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Remarks:
The references to the drawing(s) no. 3 and 4 are deemed to be deleted (Rule 56(4) EPC).

(54) **Method for controlling an injection current through an injector of an internal combustion machine and fuel injection system for controlling an injection current**

(57) The invention provides a method for controlling an injection current through an injector of an internal combustion machine. The injection current is driven by a battery voltage and the injector is connected to the battery via a wiring harness. The word current is used for the electrical current and not for the flow of fuel. Electric current through the injector makes the fuel flow into the combustion chamber. The battery voltage is sensed and the wiring harness resistance is estimated before adapting the injection current according to the battery voltage and the wiring harness resistance.

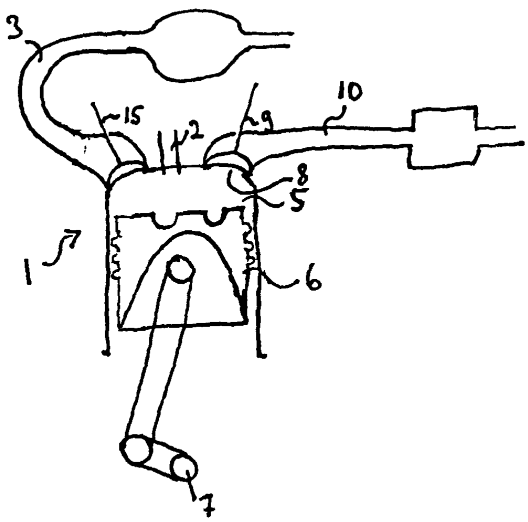

Fig.1

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Description

[0001] The invention relates to a method for controlling an injection current through an injector of an internal combustion machine and to a fuel injection system for controlling an injection current.

[0002] Electronically controlled fuel injectors can be distinguished in high voltage injectors and low voltage injectors. High voltage injectors need a boosted voltage larger than the battery voltage to ensure a reliable injection of fuel into the combustion chamber as it is shown in the US 2005/0126543 A1. However, voltage low injectors may be driven from the battery voltage of the vehicle, for example at nominal 13,5 V. It was observed that the control of the fuel is less precise than for high voltage injectors.

[0003] Hence, it is an object of the invention to provide a method for providing a precise fuel injection in a combustion chamber of an internal combustion engine and to provide a fuel injection system for generating a stable injection current.

[0004] The invention provides a method for controlling an injection current through an injector of an internal combustion machine. The injection current is driven by a battery voltage and the injector is connected to the battery via a wiring harness. The word current is used for the electric current and not for the flow of fuel that is initiated by the electric current.

[0005] The battery voltage is sensed and the wiring harness resistance is estimated before adapting the injection current according to the battery voltage and the wiring harness resistance. The injection current was observed to depend on the battery voltage and on the wiring harness resistance. Taking these parameters into account makes it possible to generate a current signal that is as precise as possible.

[0006] The usage of the low voltage injectors is critical due to the effects of battery voltage drop and wiring harness resistance on and their dependencies of the rail pressure for the delivered fuel quantity delivered. The method considers the importance of the complete management of the injection current profile peak phase to drive the low voltage injectors in right way and achieve the desired fuel quantity requirements for low voltage injectors. The precise control ensures a more precise fuel delivery and therefore lower emissions of the engine.

[0007] In an embodiment, the fuel is provided by a common rail for a plurality of injectors and the pressure in this common rail is measured to adapt of the injection current also according to the pressure in the common rail. The pressure in a common rail is usually regulated within a regulation range. A high pressure increases the volume of injected fuel and, accordingly, the current signal is also adapted according to the rail pressure to provide a complete control of the fuel quantity.

[0008] If the battery voltage in a first configuration is lower than the battery voltage in a second configuration, the injection current is started earlier in the first configuration than in the second configuration. It was observed that the voltage injection starts earlier if the battery voltage is higher. Accordingly, the injection current is corrected by adapting its start.

[0009] According to a further embodiment, the injection current signal comprises an idle phase, a pull-in phase and a hold-in phase. The idle phase is characterized in that the injection current equals an idle level A0 which is 0 A. During the subsequent pull-in phase, the current increases and reaches at least a pull-in current level A2. During the hold-in phase, following the pull-in phase, the current level equals a hold-in current level A1, whereby the following relation between A2 and A1 holds: A2 > A1 > 0.

[0010] The start of the injection current is defined as the time when the idle phase ends and the pull-in phase begins. The start of the injection current is adapted according to the battery voltage and the duration of the pull-in phase is adapted according to the rail pressure. The compensation needed for the rail pressure was found to be independent of the compensations for the battery voltage and the wiring harness such that the pressure should also be compensated independently of the other compensations. The resistance or the wiring harness was observed to be related to temperature of the wiring harness.

[0011] The wiring harness is preferably estimated by measuring a delay $t^*_{measured}$ from the start of the injection current to the time when the injected current exceeds a predetermined threshold. Then, the measured delay $t^*_{measured}$ is compared with a correlation table that comprises delays t* for a plurality of wiring harness resistances. This correction table may be generated on a test bench and be stored in the internal combustion engine during the production of the engine. The table may for example be stored in a memory of a electronic control unit (ECU) or in a separate Flash-EEPROM.

[0012] The method may be started after the cranking of the engine when the battery voltage has been stabilized.

[0013] If the estimation is performed periodically during the run time of the internal combustion engine, changes in the temperature resulting in a different wiring harness resistance are also compensated.

[0014] The invention further provides a fuel injection system for controlling an injection current through an electronically controlled fuel injector of an internal combustion engine. The fuel injection system comprises a wiring harness that connects the fuel injector with a battery voltage and a measure unit having an output for outputting a measured battery voltage. An estimation unit has an output for outputting an estimated resistance of the wiring harness. An adaptor has an output for outputting the injection current signal and adapts the injection current signal according to the outputs of the measure unit and the estimation unit. The compensation of the battery voltage drop and wiring harness resistance effects during the driving of low voltage injectors setup on a engine ensures a complete control the quantity of fuel delivered into the combustion chambers. The engine is preferable a diesel engine in which the low voltage injectors are used

[0015] If the fuel injection system further comprises a detection unit for detecting the pressure in the common rail and the adaptor adapts the injection current signal also according to the pressure in the common rail.

[0016] The adaptor adapts the start of the injection current signal according to the battery voltage and the wiring harness resistance and adapts the duration of the current according to the wiring harness resistance.

[0017] Preferably, the adaptor starts the injection current later in the case of a high battery voltage than in the case of a low battery voltage to ensure a stable injection current independently of the voltage conditions.

[0018] The invention will be further described based on the drawings showing an embodiment of the invention.

Figure 1 shows the dependency of the injection current profile from the battery voltage.

Figure 2 shows an example of the injection current profile.

Figure 3 illustrates correction factors for the injection current profile depending on the wiring harness and the battery voltage.

Figure 4 gives an overview of the compensation method for the injection current.

[0019] Exemplary waveforms of the injection current are illustrated in Figure 1 showing the injection current for eight different battery voltage conditions. The curve K_7 gives the current profile at the highest battery voltage, whereas the battery voltage decreases from curve to curve, reaching the lowest battery voltage for the curve K1. At high battery voltages, the delay between the start of the injection current and the start of the fuel quantity delivery is smaller than the respective delay for a low battery voltage. At lower voltages, for example illustrated in curve K_1, the start of the injection current is started already at t_1.

[0020] After the start of the injection current, the current increases, whereby the slope of the curves at higher battery voltages is higher than the slope of the curves of lower battery voltages. The current reaches a maximum, in case of the curve K_1, at about 16 A and, in the case of K7, at a level of more than 25 A.

[0021] After reaching the maximum, the current decreases to a hold-in current level A1, which is kept for a duration t_h. This duration t_h may vary from curve to curve. When the duration t_h has expired, the current drops to 0 A. The shown injection currents profiles are divided into three phases. The first phase is the idle phase, in which the current is zero. The idle phase is followed by the pull-in phase, which starts at the respective times t_1 to t_7. In the pull-in phase, the current is increased to a maximum. It is important to note that all curves K1 to K7 exceed a predetermined threshold pull-in current level, being labelled as A2 in Figure 1. During the third, the hold-in phase, the current is kept at a hold-in current level A1.

[0022] After the hold-in phase, the current profile returns back to the idle phase. For each fuel injection, the current profile of Figure 1 is repeated. As the fuel is injected periodically, the current profile of Figure 1 is repeated periodically, too.

[0023] The higher pull-in current exceeding the pull-in current level A2 is needed to quickly open the fuel injector. This decreases the response time, which is the time between the initiation of fuel injection current signal and the time when fuel actually begins to enter the engine cylinder. Once the fuel injection has started, a lower level hold-in current can be used to hold the injector open for the remaining injection.

[0024] The curves K1 to K7 were measured on an engine test bench. For the measurements, the battery voltages varied between 13,5 and 12 V, but the rail pressure and the wiring harness resistance were kept unchanged. The measurements show that the injection currents need to be adapted to run the internal combustion engine independently of the battery voltage conditions. To align the injection current profiles in respect to their flex points, the start of the injection needs to be corrected to maintain the desired start of the fuel delivery.

[0025] This correction works in opportune manner by starting the injection current earlier at low battery voltage conditions. The compensation of the battery voltage drop is based on a calibration table with computed correction values. These correction values are applied according to the measured battery voltage.

[0026] For example, a battery voltage is measured which would lead to the curve K_6. In the calibration table the correction value for this voltage is a time shift that equals t_6 - t_7. The pull-in phase needs to be started earlier than in the case of a battery voltage of the curve K7. Accordingly, the injection current is started t_6 - t_7 earlier.

[0027] The curve F1 to F7 show the fuel deliveries into the combustion chamber. The current injections were delayed according to the above-described method such that the fuel was delivered at the same time for all cases. Thus, the curves F1 to F7 shows basically the same course. The number of the fuel delivery curves F1 to F7 equal to the number of activating current curve K1 to K7, e.g. the fuel delivery of curve F2 was activated by the injection current according to curve

[0028] Figure 2 shows an injection current profile as in Figure 1. The time between the start of the pull- in phase and the crossing of the current with the pull-in current level A_2 is marked with t*. It should be noted that for the following method not only the pull-in current level A2, but also other current levels may be chosen.

[0029] The effect of the wiring harness has been studied by estimating the resistance value. First, the electrical characteristics of the low voltage injectors at nominal conditions, which means at nominal battery voltage and with a neglectable wiring harness, are measured.

[0030] For conditions other than the nominal one, the harness resistance value are estimated based on the measurement of the time elapsed between the start of injection current profile and the achievement of a fixed current threshold. This time is labelled as t* in Figure 2 and based on this time t* the correction factors to be applied are computed.

[0031] The application of the wiring harness compensation first requires the determination of a basic database for different wiring harness conditions. This database is based on a test in which different harness conditions were measured on a test bench. The database is then used for computing of the correction factors. The procedure to determine the basic database of correction factors is resumed by the following steps:

- Define a number of different wiring harness resistances R1, R2, ... , Rn to be connected in series to the low voltage injector.

[0032] The nominal wiring harness resistance is included in this number.

- Measure the time t* elapsed between the start of injection current profile t1, t2, ..., t7 and the achievement of the current threshold A2 at different battery voltages.

- Determine the correction factors C in terms of time for the selected wiring harness resistances as differences in respect to the nominal condition.

- Store the measurement results in terms of time t* and of the correction factor C.

[0033] At the end of this procedure, the following basic database is obtained:

$V_{Battery\ \#1}$		$V_{Battery\ \#m}$
$t^*_{R1,V1} \rightarrow C_{R1,V1}$		$t^*_{R1,Vm} \rightarrow C_{R1,Vm}$
$t^*_{R2,V1} \rightarrow C_{R2,V1}$	● ● ●	$t^*_{R2,Vm} \rightarrow C_{R2,Vm}$
...		...
$t^*_{Rn,V1} \rightarrow C_{Rn,V1}$		$t^*_{Rn,Vm} \rightarrow C_{Rn,Vm}$

$t^*_{Rx,\ Vy}$ is time elapsed between the start of injection current profile and achieving the current threshold with the wiring harness resistance Rx and battery voltage Vy condition.

[0034] $C_{Rx,\ Vy}$ is the correction factor for the wiring harness resistance Rx and battery voltage Vy condition. The correction factor comprises a delay specifying how much earlier or later the injection current has to be started in comparison to the nominal condition. In an embodiment, the delay of the injection current is in the range between +130 μs and -30 μs in relation to the nominal case, whereby the injection current starts +130 μs earlier than the nominal case for the lowest battery voltage and 30 μs later in the case of the highest battery voltage. These numbers are examples derived from several tests.

[0035] The correction factor also comprises the value describing the length of the duration of the injection current. The duration equals the sum of the length of the hold-in phase and the length of the pull-in phase. In figure 2, the duration start at the start of the time t* and ends at the time when the current reaches the zero level again. The change of the duration is in the range of [-30 μs; +130 μs] in relation to nominal conditions.

[0036] Even if the wiring harness resistance of a vehicle is unknown, the correction factor can be estimated according to the following method. Based on the stored database, the proposed method is able to determine the correction factor to be applied in any other wiring harness and battery voltage condition by the following steps:

1. Measure the time $t^*_{measured}$ elapsed between the start of the injection current and the achievement of the current threshold.
2. Measure the battery voltage $V_{measured}$.
3. Determine the relative correction factor to be applied comparing the time $t^*_{measured}$ and measured battery voltage $V_{measured}$ with time t* and V and their relative correction factors given in the basic database as shown in figure 3.

[0037] Figure 3 shows the correction factors in diagram with t* as y-axis and the battery voltage V as x-axis. The correction factors listed in the database are distributed in this t*-V-diagram. The measured values, voltage $V_{measured}$ and delay $t^*_{measured}$, are not listed in the database. However, the measured values lie between the delays t* and battery voltages V of the listed correction factors $C_{R2, Vk}$, $C_{R2, Vk+1}$, $C_{Rx-1, Vk}$ and $C_{Rx-1, Vk-1}$. The correction factors for the measured values are calculated by interpolating the correction factors of the neighbouring values $C_{R2, Vk}$, $C_{R2, Vk+1}$, $C_{Rx-1, Vk}$ and $C_{Rx-1, Vk-1}$ given in the database.
[0038] Besides the compensation of the battery voltage and the compensation of the wiring harness, the rail pressure of the common rail has an influence on the volume of injected fuel. Accordingly, deviations of the rail pressure should also be compensated.
[0039] Driving the low voltage injectors with high current is used for the opening of the needle during the pull-in phase. After this phase is not necessary to energize the injectors so much. For this reason, driving the low voltage injectors with high current is kept only for a short pull-in time based on the rail pressure measurement. After this pull-in time it is sufficient to drive the injector with a low current.
[0040] The proposed method is used in embodiment not during the cranking of the engine. In the cranking mode, the battery voltage is low and consequently the usage of the method proposed in both conditions would require to define a low current threshold (A2) which involves a low measurement resolution of the time t* elapsed between the start of injection current profile and current threshold achievement. During cranking, the most important task is to start the engine. Accordingly, the compensation is based only on the engine coolant temperature and the battery voltage.
[0041] However, at normal running of the engine, the compensation is computed with the method according to the invention.
[0042] To compensate the rail pressure, the length of the pull-in phase is changed. At high rail pressure, the duration of the pull-in phase is ceteris paribus shorter than at a low rail pressure. The rail pressure compensation is based on a calibration table, which computes the time necessary to drive the injectors with the high current as function of rail pressure.
[0043] Figure 4 gives an overview of the compensation method for the injection current. The battery voltage and the rail pressure are measured and independently compensated. The wiring harness is estimated based on the measured time t* and the battery voltage $V_{Battery}$. In one embodiment, the temperature of the engine is also taken into account because the resistance was found to highly depend also on the temperature of the wiring harness.

Claims

1. A method for controlling an injection current through an injector of an internal combustion machine, the injection current being driven by a battery voltage and the injector being connected to the battery via a wiring harness, the method comprising the following steps:

- sensing the battery voltage,
- estimating the wiring harness resistance,
- adapting the injection current according to the battery voltage and the wiring harness resistance.

2. The method according to claim 1,
further comprising the step of

- measuring the pressure in a common rail, the common rail providing fuel for a plurality of injectors, whereby the adapting of the injection current is also based on the pressure in the common rail.

3. The method according to claim 2,
wherein, if the battery voltage in a first configuration is lower than the battery voltage in a second configuration, the injection current is started earlier in the first configuration than in a second configuration.

4. The method according to one of the claims 1 to 3,
wherein the injection current signal comprises an idle phase, a pull-in phase and a hold-in phase,
wherein during the idle phase the injection current equals an idle level A0, during the pull-in phase the current

reaches at least a hold-in current level A2 and during the hold-in phase the current level equals a hold-in current level A1, whereby the following condition is met: A0 = 0, A2 > A1 > 0, wherein the pull-in phase follows the idle phase and the start (t_1, t_2, ... ,t_7) of the injection current is defined as the time when the idle phase ends and the pull-in phase begins, wherein the start (t_1, t_2, ... , t_7) of the injection current is adapted according to the battery voltage and the wiring harness resistance and wherein the duration of the hold-in phase is adapted according to the rail pressure.

5. The method according to one of the claims 1 to 4,
wherein the estimation of the wiring harness comprises the following steps:

- measuring a delay $t^*_{measured}$ from the start of the injection current to the time when the injected current exceeds a predetermined threshold (A2),
- comparing the delay $t^*_{measured}$ with a correlation table comprising delays t* for a plurality of wiring harness resistances.

6. The method according to claim 5,
wherein the correlation table is stored in the control circuit of the internal combustion engine and the comparison is performed after the start of the internal combustion engine.

7. The method according to claim 6,
wherein the comparison is performed periodically during the run time of the internal combustion engine.

8. A fuel injection system for controlling an injection current through an electronically controlled fuel injector of a internal combustion engine, comprising,

- a wiring harness connecting the fuel injector with a battery voltage,
- a measure unit having an output for outputting a measured battery voltage,
- an estimation unit having an output for outputting an estimated resistance of the wiring harness,
- and an adaptor having an output for outputting the injection current signal whereby the adaptor adapts the injection current signal according to the outputs of the measure unit and the estimation unit.

9. The fuel injection system according to claim 8, further comprising

- a detection unit for detection the pressure in the common rail, the common rail providing fuel for a plurality of injectors,

whereby the adaptor adapts the injection current signal also according to the pressure in the common rail.

10. The fuel injection system according to one of the claims 8 to 9,
wherein the adaptor adapts the start of the injection current signal according to the battery voltage and the wiring harness resistance and adapts the duration of the current is adapted according to the wiring harness resistance.

11. The fuel injection system according to claim 10,
wherein the adaptor starts the injection current later in the case of a high battery voltage than in the case of a low battery voltage.

12. The fuel injection system according to one of the claims 10 to 11,
wherein the injection current signal comprises an idle phase, a pull-in phase and a hold-in phase,
wherein during the idle phase the injection current equals an idle level A0, during the pull-in phase the current reaches at least a hold-in current level A2 and during the hold-in phase the current level equals a hold-in current level A1, whereby the following condition is met: A0 = 0, A2 > A1 > 0, wherein the pull-in phase follows the idle phase and the start (t_1, t_2, ... , t_7) of the injection current is defined as the time when the idle phase ends and the pull-in phase begins,
wherein the adaptor adapts the start of the injection according to the battery voltage and the wiring harness resistance and adapts the duration of the hold-in phase according to the pressure in the common rail.

13. The fuel injection system according to one of the claims 10 to 12,
wherein the estimation unit comprises:

- a measure unit for measuring a delay t* from the start of the injection current to the time when the injected current exceeds a predetermined threshold, and
- a comparator for comparing the delay with a correlation table comprising delays t* for a plurality of wiring harness resistances.

14. The fuel injection system according to claim 13,
wherein the correlation table is stored in an electronic control unit (ECU) of the internal combustion engine and the comparison is performed after the start of the internal combustion engine.

15. The fuel injection system according to claim 14,
wherein the comparison is performed periodically during the run time of the internal combustion engine.

16. The fuel injection system according to one of the claim 8 to 15 for a diesel internal combustion engine.

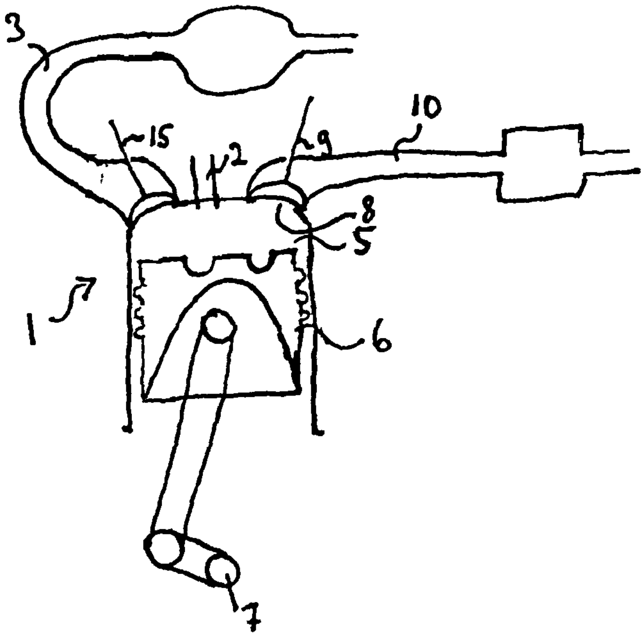

Fig.1

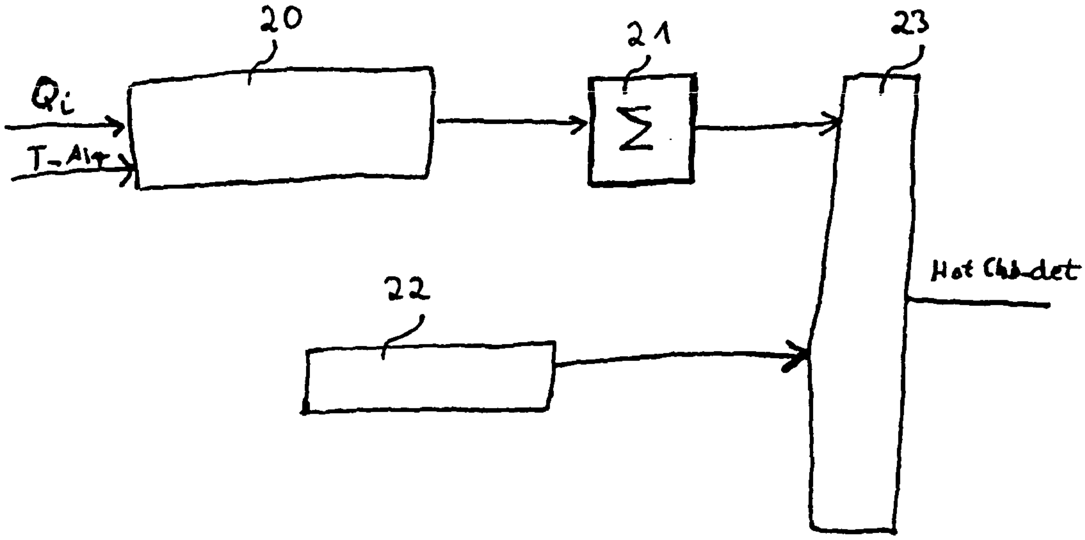

Fig. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 07 01 8760

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	4 March 2008	Libeaut, Laurent

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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2

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 07 01 8760

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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