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(54) **ENGINE FUELLING RATE CONTROL**

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(58) **Field of Search** 123/478, 480, 123/486, 492, 493, 399, 361, 403; 701/102, 104, 105

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(57) **ABSTRACT**

A method for controlling the fuelling rate for an internal combustion engine including: a) controlling the fuelling rate in a fuel led control mode whereby the fuelling rate is controlled as a function of the operator demand on the engine during at least a portion of low engine load operation; b) controlling the fuel rate in an air led control mode whereby the fuelling rate is controlled as a function of the air flow rate to the engine during at least a portion of medium-to-high engine load operation; and c) providing a point of transition between the two control modes wherein each control mode provides substantially the same predetermined fuelling rate.

18 Claims, 2 Drawing Sheets

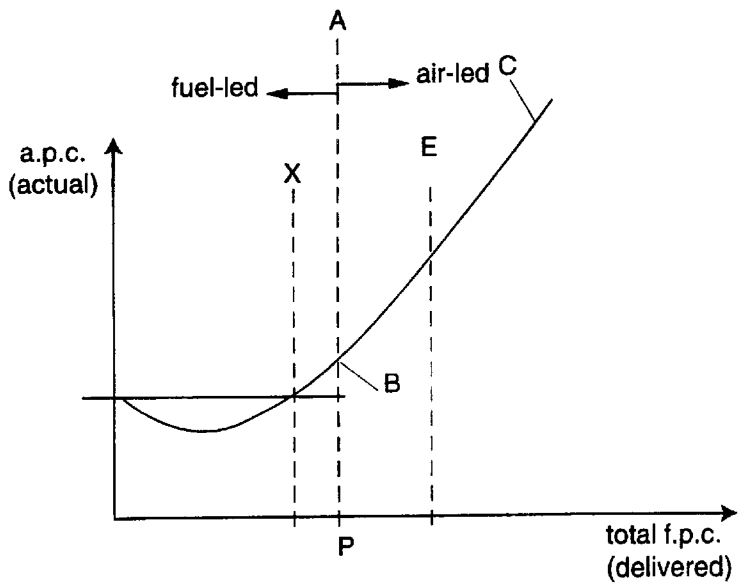
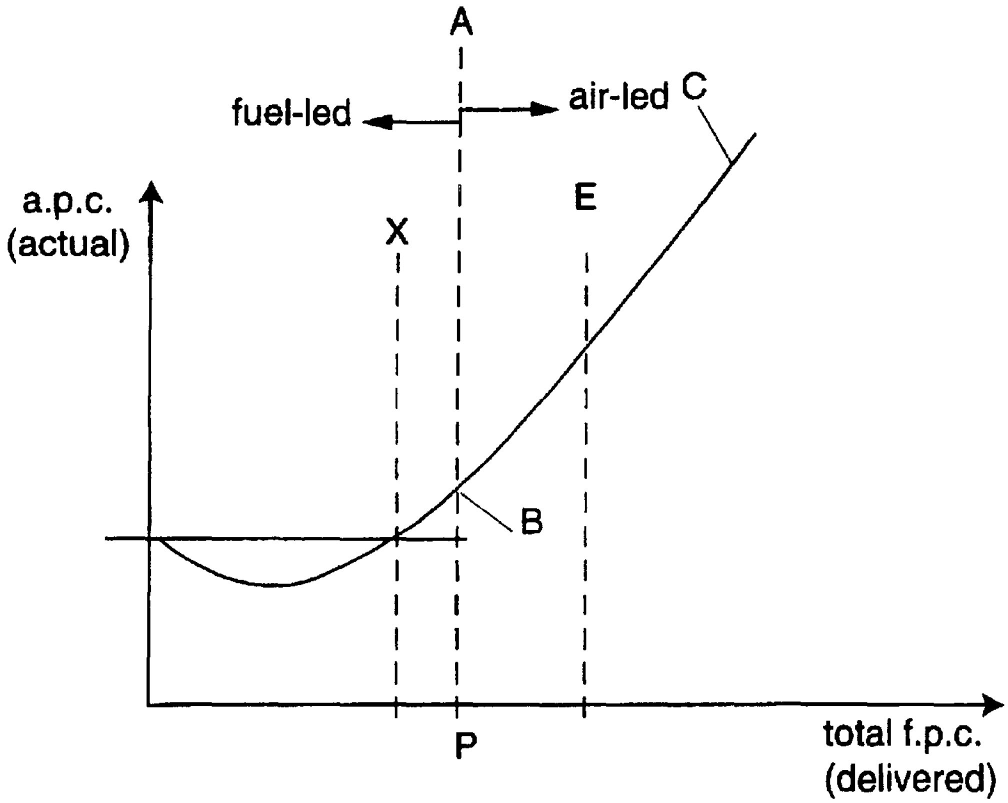


Fig 1.



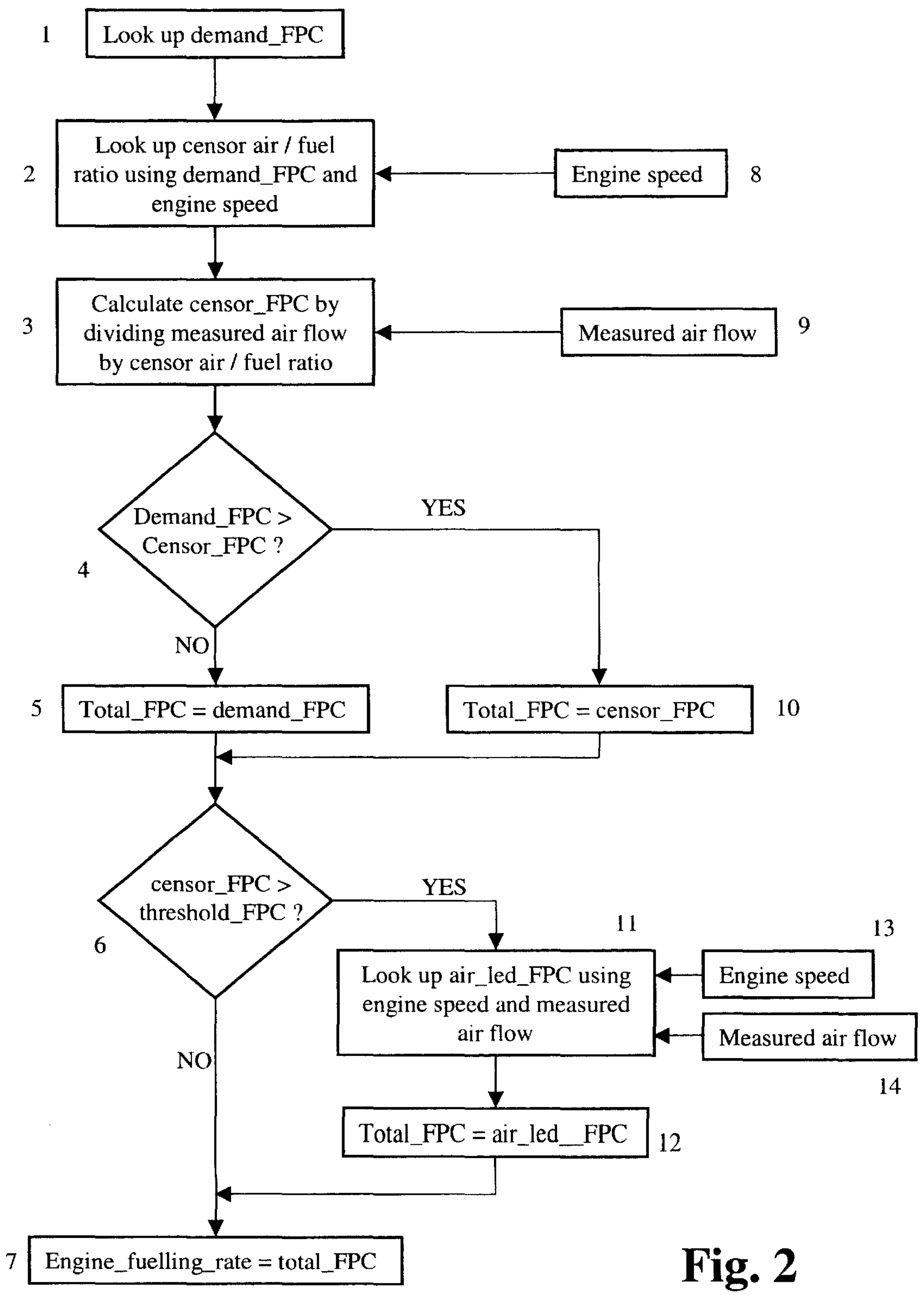

1
Look up demand_FPC
2
Look up censor air / fuel ratio using demand_FPC and engine speed
Engine speed
8
3
Calculate censor_FPC by dividing measured air flow by censor air / fuel ratio
Measured air flow
9
Demand_FPC > Censor_FPC ?
4
YES
NO
5
Total_FPC = demand_FPC
Total_FPC = censor_FPC
10
censor_FPC > threshold_FPC ?
6
YES
NO
11
Look up air_led_FPC using engine speed and measured air flow
Engine speed
13
Measured air flow
14
Total_FPC = air_led__FPC
12
7
Engine_fuelling_rate = total_FPC

Fig. 2

ENGINE FUELLING RATE CONTROL

The present invention generally relates to the control of the fuelling rate of internal combustion engines, and in particular to engines in which fuelling level and air flow level may be controlled independently, for example where fuel is supplied via electronically controlled fuel injection. In this specification, reference will be made to fuel delivery per cycle (fpc) and air flow per cycle (apc). A reference to either apc or fpc may refer to the level of fuelling/air flow determined to be required for appropriate operation of the engine (the "demand" apc/fpc), or to the fuel/air actually delivered to the engine, or to any other measure of air flow or fuelling level as the context requires.

In many internal combustion engines, such as carburettor fuelled four stroke engines, the relationship between air flow rate and fuelling rate is substantially monotonic. In these engines, each air flow rate value corresponds to a single fuelling rate value. Engines having this characteristic are able to operate under what is known as air led control. In air led control, an air flow rate is set by driver demand, and fuelling level is subsequently determined as a function of the air flow rate to the engine.

It is however not-normally possible to use such control in internal combustion engines having an air flow/fuelling level characteristic which provides non-unique values of fuelling level for a given air flow. One example of an engine having such a characteristic is the applicant's fuel injected two stroke crankcase scavenged engine. In this engine, airflow to the engine actually decreases with initial increases in fuelling level (or rate) before rising, as fuelling level increases further, to above the initial air flow rate. It can be seen that it is possible to obtain non-unique values for fuelling rate for a single air flow rate. Many variations providing non-unique values are possible. For example, initial increases in fuelling may correspond to substantially no change in airflow. It is therefore not generally possible to use air led control of the fuelling rate at low engine loads in such engines.

The Applicant's Australian Patent Application No. 34862/93, describes a method for controlling the fuelling rate of an internal combustion engine, in particular a fuel injected two stroke engine, where a fuelling rate, or "Demand__FPC" is initially determined and the required air flow rate, or "Demand__APC" is subsequently determined on the basis of the Demand__FPC value. This method of controlling the fuelling rate is referred to as fuel led control. The Demand__FPC is determined as a function of operator demand as measured, for example, by sensing the throttle pedal position and the engine speed. The Demand__FPC can then be determined by means of a look-up map provided within the engine management system plotting the Demand__FPC against the coordinates of pedal position and engine speed. This look-up map is known as the "pedal" map because the driver initiated fuelling level is assessed by determining the operator pedal position. The Demand__APC for the above determined Demand__FPC is then determined using a look-up map plotting Demand__APC against the coordinates of Demand__FPC and engine speed. The determined Demand__APC is then compared with the measured air supply rate to the engine, or Measured__APC, as measured by an air mass sensor and, if possible, the air mass flow rate adjusted to compensate for any difference between the two. The resultant air/fuel ratio of Demand__FPC against Demand__APC can also be compared with a censor air/fuel ratio which is preset on the basis of the engine load demand and engine speed. The censor air/fuel ratios are stored on a further look-up map and set predetermined minimum limits

to the air/fuel ratio that can be applied for the existing speed and load. These limits to the air/fuel ratio are set to prevent specific engine malfunctions such as engine misfire, and take into account catalyst and/or emission considerations. If it is determined that the air fuel ratio is too low (ie rich mixture), the fuel supply may be clipped to avoid delivery of such rich mixtures to the engine.

Fuel led operation may be disadvantageous in certain situations. In certain types of fuelling systems, such as those using fuel injectors, fuelling level can be altered quickly and accurately, whilst variation of the air flow rate is generally less accurate, slower and more difficult to control, particularly under transient conditions, making control of the air fuel ratio in the combustion chamber more difficult. Supplying air and fuel at an accurate air fuel ratio is important for controlling combustion emissions. As such, it is preferable to have the airflow being set by driver demand and then to control the fuelling level to give the required air fuel ratio, that is, air led control.

Another advantage of using air led control at higher load/speed occurs at or near wide open throttle (WOT) conditions where air led control can be used to achieve maximum power output from the engine. In fuel led operation, calculation of maximum fuelling for a given engine speed is based on experimental calibration of test engine(s). The calibrated maximum fuelling would normally be set at slightly lower than the test results indicated to provide a margin of safety to ensure that an overly rich mixture was not obtained. However, in actual operation, airflow to the engine may be higher than the experimental data indicated, particularly under transient conditions. This may result in the air fuel ratio in the combustion chamber being less than that for which maximum power can be obtained. At wide open throttle, for example, air flow is at its maximum, but maximum fuelling corresponding to the air flow may not be supplied due to the calibrated maximum fuelling rates, reducing the power output of the engine.

Whilst fuel led control is necessary for low engine loads/speeds, this may not be so for higher load/speed conditions. In certain engines, such as the applicant's two stroke direct injected crankcase scavenged engine, there is a substantially monotonically increasing relationship between the fuelling rate and the air flow rate at higher loads. Under these loads it is possible, and preferable as discussed above, to use air led control of the fuelling rate.

The major difficulty that arises with such an arrangement is that there can be a discontinuity at the point of transition between the two control methods. The fuelling rate determined under fuel led control could be significantly different to the fuelling rate determined under air led control at the point where the engine management system transfers between the two fuelling rate control methods. This can cause a step change in the determined fuelling rate resulting in a step change in torque. Such sudden changes may be detrimental to engine control and are undesirable as they may result in jolting through the drive train of the vehicle producing, for example, an uncomfortable ride for the occupants of the vehicle.

It is therefore an object of the present invention to provide an improved method of controlling the fuelling rate of an engine.

With this in mind, the present invention provides a method of controlling the fuelling rate for an internal combustion engine including:

(a) controlling the fuelling rate in a fuel led control mode whereby the fuelling rate is controlled as a function of the operator demand on the engine during at least a portion of low engine load operation;

(b) controlling the fuelling rate in an air led control mode whereby the fuelling rate is controlled as a function of the air flow rate to the engine during at least a portion of medium to high engine load operation;

(c) providing a point of transition between the two control modes whereat each control mode provides substantially the same predetermined fuelling rate.

As the point of transition between the two control modes occurs when the fuelling rate determined by either control mode reaches substantially the same predetermined threshold fuelling rate, there can therefore be a smooth transition in the fuelling rate when transferring between the two control modes.

The predetermined threshold-fuelling rate may be determined from a look up map depending on current engine speed, so that for a given engine speed the transition point will be at a fixed fuelling rate.

As noted above, at low loads, the airflow rate cannot be used to determine the engine load because for a given airflow rate, there may not be a unique corresponding fuelling rate. Where the engine operation is controlled by an electronic control unit (ECU) it is not possible to provide a map whereby a fuelling rate can be looked up on the basis of a given air flow rate. In this situation, a fuel led control mode for the fuelling rate is more appropriate. At medium to high loads, where there is a substantially monotonically increasing airflow rate for increasing fuel flow rate, a unique fuelling rate is therefore available for any given airflow rate at these loads, and the fuelling level can be determined on the basis of the current airflow. An air led control mode for the fuelling rate is more appropriate in this situation.

The predetermined threshold fuelling rate for transition between control modes is preferably set above fuelling levels where a single air flow rate can correspond to more than one fuelling level which occur at low loads. A margin of variation may be provided about this value to allow for any errors or system anomalies.

The engine air intake may be provided with a secondary valve such as that described in the applicant's U.S. Pat. No. 5,251,597, known commonly as a DAR-valve. The DAR-valve is an electronically controlled air flow control valve which is provided additionally to the primary air flow control valve, and provides a separately controllable airflow to the engine. In the above-mentioned U.S. patent, there is described a system wherein the primary air flow control device is a butterfly valve controlled directly by operator movement of an accelerator pedal. The DAR-valve in this situation is able, under the control of the electronic control unit (ECU), to selectively add to the volume of air provided by the primary valve device. As such, total air flow to the engine is controlled by the ECU. The DAR-valve may be used to ensure that air flow in the air led region at the transition point is at such a level that correct fuelling is provided. At higher loads, where the majority of the bulk air is provided through the primary valve (usually a butterfly valve), the ability of the DAR-valve to control air flow is diminished. As such, it is preferable to preset the transition point such that DAR-valve is in its region of authority, that is, still being effective in controlling the air flow rate through the inlet manifold to the requisite degree that the air flow may be controlled if the air flow is different to that required for the fuelling rate obtained under fuel led control. This may therefore avoid a step jump in the fuelling rate at the point of transition.

In other embodiments, the primary air flow control device may be electronically controlled, and this control can be used in a similar fashion to the above described DAR-valve air flow control method. One benefit of the use of an electronically controlled primary air flow device is that there is no problem with the "region of authority" as the primary valve obviously has authority throughout the operating range of the engine.

According to the present invention, a "demand" fuelling rate may initially be determined as a function of the load demand and the engine speed. The load demand may be determined as a function of operator pedal position. To this end, an electronic engine management system may be provided including a look-up map having the demand fuelling rate plotted against the coordinates of pedal position and engine speed. This map is referred to as the "pedal" map and provides the demand fuelling rate.

A censored air/fuel ratio referred to above may be obtained from a further look-up map setting predetermined minimum limits to the air/fuel ratio as a function of the engine speed and demand fpc. A censor fuelling rate may then be determined by dividing the air flow to the engine, measured for example by an air flow meter, by the obtained censor air/fuel ratio. This censor fuelling rate may be compared with the demand fuelling rate obtained from the pedal map. If the demand fuelling rate is greater than the censor fuelling rate, then the total fuelling rate (or delivered fpc) value may be set as being equal to the censor fuelling rate. However, if the demand fuelling rate is less than the censor fuelling rate, then the total fuelling rate may be set as being equal to the demand fuelling rate. This process is known as censoring the fuelling rate.

The total fuelling rate (following censoring) may then be compared with a predetermined threshold fuelling rate value. If the total fuelling rate is less than the threshold fuelling rate value, then the total fuelling rate obtained above may be selected as the actual-fuelling rate delivered to the engine. However, if the total fuelling rate is greater then the threshold fuelling rate value, then an air led fuelling rate value may be obtained from a further look-up map plotting air led fuelling rate against the coordinates of measured air flow rate and engine speed. The total fuelling rate may then be set as being equal to the determined air led fuelling rate and air led operation is commenced without a sudden shift in fuelling rate or overall torque.

The shift from fuel to air led operation, or air to fuel led operation, requires a change in basic operation of the engine and electronic control unit. As such, it would be undesirable to allow rapid changes between modes of operation. Such rapid changes in mode of operation could result, for example, from continuous engine operation at around the transition point. One method of preventing such rapid changes would be to provide a delay following a change of mode before allowing a return change of mode, such a delay would only need to be very short (around half a second, for example) to obtain the desired results.

A preferred method would be to set the transition point for transition from fuel led mode to air led mode at a greater fuelling level than the transition point for transition from air led mode to fuel led mode. This would mean that fuelling level would have to be reduced by a given amount from its value at the point of transition from fuel led to air led (which would only occur if fuelling level were increasing) before a subsequent transition from air led to fuel led operation would be possible.

It will be convenient to further describe the invention by reference to the accompanying drawings which illustrate a preferred embodiment of the invention. Other arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

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