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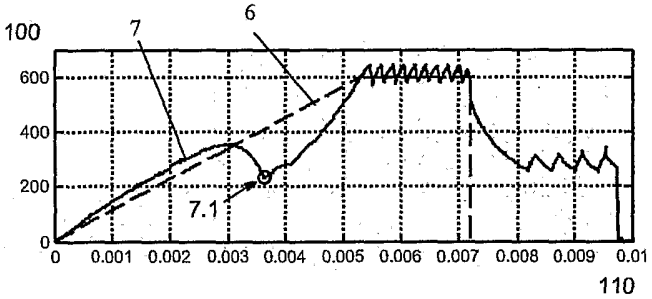
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Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A METHOD OF CONTROLLING THE OPERATION OF A SOLENOID



(57) Abstract: A method for controlling the operation of a solenoid (14), in which solenoid the movement of the plunger is caused by bringing electric energy to the solenoid, whereby an electric current flows through the solenoid, the method comprising the following steps: - defining a model (6) for describing the current signal of the solenoid at certain time intervals from the activation moment of the solenoid onwards, - measuring the true current signal (7) of the solenoid at time intervals corresponding with the model, - defining a residual signal (8), which is the remainder between the signal of the model (6) and the true current signal (7), and - performing a threshold analysis (25) for the residual signal.

WO 2004/102600 A1

A METHOD OF CONTROLLING THE OPERATION OF A SOLENOID

Technical Field

The invention relates to a method of controlling the operation of a solenoid, as set forth in the preamble of claim 1, in which solenoid the movement of the plunger is caused by bringing electric energy to the solenoid, whereby an electric current flows through the solenoid.

Background Art

A number of fuel injection systems of engines utilize solenoids for controlling the operation of injector nozzles. This can be accomplished by directly operating the valve needle or indirectly by controlling, for example, the pressure level of injector nozzle servo oil by means of the solenoid valve. In both cases the operation is always based on the movement of the plunger of the solenoid. US Patent 6,240,901 by the applicant discloses a system based on indirect control.

An electric current flows through the coil of the solenoid when a source of electric energy is connected thereto. This produces a magnetic field that causes the plunger of the solenoid to move. In a solenoid, the electric current changes on the basis of the position of the plunger, and the current starts to decrease for a while especially when the plunger has started to move, thereby forming a local maximum value of the current. This information can be used for controlling the operation of the solenoid, especially it be used for observing the opening moment of the injectors nozzle. This information can also be used for making sure that the plunger has started to move.

Publication WO 03/007317 A1 discloses a method of controlling a solenoid. The starting point in this publication is, however, to define the moment when the injector nozzle has fully opened. The above-mentioned local maximum value of the current

also occurs as the movement of the plunger stops. In the method described in the publication, the events during the movement of the injector nozzle are ignored.

Disclosure of the Invention

It is an aim of the present invention to provide a method of controlling the operation of a solenoid while minimizing the problems associated with prior art. It is an especial aim of the invention to provide a method of determining the starting point of the injection of a solenoid-controlled injector nozzle, whereby the starting point of the injection takes place reliably but simply.

The method according to the invention for controlling the operation of a solenoid, in which solenoid the movement of the plunger is caused by bringing electric energy to the solenoid, whereby an electric current flows through the solenoid, comprising the following steps.

- defining a model for describing the current signal of the solenoid at certain time intervals from the activation moment of the solenoid onwards,
- measuring the true current signal of the solenoid at time intervals corresponding with the model,
- defining a residual signal, which is the remainder between the signal of the model and the true current signal, and
- performing a threshold analysis for each residual signal.

The method according to the invention makes use of a model in which the value of the current signal of the solenoid is linearly modelled with a sequentially continuous function, the value of which is time-dependent only.

In the method, the time window for determining the model corresponds with the desired control time of the solenoid used in the method, such as retraction time. Correspondingly, the time window for defining the threshold analysis corresponds with the retraction time of the solenoid of the present method. In the threshold

analysis, the deviation of the residual signal from zero value to a predetermined limit value, whereby the resulting signal can easily be used for noticing the relatively large positive deviation caused by the beginning of the movement of the plunger. Preferably the method is used for determining the beginning of the opening of the fuel injector nozzle of an engine. The solenoid controls the operation of the injector nozzle of the engine, whereby at least the point in time, in which the value of the residual signal exceeds the said limit value, is forwarded along in the control unit to be used in controlling the operation of the engine.

The present invention also relates to a fuel injection system of an internal combustion engine, the injection system comprising at least one electrically controllable injector nozzle arranged to carry out the above-mentioned method.

Description of Drawings

In the following the invention is described by way of example and with reference to the appended drawings, of which

- Figure 1 schematically shows the behaviour of the current of the solenoid in connection with the fuel injector nozzle as a function of time,
- Figure 2 shows a behaviour of the current of a solenoid in connection with a fuel injector nozzle as a function of time and the current signal of the model determined for the corresponding solenoid,
- Figure 3 shows the residual signal of the situation of figure 2, and
- Figure 4 is a schematic representation of a method according to the invention in a fuel injection system.

Figure 1 schematically shows the behaviour of the current 100 of the solenoid when using the solenoid over a period of time 110, i.e. when a source of electric energy is connected thereto. Several stages, in different time phases, can be seen in the operation, starting from connecting the current. The first time phase 1 shows the so-called retraction time of the control, i.e. the time when the plunger of the

solenoid is supposed to move from the rest position to operation position. The current flowing through the solenoid finally increases to its largest value, the so-called retraction current 5. The figure also shows that at a certain time subsequent to the activation the current decreases for a while, which causes a formation of local maximum value 1.1. This is due to the change of inductance caused by the beginning of the movement of the plunger, the change in turn causing a change in the electric current flowing through the solenoid. When the solenoid reaches its extreme position, the momentary reduction of current is stopped and the current can increase again. This situation is the opening moment of the injection valve. During the retraction of the solenoid the current reaches its extreme value, which is so-called retraction value. Subsequent to the retraction time 1 it is supposed that the plunger of the solenoid has reached its extreme position, whereby the value of the current decreases to a level that's sufficient to keep the plunger of the solenoid in its position. The decrease of the current also takes some time, also due to the influence of the inductance. This lower current level is called holding current 4. When the injection has lasted for a pre-determined time 3, the energy source is disconnected from the solenoid, whereby the electric current disappears.

Figure 2 shows a model 6 of the current signal of the solenoid as used in the invention. In the model, the changes of current 100 are modelled in a solenoid corresponding to a real one, but the current change caused by the movement of the plunger of the solenoid are ignored. The current signal is modelled for the time 110 it is desired to control the movement of the plunger, i.e. typically over the retraction time 1, and it rises from zero, corresponding to the activation moment of the solenoid, linearly to the level of the retraction current. Thus, there is no local maximum value of current caused by the beginning of the plunger of the solenoid to be seen in normal operation of the model. In case the time interval to be controlled is supposed to be retraction time 1, changes in current are modelled to the end of the retraction time 1. Figure 2 also shows the measured current signal 7 of a working solenoid on the same time axis. This will clearly show the momentary decrease 7.1 of the current flowing through the solenoid during its retraction phase.

Thus, this phenomenon has been found to be caused by the operation of the solenoid. When the method according to the invention is applied, the model 6 of the solenoid is stored in the control system as a simulated current value set. According to the invention, it is desirable to use a static measurement frequency, whereby the value of the model can be determined solely on the basis of the ordinal number of the measurement so, that each value of the model is the previous value with a certain constant number added, the constant number being determinable from the slope of the model 6. In the method, the remainder of the current signal 7 measured after the activation of the solenoid, i.e. after the opening sequence of the injector nozzle, and the current signal of the corresponding time of the model is determined as the residual signal 8. The residual signal 8 for the case of figure 2 is shown in figure 3. A threshold analysis 25 is performed for each residual signal determined thus for finding a positive value, i.e. a peak 8.1, exceeding the zero level. In the method, a certain limit value is determined for the peak that has to be exceeded before the movement of the plunger can be considered as started. The analysis is performed after each opening sequence of the valve and the model can be corrected on the basis of each measurement sequence, so that any changes in the apparatus can be considered.

Thus, in the valve opening recognition (VOR) according to the invention, the opening time of the injector nozzle can be determined be performing a threshold analysis for the residual value defined as described above.

Figure 4 schematically shows the parts of a fuel injection system of a piston engine 10 that are essential as far as the invention is concerned. The piston engine comprises an injector nozzle 12 arranged in the cylinder head 11. Fuel is transported to the injector nozzle 12 by means of a fuel channel 13. The operation of the injector nozzle is controlled by means of a solenoid 14. In this solution the solenoid is directly in connection with the fuel nozzle, but it can also operate indirectly, for example by controlling a separate control system, such as servo oil pressure. The operation of the engine as well as the fuel injection is controlled by

means of an electronic control unit 15 arranged to perform various other engine control functions as well.

Thus, as the engine runs, the control unit controls, among others, fuel injection. Simply put, this happens by connecting the operation power on and off from the solenoid 14 controlling the operation of the injector nozzle. To accomplish this, the control unit 15 is in electrical connection 16 with the solenoid 14. According to the invention, the operation of the solenoid and especially the opening of the injector nozzle of the engine are controlled so that the current flowing through the solenoid is measured at certain intervals. As the opening sequence of the injector nozzle is relatively short in duration, it is obvious that the sampling frequency of the measurement values is chosen to be suitable for the situation. It is in addition important that the determination frequency of the model and the measured value correspond to each other. When the valve has opened, the measured signal set 7 is imported through a sample counter 19 into the residual signal computing unit 23. In addition to this, information about the ordinal number 21 of the measurement is imported into the model unit 20, into which the model being used is stored. This information is sufficient, because the method uses a static measurement frequency. The model signal 6 received from the model unit 20 on the basis of the point in time of the measurement is also imported into the residual signal computing unit 23. The residual signal computing unit now performs the subtraction of the values of the model signal 6 and the measured current signal 7, whereby the result is the residual signal 8. The residual signal 8 is imported into the threshold analysis unit 25, which performs a threshold analysis for the residual signal 8 by comparing it to the predetermined limit value, which is stored in the control unit 15. The point of time 21 that includes a positive increase can be considered the initial moment of the movement of the plunger of the solenoid, given that is has taken place within a certain time. If this is not the case, the plunger has not moved despite its control signal. The threshold analysis unit produces a signal 26 for the control system 15, the signal being capable of being used in the operation of the control system 15.

The invention is not limited to the embodiments described here, but a number of modifications thereof can be conceived of within the scope of the appended claims.

Claims:

1. A method for controlling the operation of a solenoid (14), in which solenoid the movement of the plunger is caused by bringing electric energy to the solenoid, whereby an electric current flows through the solenoid, **characterized** by the following steps.

- defining a model (6) for describing the current signal of the solenoid at certain time intervals from the activation moment of the solenoid onwards,
- measuring the true current signal (7) of the solenoid at time intervals corresponding with the model,
- defining a residual signal (8), which is the remainder between the signal of the model (6) and the true current signal (7), and
- performing a threshold analysis (25) for the residual signal.

2. A method according to claim 1, **characterized** in that the time window for determining the model corresponds to the desired control time of the solenoid of the method, such as the retraction time (1).

3. A method according to claim 1, **characterized** in that the value of the current signal of the solenoid of the model changes sequentially and linearly from the zero value of the activation moment of the solenoid.

4. A method according to claim 1, **characterized** in that in the threshold analysis the value of the residual signal (8) is compared to a certain pre-determined limit value.

5. A method according to claim 1, **characterized** in that the solenoid (14) controls the operation of the injector nozzle of the engine (10) and that at least the point in time when the value of the residual signal exceeds the said limit value is forwarded further in the control unit (15) to be used in the operation control of the engine.

6. A method according to any of the preceding claims, **characterized** in that the solenoid (14) controls the operation of the injector nozzle of the engine (10) and that the method is used for determining the beginning of the opening time of the injector nozzles.

7. A fuel injection system of an internal combustion engine (10), the system comprising at least one electrically controllable injector nozzle (12), **characterized** in that it is arranged to carry out the method according to any of the preceding claims.

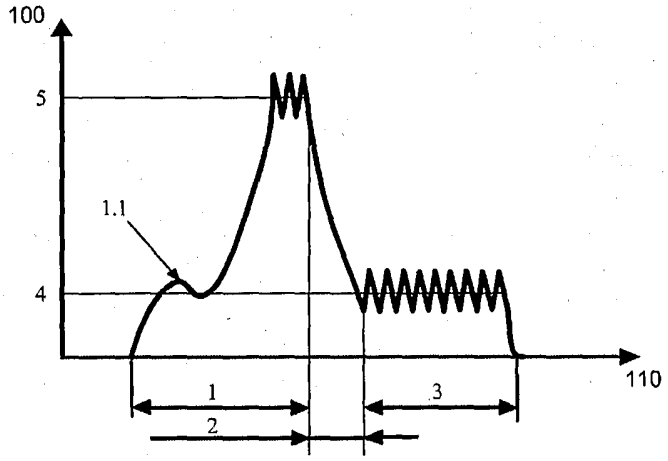

100
5
4
1.1
110
1
2
3

Fig. 1

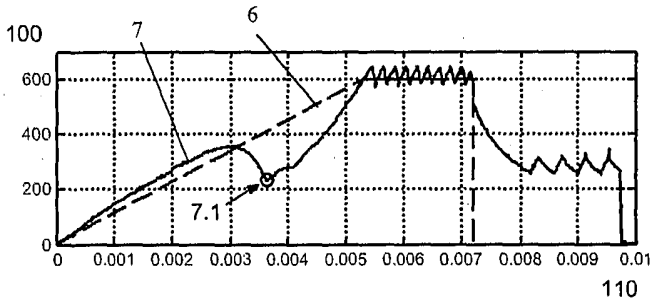

100
600
400
200
0
7
6
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0.005
0.006
0.007
0.008
0.009
0.01
110

Fig. 2

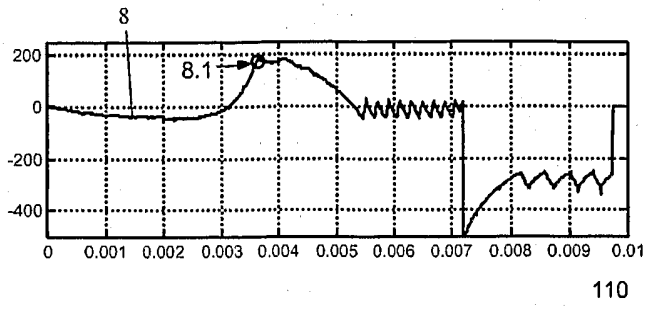

8
200
0
-200
-400
8.1
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110

Fig. 3

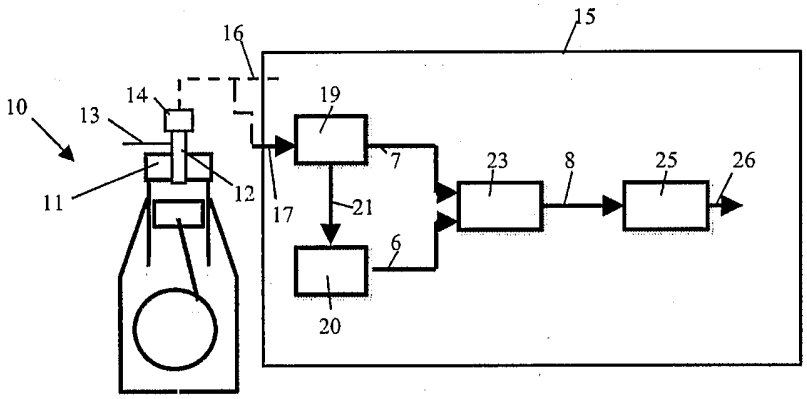

15
16
10
13
14
19
7
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25
26
11
12
17
21
6
20

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 2004/050058

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H01H 47/32, F02D 41/20
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H01H, F02D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5182517 A (ULRICH THELEN ET AL), 26 January 1993 (26.01.1993), column 2, line 25 - line 64, figure 1	1,3,6,7
X	WO 9413991 A1 (PI RESEARCH LTD.), 23 June 1994 (23.06.1994), figures 4,16	1,3,6,7
X	US 5433109 A (ANTON MAYER-DICK ET AL), 18 July 1995 (18.07.1995), column 1, line 47 - column 2, line 2	1,3,6,7

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 August 2004	09-09-2004
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Tomas Erlandsson/MN Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 2004/050058

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 3611220 A1 (KLÖCKNER, WOLFGANG, DR.), 2 January 1987 (02.01.1987), figures 1,2, abstract ---	1,3,6,7
A	US 5742467 A (GÜNTER SCHMITZ), 21 April 1998 (21.04.1998), abstract --- --------	1,3,6,7

INTERNATIONAL SEARCH REPORT

International application No.
FI2004/050058

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 1,3,6,7 (in part) 2,4,5
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

see next page

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
FI2004/050058

Box No. IV Text of the abstract (Continuation of item 5 of the first sheet)

The invention according to independent claim 1 does not include sufficient definitions to make it possible for a person skilled in the art to perform any invention. Neither does claim 1 combined with only one of the subsequent claims suffice to define any invention.

The combination of claims 1, 3 and 6 includes all necessary features for defining the invention per se. Thus, a search has been performed for a method according to claims 1, 3 and 6, as well as for a fuel injection system according to claims 1, 3, 6 and 7.

US	5182517	A	26/01/1993	DE	3942836	A,C	27/06/1991
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				SE	0438640	T3	
WO	9413991	A1	23/06/1994	GB	9225622	D	00/00/0000
US	5433109	A	18/07/1995	DE	59200861	D	00/00/0000
				EP	0573437	A,B	15/12/1993
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				WO	9215779	A	17/09/1992
DE	3611220	A1	02/01/1987	DE	3667121	D	00/00/0000
				EP	0205807	A,B	30/12/1986
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				ES	553843	A	16/02/1987
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				JP	5057403	B	24/08/1993
				JP	61250309	A	07/11/1986
				US	4823825	A	25/04/1989
US	5742467	A	21/04/1998	DE	4434684	A	04/04/1996