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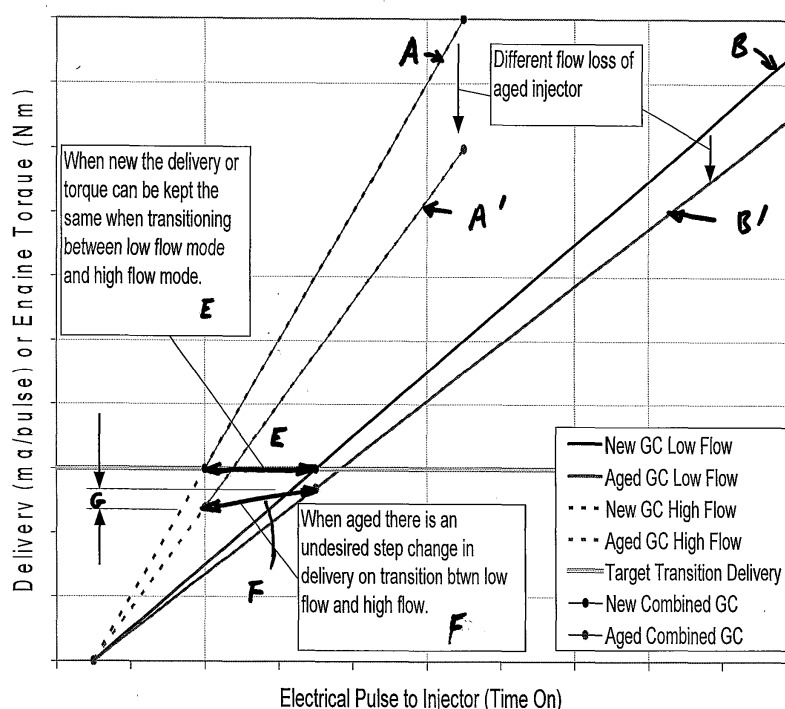
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(54) **Method and system to operate a variable orifice nozzle fuel injector**

(57) A method of controlling variable orifice nozzle fuel injectors in a combustion engine, said injectors being operable in at least two modes comprising: determining

that there is a need to switch from a first mode to a second mode, and wherein switching of the modes is performed in progressive fashion.

Fig 1



Description

Field of the Invention

[0001] This invention relates to a method of controlling fuel injectors which can operate in at least two different modes. It has particular but not exclusive application to Variable Orifice Nozzle (VON) fuel injectors.

Background to the invention

[0002] Variable Orifice Nozzle fuel injectors are fuel injectors whose effective discharge orifice can be varied e.g. by dispensing fuel into a combustion space through a variable number of orifices. Thus the injectors can be operated and thus switched between two or more modes where the effective orifice area is variable thus injecting different quantities of fuel.

[0003] When considering operation in different modes there will be thus at least two different gain curves relating the length of the pulse typically sent to the fuel injector valve to control fuel and the effective delivery quantity of fuel and consequently the torque provided.

[0004] When moving from one mode to another, it is preferable that the torque produced is substantially the same in order to reduce vibrations, and also to increase efficiency. In order to do this the ECU must know the relationship between the electrical demand time e.g. pulse time length for both modes of operation to give the same torque.

[0005] However a problem with this is that the control system is calibrated with gain curves which may be accurate when new, but gain curves will drift with time due to factors such as seat wear, actuator ageing, coking, lacquering, etc. The particular problem with VON actuators is that this drift may vary in different ways for each mode of actuation (each gain curve).

[0006] It is an object of the invention to overcome such problems and provide for a system of compensation which ensures a smooth transition between the modes.

Statement of the Invention

[0007] In one aspect of the invention is provided a method of controlling variable orifice nozzle fuel injectors in a combustion engine, said injectors being operable in at least two modes comprising: determining that there is a need to switch from a first mode to a second mode, and wherein switching of the modes is performed in progressive fashion.

[0008] The transition of modes for each injector may be performed sequentially.

[0009] The transition of modes for each injector may be performed after a set time or a set number of engine cycles

[0010] The point at which transition occurs for each injector may be performed at different set points

[0011] The injectors may be controlled to switch mode

dependent on a set value of demand torque, and wherein said set value is arranged to differ for different injectors.

[0012] There may be variation in the calibration of said injectors in terms of the point at which switching of modes takes place.

[0013] In a further aspect is provided a method of controlling and/or calibrating variable orifice nozzle fuel injectors in a combustion engine, said injectors being operable in at least two modes, comprising:

- i) switching one injector between a first mode and a second mode;
- ii) estimating or measuring the consequential torque or change in torque;
- iii) adjusting the operation of said injector with respect to one and/or the other of the two modes, dependent on the consequential change in torque.

[0014] The adjusting may comprise proportionally/correspondingly varying the quantity of fuel delivered for a particular mode, at any set point.

[0015] Varying of the quantity of fuel may be such that there is no corresponding change in torque when said injector is switched modes.

[0016] Steps i) and ii) may be performed separately to normal mode transition.

[0017] Steps i) and ii) may be performed, at a time when the engine is running at a substantially constant torque and or substantially close to the mode transition point.

Brief Description of Drawing

[0018] Figure 1 shows two different gain curves for a dual mode VON injector with corresponding aged gain curves.

Description of the Invention

[0019] Typically fuel injectors operate to inject fuel into a combustion space through a nozzle by cooperation of a needle with a nozzle. Operation of a fuel injector is typically via application of an electrical pulse to control e.g. a solenoid or piezoelectric valve arrangement. In a typical design of fuel injector the nozzle may comprise a plurality of individual orifices (e.g. holes) formed in the nozzle, such that mode selection allows the needle displacement to provide injection through one or more nozzles selectively.

[0020] VON injectors are capable of producing two different gain curves, for the two different modes, as shown in figure 1. On the x-axis is shown the duration of an electrical pulse sent to the fuel injector (time on) and the y-axis show the resultant amount of fuel injected, and the torque consequentially developed will be a function of the delivered fuel quantity.

[0021] As can be seen line A shows the gain curve (it is actually a straight line but traditionally these have been

referred to as "curves") for one mode where a single orifice is open to allow discharge of fuel and line B shows the gain curve corresponding to the use of two orifices. As can be seen, the two orifice mode allows more fuel to be injected for the same duration of pulse signal sent to the injector. Gain curves A' and B' correspond to the gain curves for mode A and B with an aged injector, which generally results in a reduced amount of fuel injected, for the same pulse duration.

[0022] As can be seen from the non-aged injector gain curves, when switching from the first mode A to the second mode B or vice versa, shown by bidirectional arrow E, the length of the electrical pulse has to be appropriately decreased /increased to achieve the same volume of fuel injected and hence torque. During calibration, the gain curves may be determined and the appropriate increase /decrease pulse length sent to injector determined in order to achieve the required volume of fuel/torque.

[0023] However as the injector ages, the changes in the gain curves are such that the deterioration results in problems such that the similar control of the electrical pulses will not give the same results; arrow F illustrates such problems. As can be seen, initiating the same change in electrical pulse duration, as before will, for an aged injector, result in a step change G (decrease or increase) in the quantity of fuel delivered. This is manifested as a step change in torque and is undesirable.

[0024] According to an aspect of the invention, when it is determined (e.g. as a result of an increase in demand torque) that there needs to be a change of mode, aspects of the invention provide for the switching of modes to be done progressively. This can be implemented in a variety of ways according to different aspects of the invention. The transition for each injector/cylinder in turn may occur after a set or variable time or a set or variable number of engine cycles, depending on operating conditions. This ensures that if there is a discrepancy in the gain curves, then the individual steps in the torque as each injector is switched, is less than if they were all switched together.

[0025] In a first example, during mode switching, the cylinders are switched one after another, e.g. in a progressive fashion. So for example in a 4 cylinder engine with one injector per cylinder, where there are two modes A and B and all the injectors are operating in mode A and there is a decision (e.g. based on torque demand) to switch to mode B, the first VON injector may be switched to mode B, and after a set period of time or number of engine cycles, the second VON injector is switched to mode B, and after a set period of time or number of engine cycles, the third injector is switched to mode B and so on. Thus, for example, in a four cylinder engine, the step torque is then only 25% of what it would have been otherwise. In other words after a decision to transition between modes, the injectors could transition progressively based on a time interval or after a certain number of engine cycles, thus reducing any large step change which may arise when all the injectors are switched at the same time.

[0026] The injector modes may be controlled (switched) progressively according to another embodiment as follows. The control may be such that each injector is switched according to (different) torque demand. So where the absolute or relative torque demand reaches a certain point (e.g. threshold) a particular injector is switched (e.g. from mode A to mode B) and when the torque demand reaches a different threshold value, another injector has its mode switched from A to B. So where in prior art system all injectors are switched at 50% for example, according to this aspect, the injectors are switched progressively one at a time, over a certain period. So at 48% torque no injectors are switched, but at 52% torque first one is switched at 56% another injector is switched, until all injectors were switched.

[0027] In another alternative strategy, the transition torque may be calibrated differently for each injector. This example is similar to the one described above, but rather than the ECU, for example, controlling when the injectors are switched, a single command is sent, e.g. indicative of demand torque, to the injectors, and injectors would be adapted to switch mode dependent on this demand torque and an inherently set threshold torque. Again each injector would be switched at a different engine torque. For instance the first injector at 45% torque the second at 50% the third at 55% etc. This means that if engine torque demand were at 48% torque continuously one injector would be switched and the other 3 not switched.

Aspect 2

[0028] In one aspect of the invention, to overcome the aforementioned problems, the relative drift in the gain curves for the different modes for a particular injector is tracked. One way of doing this is to select one of the injectors and switching this from one mode (e.g. two orifices to another mode (one orifice), or vice versa. The torque produced on the corresponding cylinder which has the fuel injector mode switched is measured and compared when operating in mode A and in mode B. This may be done separately to the mode transition, typically at a time when the engine is running at a fairly consistent torque which is near to the transition point. The measurement of torque differences is often already done in the cylinder balancing strategy - which looks at the crankshaft acceleration cylinder to cylinder and thus corrects injector drift cylinder to cylinder. Alternatively, in the event that cylinder pressure sensors are fitted then a suitable feedback signal on the fuel delivered in each operating mode can readily be obtained by that method. The two gain curves on the one injector can now be compared with each other rather than between different cylinders.

[0029] Thus in an example, for a particular cylinder or injector, a switch of mode is made and the torque (or change in torque) for the two different modes is measured. If for example, the torque from mode A (one orifice/row operation) is 5% less than from mode B (two orifices/rows) operation, then mode A operation can be

corrected/adjusted by increasing fuel flow, e.g. the electrical pulse duration, by 10%. (in the case of a 50:50 flow split). If the mode B (two row operation) is 5% less than the mode A (one row operation) then likewise the two row (Mode B) operation of the injector can be corrected up by 10%. In general the following correction strategy may be applied:

$$\text{Row1_Correction} = \max(0, (\text{Delivery_row2} - \text{Delivery_row1}) / \text{Delivery_row2} \cdot (\text{row2 \% of total nominal injector flow}))$$

$$\text{Row2_Correction} = \max(0, (\text{Delivery_row1} - \text{Delivery_row2}) / \text{Delivery_row1} \cdot (\text{row1 \% of total nominal injector flow}))$$

[0030] In essence, for a particular torque, if switching from mode A to mode B reduces torque by a value of x%, then with respect to the correction factor, the fuel delivered in mode B is increased by an appropriate amount, which may be the value of x multiplied by a factor, said factor being a function of the ratio of effective orifice areas for the two modes.

[0031] When a certain fuel delivery is demanded, the gain curve gives a "time on" (TON) value for the injector. It is common to adjust this value before it is applied to the injector. Corrections may be applied for the zero crossing point on the gain curve, the gradient, points of inflection, wear, pressure wave modulation etc. The benefit of applying the corrections as described above is that only one nominal gain curve is required for all injectors, over their whole lifetime, in any operating mode. The real gain curve of each injector at any point in its lifetime does not change, but the corrections allow the real gain curve to be adjusted to fit the nominal gain curve.

[0032] The advantage of the above methodology is that one can be much more certain about a correction of this nature than a correction applied between cylinders using for instance the cylinder balancing strategy. This new strategy thus limits the total negative drift of the injector to the minimum of the drift of either row of the injector. This assumes that injector gain curve drift is only ever a reduction in the fuel delivered for a particular electrical pulse length. This advantage is provided because one is able to look and compare the performance on an individual cylinder with all other engine parameters (friction, air path, etc) exactly the same, except the injector operating mode (i.e. the effect of switching between 1 and 2 rows). Further it allows detection of failure to inject from one or the other rows by comparison of the gain curves with each other and with a maximum drift value for normal operation.

[0033] Torque measurements (or estimates thereof e.g. from pressure measurements) are thus according to one aspect used to calibrate changes to the delivered fuel quantity. By making the measurements at two different torques, adjustments are made to the corrections for both to the gradient of the gain curve and to the zero

crossing point. Additional measurement torques might allow more complicated gain curve shapes to also be characterised.

Claims

1. A method of controlling variable orifice nozzle fuel injectors in a combustion engine, said injectors being operable in at least two modes comprising: determining that there is a need to switch from a first mode to a second mode, and wherein switching of the modes is performed in progressive fashion.
2. A method as claimed in claim 1 wherein the transition of modes for each injector is performed sequentially
3. A method as claimed in claims 1 or 2 wherein the transition of modes for each injector is performed after a set time or a set number of engine cycles
4. A method as claimed in claims 1 to 3 wherein the point at which transition occurs for each injector is performed at different set points
5. A method as claimed in claim 4 wherein said injectors are controlled to switch mode dependent on a set value of demand torque, and wherein said set value is arranged to differ for different injectors.
6. A method as claimed in any preceding claim wherein there is variation in the calibration of said injectors in terms of the point at which switching of modes takes place.
7. A method of controlling and/or calibrating variable orifice nozzle fuel injectors in a combustion engine, said injectors being operable in at least two modes, comprising:
 - i) switching one injector between a first mode and a second mode;
 - ii) estimating or measuring the consequential torque or change in torque;
 - iii) adjusting the operation of said injector with respect to one and/or the other of the two modes, dependent on the consequential change in torque.
8. A method as claimed in claim 7 wherein said adjusting comprises proportionally/correspondingly varying the quantity of fuel delivered for a particular mode, at any set point.
9. A method as claimed in claim 8 wherein said varying of the quantity of fuel is such that there is no corresponding change in torque when said injector is switched modes.

10. A method as claimed in claims 8 to 10 wherein steps i) and ii) are performed separately to normal mode transition.
11. A method as claimed in claims 8 to 11 wherein steps i) and ii) are performed, at a time when the engine is running at a substantially constant torque and or substantially close to the mode transition point. 5
12. A system method of controlling variable orifice nozzle fuel injectors in a combustion engine including a plurality of variable orifice nozzle fuel injectors, said injectors being operable in at least two modes and adapted to implement any method according to claims 1 to 11. 10 15

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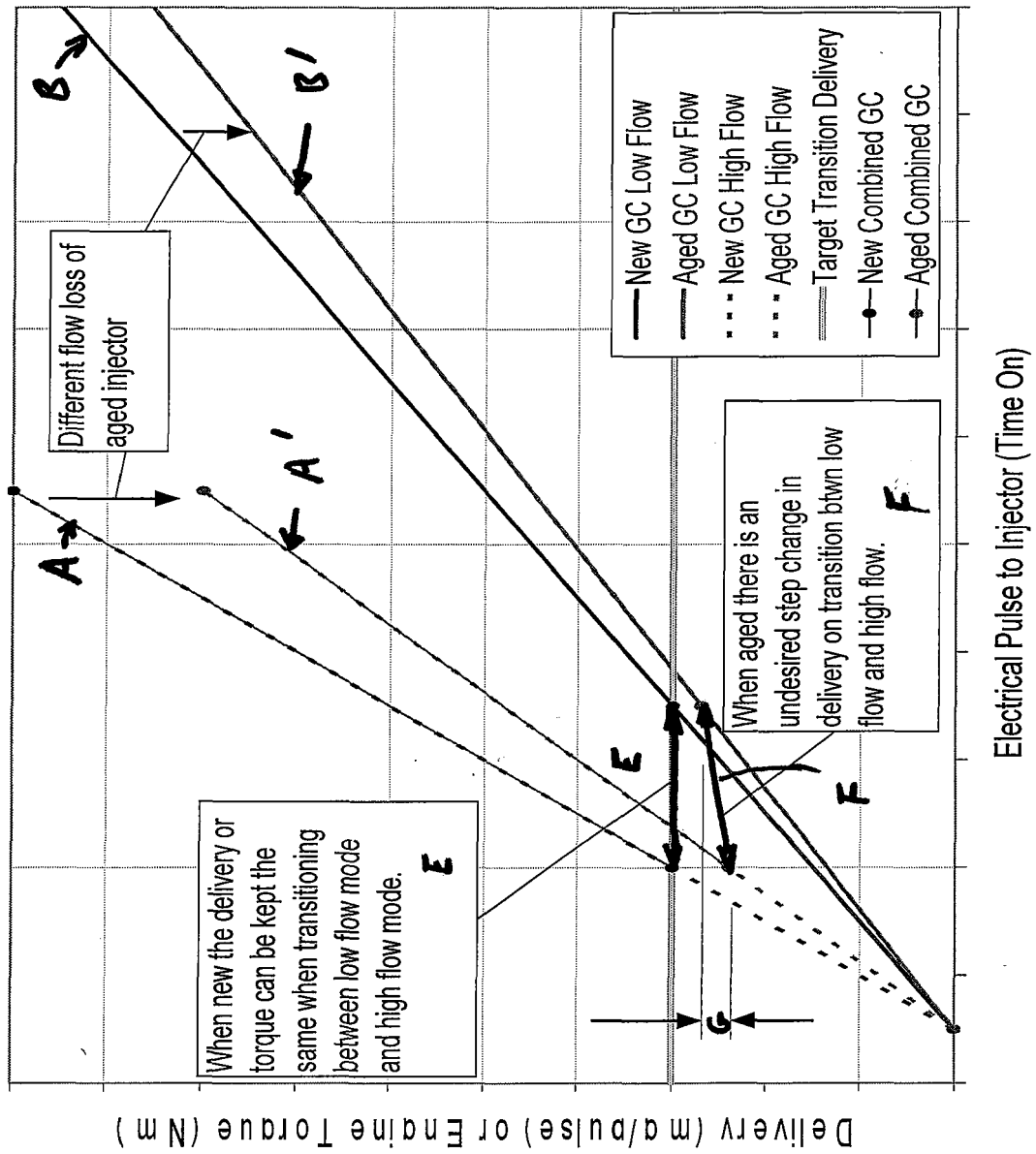


Fig 1



EUROPEAN SEARCH REPORT

Application Number
EP 13 19 7630

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 5 803 048 A (YANO TORU [JP] ET AL) 8 September 1998 (1998-09-08) * column 7, line 10 - line 18 * * column 8, line 13 - line 17 * -----	1-6	INV. F02M61/18 F02M45/08 F02M45/12 F02D41/00 F02D41/24 F02D41/30
A	WO 2008/152488 A1 (TOYOTA MOTOR CO LTD [JP]; FUTONAGANE YOSHINORI [JP]; OKUMURA FUMIHIRO) 18 December 2008 (2008-12-18) * paragraph [0002]; figure 2 * -----	1-6	
Y	US 2003/029414 A1 (BOSS JUERGEN [DE] ET AL) 13 February 2003 (2003-02-13) * paragraph [0020] - paragraph [0021]; figures 1,5 * -----	7-11	
Y	US 2011/202255 A1 (HAUSER CHRISTIAN [DE]) 18 August 2011 (2011-08-18) * paragraph [0047] - paragraph [0048]; figures 5-8 * -----	7-11	
A	DE 197 37 375 A1 (MITSUBISHI MOTORS CORP [JP]) 5 March 1998 (1998-03-05) * column 5, line 61 - line 68 * -----	1,7-9	TECHNICAL FIELDS SEARCHED (IPC) F02M F02D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 7 October 2014	Examiner Eitner, Christian
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.02 (P04C01)



Application Number

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CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



**LACK OF UNITY OF INVENTION
SHEET B**

Application Number
EP 13 19 7630

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6

Sequential switching of injector gain curves

2. claims: 7-12

Fuel injector calibration method

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 13 19 7630

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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07-10-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5803048 A	08-09-1998	US 5803048 A	08-09-1998
		US 5836287 A	17-11-1998
		US 6012428 A	11-01-2000

WO 2008152488 A1	18-12-2008	CN 101688490 A	31-03-2010
		EP 2156038 A1	24-02-2010
		JP 4433000 B2	17-03-2010
		JP 2008309081 A	25-12-2008
		US 2010163000 A1	01-07-2010
		WO 2008152488 A1	18-12-2008

US 2003029414 A1	13-02-2003	DE 10035815 A1	31-01-2002
		EP 1305520 A1	02-05-2003
		JP 2004504542 A	12-02-2004
		US 2003029414 A1	13-02-2003
		WO 0208599 A1	31-01-2002

US 2011202255 A1	18-08-2011	CN 102187075 A	14-09-2011
		DE 102008051820 A1	22-04-2010
		US 2011202255 A1	18-08-2011
		WO 2010043479 A1	22-04-2010

DE 19737375 A1	05-03-1998	DE 19737375 A1	05-03-1998
		SE 0302186 A	08-08-2003
		SE 9703060 A	28-02-1998
		US 5970947 A	26-10-1999
