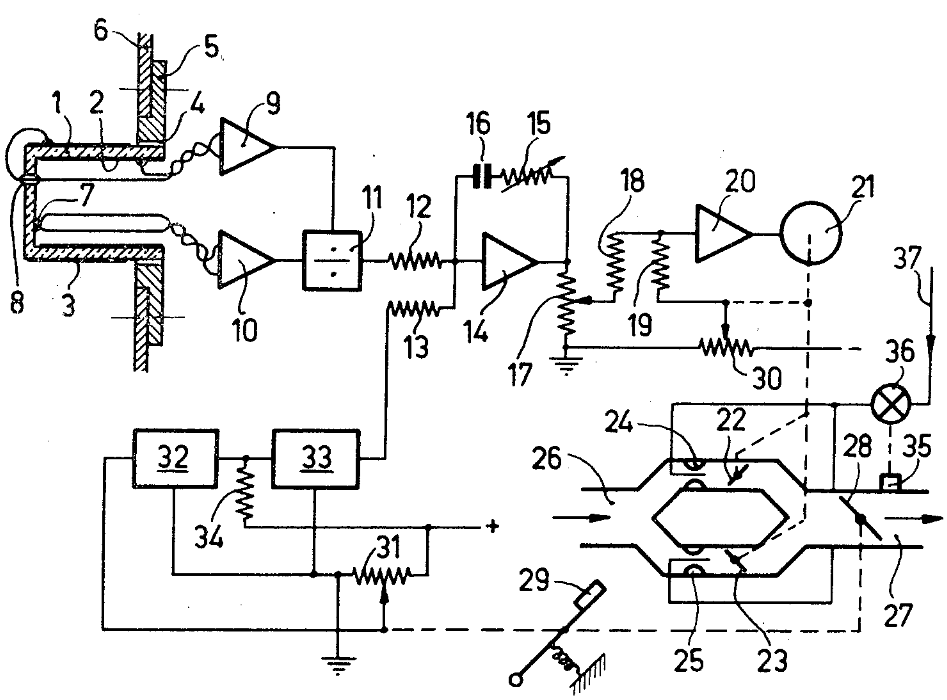

fig.2

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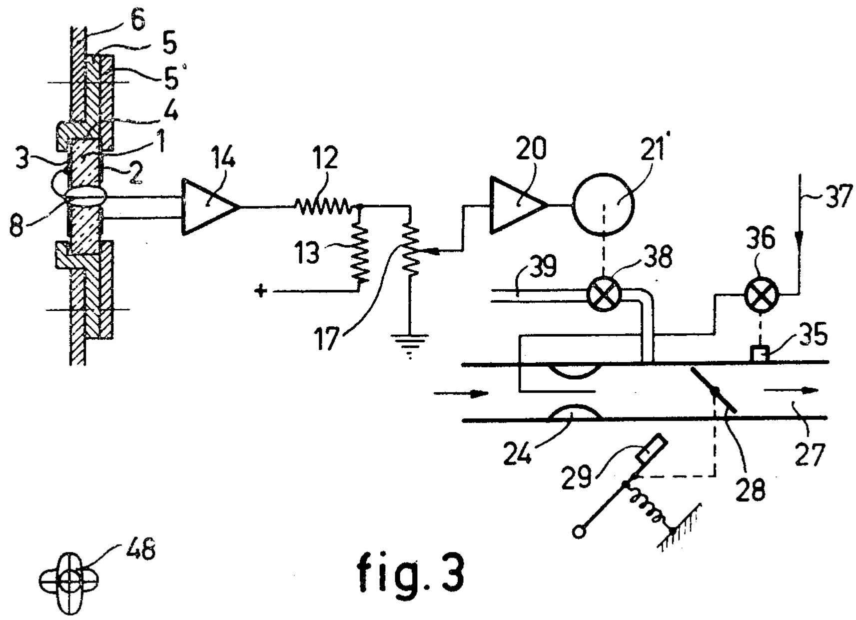

fig. 3

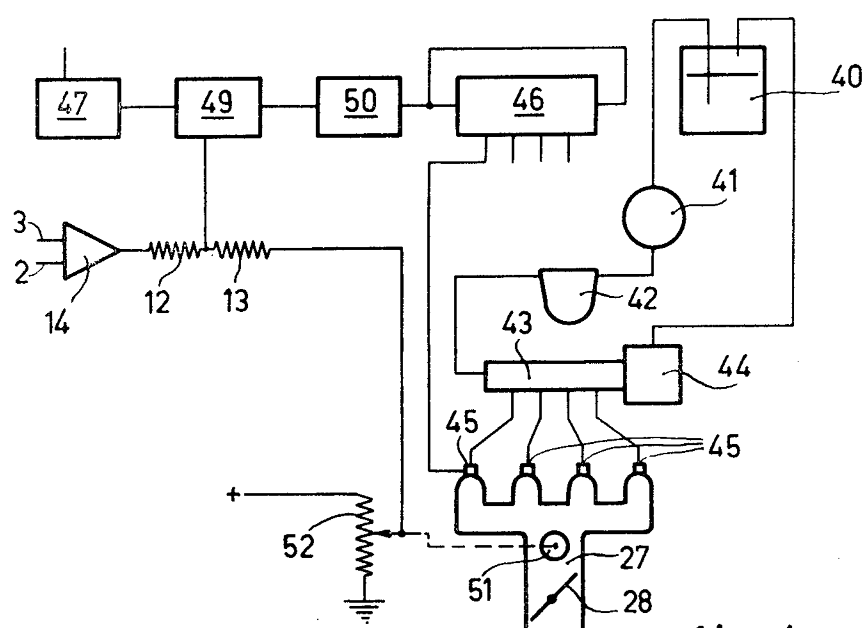

fig. 4

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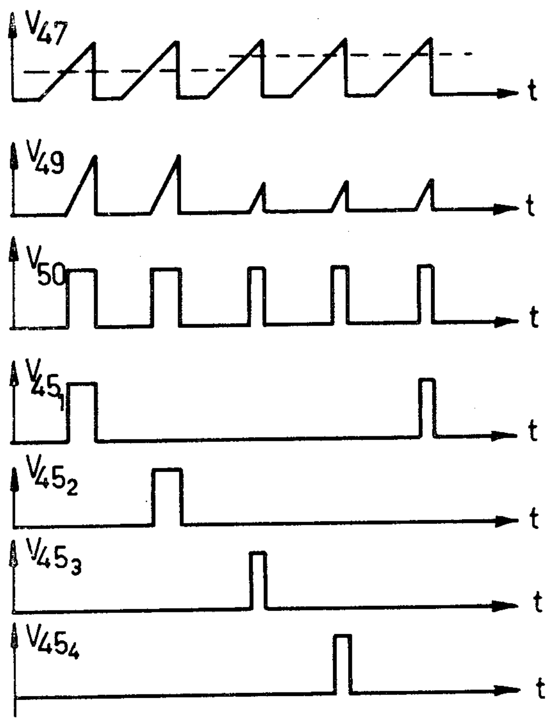

fig.5

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DEVICE FOR CONTROLLING THE AIR-FUEL RATIO λ IN A COMBUSTION ENGINE

CROSS REFERENCE

This is a continuation of applicant's application Ser. No. 19,438, filed Mar. 13, 1970 now abandoned.

The invention relates to a device for the automatic control of the air-fuel ratio λ of the mixture supplied to a combustion engine.

In petrol engines comprising one or more carburetters the ratio λ is controlled so far by means of different fuel and air nozzles, so that at any speed of the engine and at any position of the throttle, the ratio remains at approximately the same value, for example, an optimum value with respect to the fuel consumption or to the power developed by the engine. Usually corrections are carried out on account of the atmospheric pressure, the temperature of the air and/or of the engine. There are furthermore often employed an acceleration nozzle and/or an acceleration pump in order to reduce the ratio λ when the throttle is pressed down so that the engine power is temporarily increased and the increase in speed is accelerated. Moreover, the ratio λ is usually reduced at the start by means of a "choke," which cuts off the air supply in order to ensure a ready ignition of the mixture in the cold cylinder at a very low speed. This effect may as an alternative be obtained by means of a separate fuel-air nozzle, which is actuated under the same conditions.

In fuel injection engines the quantity of fuel supplied to each cylinder prior to each useful stroke is dosed on the same principle by controlling the useful stroke of an injection pump, the duration of opening of an injection valve or the excess pressure of the fuel supplied to said valve. This dosage may be carried out mechanically, electrically or electronically, and it is known to observe further parameters, for example, the temperature of the open air, of the lubricant of the engine, of its cylinder head and/or the position of the throttle.

The ever increasing motor-vehicle traffic has put into evidence the problem of air pollution by the flue gases of combustion engines.

In various countries prescriptions have been designed in formulating requirements to be satisfid by combustion engines, particularly for use in motor-vehicles and in the United States of America the so-called "California test" has been introduced, which is applied to new motor-vehicles before they are allowed to take part in the traffic.

The flue gases of combustion engines contain three different air-pollution constituents:

a. carbon monoxide (CO), which has a directly poisoning effect,

b. non-combused hydrocarbons, of which the hexame content (C_6H_{14}) is considered to be characteristic,

c. nitrogen oxides, particularly dioxide, which produces by chemical conversions under the action of sunlight compounds disagreeably irritating the mucous membranes and damaging the respiration organs.

The greatest danger lies in the carbon monoxide whose content in the flue gases of an combustion engine decreases strongly with an increasing air-fuel ratio λ , whereas the content of non-combusted hydrocarbons first decreases with an increasing λ, reaches a minimum Value lying, in accordance with the load, for

example, between λ = 0.86 at no-load and λ = 1.13 at full load, and then increases again.

On the contrary the content of nitrogen oxides increases with λ, reaches a maximum laying, dependent upon the load, for example, between λ = 1.03 at low load and λ = 1.12 at full load and then decreases again. An acceptable compromise might consist in choosing the parameter λ at any load and rotational speed to be higher than 1, but lower than the value corresponding to the maximum content of nitrogen oxides and/or to the minimum content of non-combusted hydrocarbons, for example, by keeping it constant, approximately equal to 1.05.

With stationary engines operating with a constant speed and only slightly varying load this can be readily achieved. With vehicle engines whose load may vary drastically, often between zero or even a negative value (braking by the engine) and a maximum value and whose number of revolutions may constantly vary with a ratio of 1 : 6 or even 1 : 10, practice gives rise to great dufficulties and only with the aid of a complicated and expensive apparatus it can be achieved.

It is a logical idea to continuously analyse the flue gases of an combustion engine of a vehicle and to correct the parameter λ , particularly by controlling the fuel supply in accordance with the result of this analysis. The most suitable analysis is that assessing the carbon monoxide content: maintaining λ at a value corresponding to a minimum content of non-combusted hydrocarbons would involve an insensitive control with a comparatively low value of λ and an excessively high carbon monoxide content at no-load and at full load, while a control aiming at a maximum content of nitrogen oxides at no-load and at full load would have no effect, since a corresponding maximum does not exist or is too low, whereas at high loads an unnecessarily high content of nitrogen oxides would occur. A magnitude to be controlled, which reaches a maximum or a minimum dependent upon the control, can, moreover, not be used without complicated expedients for regulation, because the amplification of the control-loop had to change its polarity. The apparatus hitherto known for the continuous measurement of the carbon monoxide content of a gas are, however, too complicated, expensive and sensitive for being used on board a motor-vehicle in conjunction with the exhaust system of a combustion engine.

The invention has for its object to provide a device by which the difficulties defined above are overcome. It is based on the recognition of the fact that on account of the high number of parameters affecting the air-fuel ratio λ (temperature and pressure of the atmospheric air, temperature of the engine, rotational engine speed, desired power or torque, etc) it might be more effective to use a negative feedback on the basis of an appropriate variable, instead of controlling said ratio by means of the most important parameters, as has been done hitherto with carburetters or injection systems. Said appropriate variable is the composition of the flue gases of the engine and the carbon monoxide content is the most characteristic parameter of said composition because it varies unambiguously with the parameter λ so that negative feedback is possible even without accurate measurement of the characteristic parameter.

The device according to the invention is characterized in that it comprises a pick-up sensitive to the carbon monoxide content of a gas mixture and arranged in an exhaust duct of the engine and producing a voltage increasing with said content, a member for controlling the air-fuel ratio λ and a feedback acting upon said member, so that the ratio λ is raised when the voltage produced by the pick-up increases.

Instead of a complicated device for the continuous measurement of the carbon monoxide content of the flue gases of the engine, a simple pick-up may be employed. This pick-up is preferably of the very simple,-known type comprising a partition of at least one solid substance preferably zirconium oxide, coated on both sides with a porous electrode layer, preferably of platinum, said partition producing a potential difference between the electrode layers in the presence of different oxygen concentrations on either side ef said partition. Such a plck-up may be readily arranged in the exhaust branch pipe of a comustion engine so that the separation wall forms part of the wall of said branch pipe and one side thereof iS in contact with the flue gases of the engine and the other side is in contact with the atmospheric air.

The invention will be described more fully with reference to the drawing.

FIG. **1** shows diagrams illustrating the carbon monoxide content and the reduced nitrogen dioxide and hexane contents in the flue gases of a four-stroke combustion engine as functions of the air-fuel ratio λ .

FIG. **2** is a scheme, partly in a block diagram of a first embodiment of the device in accordance with the invention.

FIG. **3** is the diagram of a drastically simplified, second embodiment thereof.

FIG. **4** is the diagram of a third embodiment.

FIG. **5** shows diagrams for elucidating the operation of the third embodiment.

The left-hand diagram of FIG. **1** illustrates the carbon monoxide content in the flue gases of a four-stroke combustion engine under extreme conditions as a function of the air-fuel ratio λ . The upper curve *v* was recorded at full load of the engine and at approximately maximum number of rotations. The left-hand curve *l* corresponds to idling speed of the engine at a low number of revolutions and the lower curve *k* was measured at a slight load of the engine and at a moderate rotational speed.

The right-hand diagram of FIG. **1** illustrates for the same conditions the nitrogen dioxide content in full lines and the hexane content in broken lines. In the two diagrams the dot-and-dash line indicateS the maximum permissible carbon monoxide content and hexane content respectively in accordance with the "California test." No maximum is prescribed for the nitrogen dioxide content because a continuous analysis of this content is fairly difficult and because a relevant requirement would involve inadmissibly high contents of carbon monoxide and hexane at $\lambda < 1$ or an inadmissibly high content of hexane and a very poor efficiency of the engine at $\lambda > 1.2$.

From the curves of FIG. **1** it will be apparent that the carbon monoxide content in an unambiguous function of the air-fuel ratio λ under given conditions (load and rotational speed). The curves corresponding to other conditions are located between the curve *v* for full load at a igh rotational speed and the curves *l* and *k* for idling speed and low load so that the function CO% = *f* (λ) or each rotational speed and for any load is also

unambiguous. The problem can apparently be solved in a simple manner: λ has to be chosen and maintained slightly higher than 1 but lower than 1.1. However, manY factors have to be taken into consideration: the temperature of the engine, particularly of the cylinder head, the temperature of the air and the atmospheric pressure. The air supply has to be measured and after the relevant correction the quantity of fuel to be added has to be calculated and supplied. Therefore this "compensation" or forward control is complicated.

According to the invention this difficulty is avoided by using a pick-up sensitive to the carbon monoxide of a gas mixture, arranged in the exhaust gas duct of an engine and producing a voltage increasing with said content and a member for controlling the air-fuel ratio λ of the mixture supplied to the engine and a feedback acting upon said member so that the ratio λ is raised when the voltage produced by the pick-up increases. With this kind of negative feedback all influences mentioned above need not be known, measured and compensated.

FIG. **2** shows the pick-up in the form of a hollow cylinder **1**, closed at one end and made of a solid substance such as zirconium oxide, having on the outer side a porous electrode layer **3** and on the inner side a porous electrode layer **2**, both consisting, for example, of platinum. If different oxygen concentrations prevail on either side of the cylinder wall, the surface potential of each side differs from the other so that also the potentials of the electrode layers **2** and **3** are different. By means of an intermediate layer **4** of compressible material, for example, asbestos-filled hollow rings of soft copper, the open end of the cylinder **1** is urged through the circular opening of a flange **5**, which is fastened in a circular opening in the wall of an exhaust duct **6** of the engine, for example, of the exhaust branch pipe. The inner side of the bottom of the cylinder **1** is provided with a thermo-element **7**, for example, by soldering and the bottom has an insulated through connection **8** for establishing a connection to the outer electrode layer **3**.

The outer and inner electrode layers **3** and **2** are connected to the input terminals of a first pre-amplifier **9**, and the thermo-element **7** is connected to the input terminals of a second pre-amplifier **10**. The output terminals of the pre-ampifier **9** are connected to the dividend-input terminals of a divider-amplifier **11** and those of the pre-amplifier **10** are connected to the divisor-input terminals of said amplifier **11**.

Through a resistor **12** of a first adder network **12, 13** the output of the divider-amplifier **11** is connected to the input of an amplifier having a negative feedback network **15, 16,** whereas the resistor **13** of the network **12, 13** is connected to the positive terminal of a reference voltage source.

The amplifier **14** is constructed so as to ensure optimum behavior of the feedbck loop with respect to accuracy, rate of adjustment and stability. The required properties are also determined by the dynamic behaviour of all components, such as the engine itself, so that they may vary strongly with the type of engine to be regulated. In a possible embodiment said amplifier comprises a filter and has smoothing and integrating properties.

By way of a potentiometer **17**, operating as a gain control, and a resistor **18** of a second adder network

18, 19 the amplifier 14 controls a power amplifier 20 which energizes a servo-motor 21.

The servo-motor checks the respective positions of two throttle valves 22 and 23 operating in opposite senses, arranged in the outlets of two parallel carburetors 24 and 25 having a common air inlet duct 26, the upper one 24 being adjusted (for example by a larger nozzle) so that it supplies an excessively rich mixture ($\lambda < 1$), whereas the lower one 25, having for example a smaller nozzle, is adjusted so that it supplies an excessively poor air-fuel mixture with a ratio $\lambda > 1$. Consequently, by adjusting the valves 22 and 23 the total quantity of air taken by the engine is practically not varied, but solely the air-fuel ratio λ of the mixture supplied to the engine is affected.

The total amount of air intake is controlled by means of a main throttle valve 28, included in a common inlet duct 27, the positon of which valve is controlled by means of the pedal 29 of a vehicle driven by the engine.

The normal or rest position of the servo-motor 21 and of the throttle valves 22 and 23 is determined by the reference voltage applied to the input of the amplifier 14 via the resistor 13, while a stabilizing feedback voltage is fed back to the input of the power amplifier 20 from the tap of a second potentiometer 30 mechanically coupled with the shaft of the servo-motor 21, and via the resistor 19 of the second adder network 18, 19.

The tap of a third potentiometer 31, connected to earth at one end and to the positive terminal + of the reference voltage source at the other end, mechanically coupled with the pedal 29. To this tap is connected the input terminal of a differentiating network 32. The output terminal of this network is connected to an input of a limiter 33 and to a resistor 34, connected to the pOsitive terminal of the reference voltage source. The output of the limiter 33 is connected to the input of the operation amplifier 14 through the second resistor 13 of the first adder network 12, 13 so that this input is connected to the positive terminal of the reference voltage source via the resistor 13, the limiter 33 and the resistor 34.

Finally a pressure pick-up 35 is included in the common inlet duct 27 beyond the main throttle valve 28, viewed in the direction of flow and it is mechanically coupled with a valve 36 by which the supply of fuel to the two carburetors 24 and 25 through a common duct 37 can be interrupted.

It will provisionally be assumed that the device is not yet provided with the auxiliary circuits with the elements 31 to 33, 35 and 36, that the engine is started, has reached its normal working temperature and is rotating at a given, invariable position of the pedal and of the main throtte valve 28, for example, with 30 percent of the maximum load and at a speed of 3,000 rev/min.

The carburetors 24 and 25 are adjusted so that a closed throttle valve 23 and completely open throttle valve 22 the air-fuel ratio λ of the mixture through the common outlet 27 is lower than 1, for example, equal to 0.7. The reference voltage, for example, at the highest position of the tap of the first potentiometer 17, is chosen so that in the absence of a signal at the output of the divider-amplifier 11 this ratio λ is brought to a value of about 1.0, for example, 1.05 by the servo-motor 21, which turns the valve 23 in the opening sense and the valVe 22 in the closing sense, which value corresponds to the carbon monoxide content in the flue gases of the engine.

The flue gases of the engine heat the wall 6 of the branch pipe and hence also the cylindrical separation wall 1 of the pick-up at a temperature of more than 400°C, for example, at 500°C. The pick-up thus attains an effective working range and produces its electrode layers 2 and 3 a potential difference of the nature of a Nernst potential equal to

$$k, T, \ln\ (0_2 \text{ internal}/0_2 \text{ external})$$

wherein k is a constant of the pick-up, T is the absolute temperature (773°K) of its separation wall, (0_2) are the oxygen concentrations of the gas mixtures in contact with the electrode layers 2 and 3 (atmospheric air and flue gases). The pick-up is therefore sensitive to the oxygen content. At lower oxygen contents it responds, however, to the carbon monoxide content because this monoxide is in a state of equilibrium with oxygen. The internal resistance of the order of 10 Ohms and the response time amounts to about 0.1 sec.

To the input of the amplifier 9 is thus applied a voltage proportional to the logarithm of the carbon monoxide content in the flue gases.

On the other hand the thermo-element 7 produces a voltage proportional to the temperature difference between this element and hence the partition 1 and a "cold" junction, which is approximately at the ambient temperature. This voltage is applied to the input of the pre-amplifier 10 and by dividing the output voltage of the pre-amplifier 9 by that of the pre-amplifier 10 in the divider-amplifier 11 the influence of the temperature of the flue gases and of the partition 1 on the control can be eliminated.

At the input of the amplifier 14 the output voltage of the divider-amplifier 11 is superimposed on the reference voltage, which is applied to said input via the resistor 34, the limiter 33 and the resistor 13. Through the amplifer 14, the first potentiometer 17, the second adder network 18, and the power amplifier 20 this voltage checks the position of the servo-motor 21. With an increasing carbon monoxide content in the flue gases of the engine and with an increasing output voltage of the amplifier 14 the servo-motor 21 turns the throttle valve 22 in the closing sense and the throttle valve 23 in the opening sense so that the air-fuel ratio λ of the mixture in the inlet duct 27 increases. This results in a reduction of the carbon monoxide content in the flue gases of the engine without the total quantity of mixture taken in being affected. A further advantage of the differential throttle valves 22 and 23 is that in the event of some disturbance in the device or of a complete failure thereof during a start in the cold state, in which the pick-up 1, 2, 3 is not yet operating, the vehicle driven by the controlled engine can ride on without the need for further means, since the air-fuel ratio λ can vary only between two fixed values which are determined by the adjustments of the two carburet-ters 24 and 25.

It will be seen from the left-hand diagram of FIG. 1 that the curves CO % $= f(\lambda)$ have the form of more or less exponential functions so that the logarithmic relationship betwen the output voltage of the pick-up 1, 2, 3 and the carbon monoxide content of the flue gases is, on a first approximation, compensation. The "control function" of the whole device is therefore approximately linear and in practice linear within the narrow useful range ($\lambda = 0.8$ to 1.2) of the device. The influence of the "error voltage" produced by the pick-up and hence the maximum excursions of λ from the adjusted value can be adjusted by means of the first potentiometer **17**.

During setting of the throttle valves **22** and **23** the servomotor **21** also displaces the tap of the second potentiometer **30** so that each variation of the control voltage applied to the input of the power amplifier **20** via the resistor **18** is compensated for by a variation of the voltage derived from the tap of the potentiometer **30** via the resistor **19**. This feedback counteracts strongly any electrical or mechanical hysteresis: without the risk of over-excitation, of transgression of the desired position or of fluctuations the amplifier **20** may have a high gain, since it is effectively fed back negatively to a high extent by way of the servo-motor **21**. If, for example, due to an increase in control-voltage across the potentiometer **17** the valve **22** is turned by the servo-motor **21** in the closing sense and the valve **23** is turned in the opening sense, the tapping of the potentiometer **30** is simultaneously shifted to the right into a position in which the increase in negative voltage applied to the input of the amplifier **20** via the resistor **19** corresponds to the new position of the valves, the increase in control-voltage being compensated for via the resistor **18**.

The most modern carburetors are provided with a so-called acceleration pump, which may be combined or not combined with an additional acceleration nozzle by which an additional quantity of fuel is temporarily injected into the gas mixture flowing towards the inlet, when the pedal is depressed. The purpose thereof is a temporary reduction of the air-fuel ratio λ of this gas mixture, it being intended to have the engine operate with the λ value at which it develops its maximum torque at any rotational speed so that it attains the desired higher speed as soon as possible.

Such a "forced" acceleration is unavoidably attended by a temporary increase in the carbon monoxide content in the flue gases. If it is desired to obtain a comparatively long acceleration with maximum torque by a single movement of the pedal, for example, for 2 to 3 seconds, a comparatively low minimum value of λ , for example, 0.8 will temporarily be attained and it will then be even more difficult for the vehicle driven by the motor to satisfy said dynamic "California test." Yet according to circumstances an optimum acceleration is an important property for every vehicle, particularly with respect to safety.

In the device shown in FIG. **2** the elements **31** to **33** have the function of the aforesaid acceleration pump. When the pedal **29** is depressed or when another equivalent control-member is moved accordingly the main throttle valve **28** is turned in the opening sense and at the same time the tap of the third potentiometer **31** is shifted to the right, i.e. to the positive end of said potentiometer. The potentiometer **31** operates as a pick-up by which the position of the control-member **29** is converted into a voltage. The positive step of the potential of the tap of said potentiometer is applied to a differentiating network **32**, which converts it into a positive, sawtooth-like voltage peak having a steep leading edge and an exponentially sloping trailing edge and being insensitive to negative steps. This voltage peak is applied to the input of the limiter **33** via the resistor **34** and thus superimposed On the reference voltage so that the adjusted value of λ is temporarily reduced. This reduction is, however, restricted, for example, to 0.9 from 1.0 by the limiter **33** and the restricted λ reduction remains the longer effective, the higher is the differentiated voltage peak and the more abrupt the pedal is depressed. It is thus also possible to restrict the temporary increase in carbon monoxide content in the flue gases of the engine, for example, to 4.5 percent.

The restriction may be obtained in a different way without the limiter **33**, for example, by adjusting the carburetter **24** so that with a completely open valve **22** and a closed valve **23** the air-fuel ratio λ just attains the desired minimum value of, for example, 0.9. The attainable minimum value of λ may also be determined by restricting the stroke of the servo-motor **21** in the corresponding direction of rotation, for example, by means of a mechanical or electro-mechanical stop.

Whichever means is employed, the acceleration part **31** to **33** of the device will scarcely or not at all affect the chosen value of λ , for example an effective value corresponding to a carbon monoxide content of less than 1 percent at the idling speed and with a slow deceleration or acceleration of the engine and the device ensured that λ does not drop below this value. When the pedal is rapidly depressed, the adjustment is shifted towards richer mixtures the more rapidly, the more rapidly and abruptly the pedal is depressed so that the high useful effect of the engine is temporarily sacrificed to the benefit of a higher torque, it being possible to adjust some inhibition or other so that the attainable minimum value of λ corresponds with that at which the torque is at a maximum or is slightly lower than the latter value, for example, 0.9.

It has finally been found that the carbon monoxide content in the flue gases of a combustion engine driven by a riding vehicle and hence having a braking effect and being otherwise intended to drive said vehicle, is comparatively high and this is again a difficulty in satisfying the "California test." This difficulty may be overcome by providing the vehicle with a free running device, which is comparatively costly.

The device shown in FIG. **2** provides a still better result by interrupting the fuel supply as is already done with combustion engines with fuel injection. The interruption is performed here by the valve **36**, under the action of the pressure pick-up **35**, said valve interrupting the fuel supply to the carburetors **24** and **25** when the pressure in the inlet duct **27** drops beneath a given value, This only occurs when the engine rotates, the main throttle valve **28** being completely closed, with a speed of, for example, 1,200 rev/min, exceeding considerably the normal idling speed of, for example, 800 rev/min and hence when the engine is driven by the vehicle, which is thus braked.

At the start and heating-up of the engine the control-voltage at the output of the divider-amplifier **11** is practically zero so that the device becomes operative only with a time-lag and only gradually when the partition **1** of the pick-up becomes hot. In a variant this heating-up time of the pick-up may be considerably reduced by heating it electrically, for example, by means of a resistor wound on the electrode layer **3** and insulated therefrom. This is, however, not necessary because the signal produced by the pick-up **1, 2, 3** always provides a slight crrection of the ratio λ so that without this correction the engine can as readily start and heat up with a slightly higher carbon monoxide content in the flue gases.

On the other hand it has been found that the influence of the temperature of the partion **1** of the pick-up on the fuel dosing is comparatively slight and may even be neglected. If this temperature is, for example, equal to 450°C instead of 500°C, which might occur with an extremely high differ-ence from the ambient temperature, the output voltage of the pre-amplifier **9** is reduced by the ratio: 723/773 or approximately 7 percent and because this voltage is a logarithmic function of the carbon monoxide content in the flue gases, the corresponding increase of this content is also slight, for example, 1 to 16 percent with a decrease of λ from 1.05 to 1.04. In numerous cases the temperature correction by means of the thermo-element **7** or a similar resistance thermometer of the pre-amplifier **10** and the divider amplifier **11** may be dispensed with.

FIG. **3** shows the diagram of a drastically simplified, second device embodying the invention. The pick-up is not provided with a thermo-element and its partition **1** is formed by a zirconium oxide tablet having a central through-connection insulator **8**, an outer electrode layer **2** and an inner electrode layer **3**, both of platinum. With an intermediate layer **4** of compressible material the pick-up **1, 2, 3, 8** is held between two flanges **5** and **5'**, which are secured in a circular opening of the branch pipe **6** of the engine. The electrode layers **2** and **3** are connected to the input terminals of an amplifier **14**, the output of which is connected to a resistor **12** of an adder network **12, 13.** The second resistor **13** of said network is directly connected to the positive terminal + of a reference voltage source and the junction of the resistors **12** and **13** is directly connected to one end of a potentiometer **17**, the other end of which is earthed. The tapping of the potentiometer **17** is connected to the input of a power amplifier **20**, the output current of which energizes an electro-magnetic setting member **21'**. The setting member **21'** may be an electro-magnet having an end position and a rest position, the excursion of which depends in operation on the magnitude of the energizing current. This setting member actuates a small throttle valve **38** in a duct **39**, through which additional air can be introduced into the air-fuel mixture in the inlet duct **27** beyond the carburetor **24**, viewed in the direction of flow.

The device shown in FIG. **3** operates basically like the device shown in FIG. **2**. The important differences are:

a. that no temperature correction is involved,
b. that a temporary reduction of the air-fuel ratio λ for acceleration purposes is not used and
c. that a negative feedback loop for stabilisation of the position of the control-member **38** is lacking. Nevertheless the device of FIG. **2** is in many cases effective, for example, in conjunction with an existing carburetter having an inlet for additional air and having an acceleration pump.

Many variants of the embodiments described above are possible, particularly in view of the manner in which the parameter λ is checked.

The differential valves **22, 23** of FIG. **2** may serve in addition as a main throttle valve because they can be simultaneously and differentially actuated by the servomotor **21**, as described above and be both displaced in the same opening sense by the throttle **29**. However, this requires a complicated coupling mechanism. The additional air supply duct of FIG. **3** may be replaced by a duct for the supply of an additional mixture having a high or low air-fuel ratio λ', in connection with an additional carburetor, so that the final ratio λ is affected in the same sense or in the reverse sense.

The control-member **21** or **21'** may act upon a controllable nozzle or on the pressure of the fuel supplied to the nozzle(s), for example, the level of the fuel above the nozzle(s) in the float chamber of the carburetor can be adjusted, particularly by the adjustment of the air pressure in the float chamber. This air pressure may be adjusted by an electrically controlled on-off valve by means of a pulsatory signal whose pulse width is modulated by the signal at the output of the amplifier **14** or of the preamplifier **9** or of the divider-amplifier **11** of FIG. **2.**

In the third embodiment shown partly and schematically in FIG. **4** the device according to the invention is employed with a combustion engine having fuel injection. From a fuel tank **40** the fuel is pumped by a pump **41** via a filter **42** into a fuel distributor **43.** Through a fuel pressure control **44**, which keeps the pressure in the distributor constant, the redundant fuel flows back to the tank **40.** From the distributor **43** the fuel flows towards injection valves **45** arranged in the inlet ducts to each engine cylinder near the inlet valve of said cylinder. The injection valves **45** are normally closed and are alternately opened electro-magnetically prior to every working stroke of the relevant cylinder by current pulses supplied from a pulse distributor **46** formed by a ring counter operating as a gate. These pulses are derived from pulses produced by a monostable trigger **47**, which is controlled by a mechanical, electro-magnetic, piezo-electric, capacitative or Hall-effect-operated pick-up (not shown) in synchronism with the rotation of the combustion engine, for example, of the cam shaft **48** thereof, so that during each revolution of the cam shaft of a four-stroke engine the trigger produces a pulse for each engine cylinder. The trigger **47** is provided with a network which integrates solely the front flank of each pulse, so that it supplies pulses of the form indicated at V_{47} on the first line of FIG. **5.** These pulses are applied to a modulator **49**, in which they are converted by means of an adjustable threshold into pulses V_{49} of controlled width or duration having a fixed steep trailing edge, indicated on the second line of FIG. **5.** The modulated pulses are strongly amplified in a pulse shaper **50** and then clipped to substantially square-wave, width-modulated pulses V_{50} (third line of FIG. **5**), which are applied by this pulse shaper to the pulse distributor **46.** The latter distributes these pulses as is indicated at V_{45} on the last four lines of FIG. **5.**

The pulse-width modulation is performed primarily in dependence upon the air pressure in the inlet duct **27** beyond the choke **28**, viewed in the direction of flow, by a pick-up **51**, which varies the position of the tapping of a potentiometer **52** in accordance with the pressure. From this tapping, via the resistor **13**, a first threshold voltage corresponding to the pressure in the inlet duct **27** and hence to the rotational speed of the engine and to the position of the throttle valve **28** is applied to the modulator **49.**

According to the invention the device comprises a pick-up sensitive to the carbon monoxide content of the gas mixture and included in an exhaust gas duct of the engine, which pick-up produces a voltage increasing with said content. The electrode layers **2** and **3** of a pick-up of the kind shown in FIGS. **2** or **3** are connected to the input terminals of an amplifier **14.** The output of this amplifier is connected to the modulation voltage input of the modulator **49** so that the output pulses of this modulator, modulated in width by the voltage at the tap of the potentiometer **52** are also affected by the voltage produced by the pick-up with the electrode layers **2** and **3**. Thus each injection valve **45** forms a member for controlling the air-fuel ratio λ of the gas mixture taken in by the relevant engine cylinder and the pick-up with thP electrode layers **2** and **3** together with the resistor **12**, the modulator **49**, the pulse-shaper **50** and the pulse distributor **46** form a feedback which increases the ratio λ, when the voltage produced by the pick-up increases.

Also, with a fuel-injection combustion-engine various other possibilities are available for acting upon the air-fuel ratio λ. For example, the injection valves **45** could be energized by current pulses of constant width, while the excess pressure in the fuel distributor **43** could be controlled. For this purpose the input of the pulse distributor **46** could be connected directly to an output of the monostable trigger **47** located in front of the integrating network thereof and the width-modulated pulses at the input of the pulse-shaper **50** could be used for controlling the pressure in the fuel distributor **43**, as described above.

In a fuel-injection combustion-engine the air-fuel ratio λ can be better checked and kept constant than in an engine comprising carburetors. Particularly a fuel-injection combustion-engine can be adjusted sooner so that it satisfies the "California test" than an otherwise identical engine with carburetors. Nevertheless this adjustment requires a complicated mechanism and/or a complicated, for example, electronic dosing device which takes into account particularly the atmoshperic pressure, the temperature of the air and as a function of the rotational speed and of the desired driving torque has to be adjusted separately for a great number of working points. By using a device according to the invention said corrections may be dispensed with and the adjustment of dosing may be performed less accurately and considerably more simply.

The devices described above are capable of acting very rapidly and directly so that even with strongly varying working conditions, for example, with a motor-vehicle in urban traffic, the air-fuel ratio λ of the mixture supplies to the engine is always correct, while the fuel consumption is at the optimum minimum and the carbon monoxide content in the flue gases of the engine remains very low.

What is claimed is:

1. A device for automatic control of the air-fuel ratio λ of the mixture supplied to a combustion engine, including an exhaust gas duct through which exhausts gas having a varying percentage of CO, the device comprising a pick-up formed as a partition of at least one solid substances, such as zirconium oxide, which is coated on both sides with a porous electrode layer such as platinum, said pick-up partition formed as part of said exhaust gas duct with one of said sides contacted by said exhaust gases and the other side contacted by atmospheric air, said pick-up, when its partition is contacted on opposite sides by gases having different oxygen concentration, producing an electrical potentional between said electrode layers, the voltage increasing with an increase in CO on the exhaust gas side, a member for physically controlling the air-ufel ratio λ, and feedback means responsive to said voltage and any change thereof and correspondingly acting upon said member, the ratio λ being raised when the voltage produced by the pick-up increases.

2. A device according to claim **1** further comprising a temperature pick-up disposed near the first-mentioned pick-up, and in the feedback means an electronic distribution circuit by which the voltage produced by the first pick-up is corrected in accordance with the signal produced by the temperature pick-up.

3. A device according to claim **1** wherein the feedback means includes an amplifier having integrating properties.

4. A device according to claim **1** wherein the feedback means includes a servo-motor acting upon the member for controlling the air-fuel ratio λ.

5. A device according to claim **1** for controlling an engine driving a vehicle, the device comprising a pick-up converting the position of a control-member regulating the gas mixture taken in by the engine into a voltage and a differentiating network converting a comparatively rapid variation of said voltage into a voltage peak which temporarily reduces the adjusted air-fuel ratio λ at a rapid movement of the control-member in the opening sense.

6. A device according to claim **5** further comprising means for restricting the amplitude of the temporary reduction of the adjusted air-fuel ratio λ.

7. A device for automatic control of the air-fuel ratio of the mixture supplied to a combustion engine including an exhaust duct, the device comprising a pick-up disposed in said exhaust gas duct and formed as a partition of at least one solid substance, such as zirconium oxide, which is coated on both sides with a porous electrode layer, such as platinum, said pick-up producing a potential difference between the electrode layers in the presence of different oxygen concentrations on either side of said partition, one of said sides contacting the exhaust gases in said exhaust gas duct, the other side contacting oxygen with a reference concentration, the device further comprising a member for controlling the air-fuel ratio λ, and a feedback means acting upon said member in response to said potential difference and any change thereof, the ratio λ being automatically adjusted to a desired value.

8. A device as claimed in claim **7** wherein said pick-up arranged in the exhaust branch pipe of the engine so that its partition wall forms part of the wall of said branch pipe, whereby one side is in contact with the flue gases of the engine and the other side with the atmospheric air comprising the said oxygen reference concentration.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3738341 Dated June 12, 1973

Inventor(s) CORNELIS HENRICUS LOOS

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

Col. 3, line 51, "indicateS" should be --indicates--
line 66, "igh" should be --high--

Col. 4, line 4, "manY" should be --many--

Col. 5, line 34, "pOsitive" should be --positive--
line 66, "valVe" should be --valve--

Col. 9, line 4, "differ-ence" should be --difference--
line 10, "16" should be --1.16%--

Col. 11, line 8, "thP" should be --the--

IN THE CLAIMS

Col. 11, line 59, "atmosh" should be --atmos--

Col. 12, line 1, "peric" should be --pheric--
line 6, "ufel" should be --fuel--

Signed and sealed this 26th day of March 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents