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(54) **A method for controlling the supply of fuel to an internal combustion engine.**

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Description

This invention relates to methods for controlling the supply of fuel to an internal combustion engine.

There are two types of systems for controlling electrically the amount of fuel metered to an internal combustion engine. One of these is the mass air flow system, in which the volume or mass of air flowing into an engine is actually measured and the fuel is metered accordingly. The other system, speed-density, uses engine speed and the engine intake manifold absolute pressure to determine indirectly the amount of air entering an engine. In both types of electronic fuel control systems, the appropriate quantity of fuel is metered with a suitable fuel control apparatus. This apparatus typically has been a plurality of electromagnetic fuel injectors intermittently operated to deliver fuel into the intake manifold upstream of the usually provided intake valves.

In the speed-density fuel control system described in US—A—4,086,884, the fuel control system employs a digital computer to calculate the amount of fuel required by the engine. The calculation is done respectively to permit the fuel supply to be adjusted sufficiently often so that adequately precise control of fuel is achieved on a real-time basis. The computer preferably controls fuel in an interactive manner, that is, fuel supply, ignition timing and exhaust gas recirculation all are controlled simultaneously as interdependent output variables.

US—A—3,969,614 describes an interactive engine control system. In such a digital computer engine control system, an output variable, such as ignition timing, is taken into account in the determination of another output variable, such as the time and duration of injection in an intermittent-type fuel injection system. (If the injection is continous, of course, determination of the usual points in the engine cycle at which injection is to be initiated is unnecessary).

The speed-density fuel injection system described in US—A—4,086,884 requires that the volumetric efficiency of the engine to be used, directly or indirectly, in the calculation of the quantity of fuel to be supplied to the engine. Unfortunately, the volumetric efficiency is a function of several parameters including engine speed and engine load. This means that these changing factors have had to be taken into account in the calculation of the quantity of fuel to be metered to the engine to satisfy the oxygen content of the intake mixture that actually enters the engine's combustion chambers. The desired fuel amount at any given time may, of course, be selected to provide a rich, a stoichiometric or a lean air/fuel mixture as may be required for engine operation in an open or closed-loop mode of engine operation.

According to the present invention, there is provided a method for controlling the supply of fuel to an internal combustion engine having an intake conduit and an exhaust conduit, characterised by the steps of:

(a) determining the ratio of the engine's intake conduit absolute pressure to its exhaust conduit absolute pressure or vice versa;

(b) using the determined ratio and a second factor representing the frictional and inertial forces acting upon the mixture of gases flowing through the engine's intake conduit to determine the volumetric efficiency of the engine, the volumetric efficiency being determined with respect to the flow of gases into at least one combustion chamber of the engine;

(c) metering fuel to the engine in a quantity based upon such determined volumetric efficiency; and

(d) repeating steps a, b and c.

The method of the invention improves fuel control in an internal combustion engine by providing for the computer calculation of an engine's current volumetric efficiency. The volumetric efficiency varies as a function of engine operating parameters, such as engine load, engine speed and other less significant variables.

Preferably, the method of the invention comprises the steps of determining the ratio of the absolute pressure in an engine's intake manifold to the absolute pressure of the products of combustion in a passage through which the products of combustion pass after leaving the engine's combustion chamber or chambers.

This ratio of intake mixture and exhaust gas absolute pressures, or the inverse ratio, is combined mathematically with a second factor, which may be related to the engine speed, representative of forces acting upon the intake mixture as it flows toward the combustion chambers. The combined ratio and second factor are used to determine the volumetric efficiency of the engine with respect to the flow of gases into at least one combustion chamber thereof. This real-time volumetric efficiency may then be used to determine the amount of fuel metered to the engine.

The method of the invention is of value as compared to the prior art because of the simplicity and accuracy with which an engine's current volumetric efficiency can be determined. The ratio of the intake mixture and exhaust gas absolute pressures is easily determined with the use of sensors typically found on engines having speed-density fuel control systems. Also, the engine speed is a variable that is readily available on a continuous basis in electronic engine control systems. The prior art speed-density systems, in contrast, have required the use of many time-consuming calculations, either digital or analog or both, based upon approximations of engine characteristics and design features. The system described US—A—4,086,884 mentioned above avoided this. The volumetric efficiency was treated as a function of temperature and pressure conditions in the intake manifold at the time the quantity of fuel to be delivered to the engine, i.e., the injector pulse width, was being calculated.

A very significant advantage of the invention is that the real-time determination of volumetric efficiency takes into account the effects of changes in altitude on the characteristics of an engine's operation.

The prior art calculation of the quantity of fuel to be supplied to an engine employing a speed-density fuel control system, whether accomplished with analog electronic circuitry or with a digital computer and associated software or a combination of these, has been based primarily on the speed of the engine and the intake manifold pressure at the time the calculation is made. In these prior art control systems for spark ignition internal combustion engines, the other parameters of engine operation have been regarded as being of substantially lesser significance. The other parameters are less variable, generally speaking, and consequently can be treated as environmental conditions that should be taken into account for purposes of accuracy and calibration. The more extreme modes of engine operation, such as occur during engine cranking at start, cold-engine warm-up and wide-open throttle, usually have been treated as situations requiring separate control provisions. Because catalysts of the three way type now are used extensively in automotive engines and because exhaust gas recirculation makes the oxygen content of the intake mixture less predictable under all conditions of engine operation, the use of engine speed and intake manifold pressure alone to determine the quantity of fuel to be supplied to an engine no longer is satisfactory, whether or not the density of the intake mixture is taken into account.

The system disclosed in US—A—4,086,884 was intended to improve the speed density fuel control system by taking into account the effect of exhaust gas recirculation on the amount of fuel required by an engine. This much improved system also was designed to allow the slowly varying parameters of engine operation, such as volumetric efficiency, to be updated less frequently than the more rapidly varying parameters, such as intake manifold pressure and the quantity of recirculated exhaust gas. The method of the present invention carries the development of electronic fuel metering an additional step by providing an effective way to allow an engine's volumetric efficiency to be monitored on a real time basis.

Mention is also made of US—A—4,112,879 which relates to a process for defining the nominal fuel quantity based on the volumetric efficiency of the engine but here the volumetric efficiency is derived from measurement of the induction manifold pressure. This system also suffers from some of the problems discussed previously.

The volumetric efficiency of the engine can be of great significance where precise control of the air/fuel ratio of the mixture supplied to an engine is required. If fuel economy, engine performance and exhaust emissions are of concern, air/fuel mixtures must be precisely controlled over a range of rich, stoichiometric and lean air/fuel ratios. The volumetric efficiency of an engine is the volume gaseous material that enters the combustion chamber or chambers of the engine divided by the displacement volume of such combustion chamber or chambers of the engine; the volume of gaseous material entering the engine is reference to a selected temperature and pressure and in effect is a mass flow. This definition is useful here in that it indicates that volumetric efficiency, for an engine of fixed displacement, is dependent only upon the volume of gaseous material that enters the combustion chamber or chambers of the engine. Necessarily, this volume is not the same as the volume exhausted because additional gases are formed during combustion.

Volumetric efficiency of an engine in the past has been determined primarily from the intake manifold absolute pressure and the engine speed based upon accumulated engine dynamometer data for a given engine and exhaust system design. Every variation in intake manifold pressure changes the volumetric efficiency; intake manifold pressure is a function of both engine speed and engine load, as well as the density of the gaseous mixture in the manifold.

The present invention is based on the appreciation that the volumetric efficiency, regardless of engine operation in geographical locations of widely varying altitudes, is related to the ratio of the intake manifold absolute pressure and the engine exhaust system absolute pressure immediately downstream of the combustion chamber. The relationship is almost hyperbolic. If the ratio is inverted, it is almost linear. Otherwise stated, the ratio of intake manifold absolute pressure to the absolute pressure in the engine's exhaust conduit, when combined with a second factor, can be used to determine volumetric efficiency. The second factor represents the frictional and inertial forces that are resisting the flow of the gaseous intake mixture entering the combustion chamber or chambers of the engine.

All of the gaseous mixture entering the engine's intake system and flowing toward the engine's combustion chamber or chambers travels through the engine's intake conduit or manifold before passing through the respective intake valves and into the corresponding combustion chambers. There is resistance to this flow in the form of frictional and inertial forces. The frictional forces are the result of the interaction of the fluids entering the combustion chambers with the intake conduit and the intake valves.

Volumetric efficiency of an engine is a measure of the quantity of gaseous material inducted into a combustion chamber or chambers. Accurate determination of the volumetric efficiency makes possible delivery of exactly the right amount of fuel to the combustion chambers to satisfy the requirements of the air or oxygen in the combustion chambers. In other words, exact knowledge of an engine's volumetric efficiency throughout the operation of the engine allows the proper amount of fuel for the oxygen entering the combustion chamber or chambers during each cycle of the engine to be calculated and delivered.

The pressure ratio of the engine can be expressed by a mnemonic suitable for use in computer programming. Thus, it may be represented as PIOPE, which means intake conduit absolute pressure, over or divided by exhaust conduit absolute pressure.

The pressure ratio also can be represented mnemonically in other ways. For example, the pressure ratio may be written as PEOPI, meaning exhaust pressure over or divided by intake pressure; the PEOPI is a pressure ratio, as is PIOPE. Volumetric efficiency VEFF preferably is related to PEOPI as follows:

$$\text{VEFF}=((\text{PEOPI})(K_1)+K_2)(\text{second factor}).$$

In this equation, K_1 and K_2 are constants. The second factor represents the frictional and inertial forces acting on the air, or air and exhaust gas, or air, exhaust gas and fuel mixture moving within the intake conduit toward the intake valves and combustion chambers.

Whatever the mnemonic representation in the digital computer computation of volumetric efficiency or its equivalents, the significant factor is the use of the PIOPE or PEOPI ratio of absolute pressures. These pressures in ratio and when combined with a second factor provide direct and accurate indications of current or real-time engine volumetric efficiency, i.e., volumetric efficiency as of the time the absolute pressures are determined. (This of course, assumes the intake and exhaust conduit pressures are measured or determined at the same or insignificantly different times). The second factor mentioned above is representative of the dynamic forces of friction and inertia that act upon, and tend to retard the flow of, the gaseous mixture in the engine's intake conduit; these forces are proportional to engine speed and other engine operating parameters of lesser significance. The second factor, and also the constants K_1 and K_2 above, can be determined by multiple regression analysis of data obtained by testing a particular engine design on an engine dynamometer. This method for determining the second factor typically results in the second factor being defined by a quadratic equation, having known constants K_3, K_4 and K_5, as follows:—

$$\text{second factor}=K_3+(K_4)(\text{engine RPM})+(K_5)(\text{engine RPM}^2).$$

A particularly suitable method for determining volumetric efficiency on a real-time basis is with the aid of values placed in computer memory in tabular form as a function of PIOPE and engine speed. The PIOPE and engine speed may be represented as binary numbers used to obtain access to a value or values of volumetric efficiency retained in computer memory. Well known techniques preferably are employed to interpolate between volumetric efficiency values stored in the memory; four-point interpolation is most accurate. The accessed volumetric efficiency value then can be used in a computer program for determining required fuel delivery. An example of a suitable equation for use in calculating fuel injection pulse width using the engine's volumetric efficiency, in a speed-density system, is given in US—A—4,086,884. Engine period and PEOPI, or some other suitable combination of pressure ratio with a second factor that together reflect the engine's current operational volumetric efficiency, can be used to obtain the fuel delivery required for such current volumetric efficiency.

In the determination of the absolute pressure ratio, it is not necessary to actually measure the absolute pressure in the exhaust conduit of the engine. The intake manifold absolute pressure is a quantity that is routinely used and available in known speed-density fuel injection systems for spark-ignition internal combustion engines. The ambient or barometric pressure also is available in such systems. The engine's combustion chamber displacement is a constant equal to the current mass flow of gases into the engine divided by the volumetric efficiency of the engine as calculated on the last cycle of the engine. (It should be noted that the exhaust conduit back pressure also is very much related to the mass flow of gases into the engine's combustion chamber or chambers immediately before it is exhausted to produce the exhaust pressure. This is a factor in determining the volumetric efficiency for the next succeeding engine cycle). The mass gas flow into the engine or volumetric efficiency for a preceding cycle may, therefore, be used to determine the volumetric efficiency for succeeding cycle. To do this, the displacement of the engine's combustion chambers may be divided by the volumetric efficiency last determined to yield a number approximately equal to the actual gas flow through the engine per complete engine cycle. If then this number is multiplied by the number of engine cycles per unit time (usually RPM/2), the gas flow rate through the engine is found. This flow rate may include recirculated exhaust gas and the amount of its contribution to the gas flow rate may be substracted as taught in the US—A—4,086,884. The exhaust conduit gage pressure is a simple quadratic function of engine air mass flow rate, that is, exhaust conduit gage pressure is equal to a constant times the sqaure of the air mass flow rate. The absolute value of the exhaust pressure is the gage pressure plus the known or sensed barometric pressure. Following this, the ratio PIOPE or PEOPI can be obtained with the use of the most recently available intake manifold absolute pressure and the calculated exhaust conduit absolute pressure. The ratio then is used, in combination with the aforementioned second factor representing frictional and inertial forces, to produce a new engine volumetric efficiency value. The calculation is repeated continually during engine operation.

If it is desired to use the digital computer program and memory for more than one engine or vehicle system without changing the volumetric efficiency table that is selected, this can be accomplished by the use of scaling factors and terms in the basic equation that relates mass air flow into the engine's combustion chambers to the exhaust system gage pressure. For this purpose, the exhaust system gage pressure may be regarded as a term that is equal to the sum of a constant and two or more other terms each having air mass flow as a factor with a coefficient that is selected for the particular engine or vehicle system in question.

Claims

1. A method for controlling the supply of fuel to an internal combustion engine having an intake conduit and an exhaust conduit, characterised by the steps of:

(a) determining the ratio of the engine's intake conduit absolute pressure to its exhaust conduit absolute pressure or vice versa;

(b) using the determined ratio and a second factor representing the frictional and inertial forces acting upon the mixture of gases flowing through the engine's intake conduit to determine the volumetric efficiency of the engine, the volumetric efficiency being determined with respect to the flow of gases into at least one combustion chamber of the engine;

(c) metering fuel to the engine in a quantity based upon such determined volumetric efficiency; and

(d) repeating steps a, b and c.

2. A method accoriding to Claim 1, wherein the exhaust conduit absolute pressure is measured.

3. A method according to Claim 1, wherein the exhaust conduit absolute pressure is calculated.

4. A method according to Claim 3, wherein the exhaust conduit absolute pressure is calculated with the use of the intake conduit absolute pressure.

5. A method according to Claim 3, wherein the exhaust conduit absolute pressure is calculated using both the intake conduit absolute pressure and a volumetric efficiency value.

6. A method according to Claim 5, wherein the value of the engine's volumetric efficiency used to calculate the exhaust conduit absolute pressure is a value previously calculated in accordance with step (b) in Claim 1.

7. A method according to any one of Claims 1 to 6, wherein the volumetric efficiency is established from data contained in a table stored in the memory of a digital computer as a function of the ratio of the intake conduit absolute pressure to the exhaust conduit absolute pressure and as a function of the engine speed.

Revendications

1. Procédé de commande de l'alimentation en combustible d'un moteur à combustion interne possédant un conduit d'entrée et un conduit d'échappement, caractérisé par les phases consistant à:

(a) déterminer le rapport de la pression absolue de conduit d'admission à la pression absolue de son conduit d'échappement ou inversement;

(b) utiliser le rapport obtenu et un deuxième facteur qui représente les forces de frottement et d'inertie agissant sur le mélange de gaz qui circule dans le conduit d'admission du moteur pour déterminer le rendement volumétrique du moteur, le rendement volumétrique étant déterminé par rapport au flux de gaz pénétrant dans au moins une chambre de combustion du moteur;

(c) fournir le combustible au moteur dans une quantité basée sur ce rendement volumétrique; et,

(d) répéter les phases *a*, *b* et *c*.

2. Procédé selon la revendication 1, dans lequel la pression absolue du conduit d'échappement est mesurée.

3. Procédé selon la revendication 1, dans lequel la pression absolue du conduit d'échappement est calculée.

4. Procédé selon la revendication 3, dans lequel la pression absolue du conduit d'échappement est calculée en utilisant la pression absolue du conduit d'admission.

5. Procédé selon la revendication 3, dans lequel la pression absolue du conduit d'échappement est calculée en utilisant la pression absolue du conduit d'admission et une valeur du rendement volumétrique.

6. Procédé selon la revendication 5, dans lequel la valeur du rendement volumétrique du moteur utilisée pour calculer la pression absolue du conduit d'échappement est une valeur qui a été calculée précédemment conformément à la phase (b) de la revendication 1.

7. Procédé selon l'une quelconque des revendications 1 à 6, dans lequel le rendement volumétrique est établi à partir de données contenues dans un tableau mémorisé dans la mémoire d'un calculateur numérique en fonction du rapport de la pression absolue du conduit d'admission à la pression absolue du conduit d'échappement et en fonction de la vitesse du moteur.

Patentansprüche

1. Methode zur Regelung der Kraftstoffzufuhr zu einem Verbrennungsmotor mit einem Ansaugrohr und Auspuffrohr, gekennzeichnet durch folgende Stufen:

(a) Bestimmung der Verhältnisses des absoluten Drucks im Ansaugrohr des Motors zum absoluten Druck in dessen Auspuffrohr bzw. umgekehrt,

(b) Verwendung des festgestellten Verhältnisses und einer zweiten, die auf das durch das Ansaugrohr des Motors strömende Gasgemisch einwirkenden Reibungs- und Trägheitskräfte darstellenden Grösse zur Bestimmung des volumetrischen Wirdungsgrads des Motors, wobei der volumetrische Wirkungsgrad bezüglich der Gaströmung in mindestens eine Brennkammer des Motors bestimmt wird,

(c) Dosierung von Kraftstoff für den Motor in einer von jenem festgestellten volumetrischen Wirkungsgrad abgeleiteten Menge und

(d) Wiederholung der Stufen a, b und c.

2. Methode nach Anspruch 1, worin der absolute Druck im Auspuffrohr gemessen wird.

3. Methode nach Anspruch 1, worin der absolute Druck im Auspuffrohr berechnet wird.

4. Methode nach Anspruch 3, worin der absolute Druck im Auspuffrohr unter Verwendung des absoluten Drucks im Ansaugrohr berechnet wird.

5. Methode nach Anspruch 3, worin der absolute Druck im Auspuffrohr unter Verwendung sowohl des absoluten Drucks im Ansaugrohr als auch einer Grösse des volumetrischen Wirkungsgrads berechnet wird.

6. Methode nach Anspruch 5, worin die zur Berechnung des absoluten Drucks im Auspuffrohr verwendete Grösse des volumetrischen Wirkungsgrads des Motors eine zuvor gemäss Stufe (b) nach Anspruch 1 berechnete Grösse ist.

7. Methode nach einem der Ansprüche 1 bis 6, worin der volumetrische Wirkungsgrad gemäss in einer im Speicher eines Digitalrechners gespeicherten Tabelle enthaltenen Daten in Abhängigkeit vom Verhältnis des absoluten Drucks im Ansaugrohr zum absoluten Druck im Auspuffrohr sowie in Abhängigkeit von der Motordrehzahl festgelegt wird.