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(72) Inventors:
• **PAROTTO, Marco**
20011 CORBETTA (MI) (IT)
• **DE CESARE, Matteo**
20011 CORBETTA (MI) (IT)
• **GUIDO, Claudio**
20011 CORBETTA (MI) (IT)

(30) Priority: **21.12.2021 IT 202100031979**

(74) Representative: **Studio Torta S.p.A.**
Via Viotti, 9
10121 Torino (IT)

(71) Applicant: **Marelli Europe S.p.A.**
20011 Corbetta (MI) (IT)

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(54) **HEATING DEVICE FOR AN EXHAUST SYSTEM OF AN INTERNAL COMBUSTION ENGINE AND RELATIVE CONTROL METHOD**

(57) A heating device (6) for an exhaust system (1) of an internal combustion engine (2). The heating device (6) has: a tubular body (12), which contains a combustion chamber (7); a fuel injector (9), which is coupled to the tubular body (12) in order to inject fuel into the combustion chamber (7), is passive, namely it lacks actuators that can be electrically controlled to generate a movement, and has a movable shutter (21), which is pressure-controlled in order to inject fuel only when the fuel pressure

inside the injector (9) is greater than a predetermined pressure threshold value; a spark plug (10), which is coupled to the tubular body (12); a supply duct (18), which is designed to connect the injector (9) to a pump (17), which is configured to supply fuel under pressure; and a shut-off solenoid valve (23), which can be electrically controlled and is arranged along the supply duct (18) between the pump (17) and the passive injector (9).

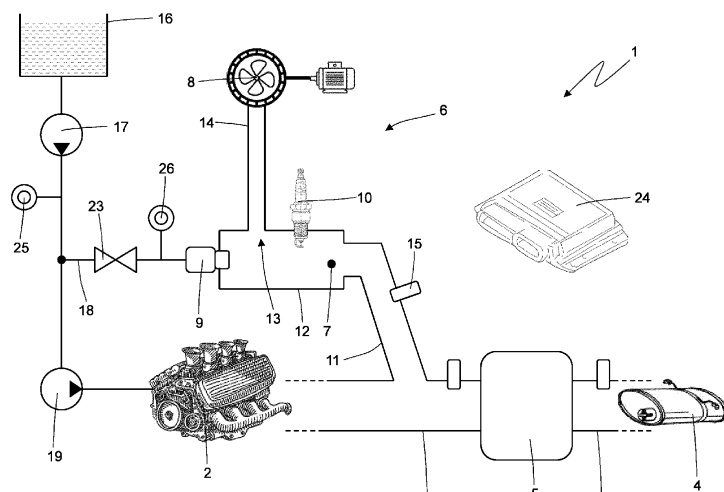


Fig. 1

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority from Italian patent application no. 102021000031979 filed on December 21, 2021, *the entire disclosure of which is incorporated herein by reference.*

TECHNICAL FIELD

[0002] The present invention relates to a heating device for an exhaust system of an internal combustion engine and to a relative control method.

PRIOR ART

[0003] An exhaust system of an internal combustion engine comprises an exhaust duct along which at least one treatment device is installed for treating exhaust gases coming from the internal combustion engine; in particular, a (oxidizing or reducing) catalyser is always provided to which a particulate filter can be added. In order to operate (i.e. in order to produce the catalytic conversion), the catalyser requires to operate at a relatively high operating temperature (a modern catalyser works at temperatures also near 800°C) since the chemical reactions for converting unburnt hydrocarbons, i.e. nitrogen oxides and carbon monoxide into carbon dioxide, water and nitrogen take place only once the working temperature has been reached.

[0004] During a cold starting step (i.e. when the internal combustion engine is started after a prolonged stop by effect of which the temperature of the various components of the internal combustion engine has reached the room temperature), the temperature of the catalyser remains for a relatively long time (also several minutes in winter and during a city route along which the internal combustion engine always or almost always runs at idle) very much below the operating temperature. Consequently, during the cold starting step, i.e. during the period of time in which the catalyser has not yet reached its operating temperature, the pollutant emissions at the outlet are high because the purification effect of the catalyser is null or anyway not very effective.

[0005] In order to quicken the reaching of the operating temperature of the catalyser, patent documents EP0631039A1, WO2012139801A1 and US8006487B2 propose to install along the exhaust duct a heating device which by burning fuel generates a (very) hot air flow which passes through the catalyser. In particular, the heating device comprises a combustion chamber which is connected at the outlet to the exhaust duct (immediately upstream of the catalyser) and is connected at the inlet to a fan which generates an air flow which passes through the combustion chamber; in the combustion chamber a fuel injector is also arranged which injects fuel that mixes with the air and a spark plug is also arranged which cy-

clically gives off sparks for igniting the air-fuel mixture so as to obtain the combustion which heats the air.

[0006] For the injection of fuel into the combustion chamber it has been proposed to use an electromagnetic injector entirely similar to the electromagnetic injectors currently used for injecting fuel into the internal combustion engines; in this manner, it is possible to use components already available on the market having proven efficiency and reliability and it is thus unnecessary to develop new components with evident saving as to costs and time.

[0007] However, the assembly in a heating device of a commercial electromagnetic injector for injecting fuel has turned out to be problematic, since the temperatures that can be reached inside the combustion chamber can be very high (also above 800-900 °C) and can produce an excessive overheating of the electromagnetic injector with a consequent destruction of the electromagnetic injector (in particular of the electric insulations of the wire constituting the coil which is the material most susceptible to heat inside an electromagnetic injector). By way of example, the temperature of the outer shell of an electromagnetic injector currently produced must not exceed 140- 150°C so as to prevent the insulation of the copper conductor which forms the coil of the electromagnet from melting, whereas the nose of an electromagnetic injector currently produced must not exceed approximately 250°C so as to prevent annealing phenomena of the steel which could alter the mechanical features thereof.

[0008] Furthermore, it should be noted that not only is it necessary to ensure a suitable thermal insulation of the electromagnetic injector from the heat produced in the combustion chamber, but it is also necessary to simultaneously ensure an effective disposal of the heat which is inevitably transmitted by conduction and radiation to the electromagnetic injector and of the heat produced by Joule effect by the coil of the electromagnet inside the electromagnetic injector.

[0009] Consequently, assembling directly inside the combustion chamber of the heating device a commercial electromagnetic injector designed for injecting fuel into an internal combustion engine is particularly complex and thus expensive due to the inevitable requirements for the thermal screening of the electromagnetic injector and for the heat dissipation from the electromagnetic injector.

[0010] Patent application CN111997715A describes a burner which lacks an outer air source and is completely arranged inside an exhaust system for heating the exhaust system.

DESCRIPTION OF THE INVENTION

[0011] The object of the present invention is to provide a heating device for an exhaust system of an internal combustion engine and a relative control method, said heating device being easy and cost-effective to manufacture.

[0012] According to the present invention a heating de-

vice for an exhaust system of an internal combustion engine and a relative control method are provided, according to what is claimed in the appended claims.

[0013] The claims describe preferred embodiments of the present invention forming integral part of the present description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The present invention will now be described with reference to the accompanying drawings, which illustrate a non-limiting example embodiment thereof, wherein:

- Figure 1 is a schematic and partial view of an exhaust system of an internal combustion engine provided with a heating device manufactured in accordance with the present invention;
- Figure 2 is a schematic side view, with parts removed for clarity, of a passive fuel injector of the heating device of Figure 1;
- Figure 3 is a schematic side view, with parts removed for clarity, of a different embodiment of the passive fuel injector of Figure 2;
- Figure 4 is a schematic side view, with parts removed for clarity, of a further embodiment of the passive fuel injector of Figure 2; and
- Figure 5 is a section according to line V-V of the passive fuel injector of Figure 4.

PREFERRED EMBODIMENTS OF THE INVENTION

[0015] In Figure 1, reference numeral 1 indicates, as a whole, an exhaust system of an internal combustion engine 2.

[0016] The exhaust system 1 comprises an exhaust duct 3 which originates from an exhaust manifold of the internal combustion engine 2 and ends with a silencer 4 from which the exhaust gases are let into the atmosphere. Along the exhaust duct 3 at least one treatment device 5 is installed for treating the exhaust gases coming from the internal combustion engine 2; in particular, a (oxidizing or reducing) catalyser is always provided to which it is possible to add a particulate filter. In order to work (i.e. in order to produce the catalytic conversion), the catalyser requires to operate at a relatively high operating temperature (a modern catalyser works at temperatures also near 800°C) since the chemical reactions for converting unburnt hydrocarbons, nitrogen oxides and carbon monoxide into carbon dioxide, water and nitrogen take place only once the working temperature has been reached.

[0017] In order to quicken the heating of the treatment device, i.e. in order to allow the treatment device 5 to reach more quickly its operating temperature, the exhaust system 1 comprises a heating device 6 which by burning fuel generates a (very) hot air flow which passes through the treatment device 5.

[0018] The heating device 6 comprises a combustion chamber 7 which is connected at the outlet to the exhaust duct 3 (immediately upstream of the treatment device 5) and is connected at the inlet to a fan 8 (i.e. to an air pump) which generates an air flow which passes through the combustion chamber 7; in the combustion chamber 7 a fuel injector 9 is also provided which injects fuel that mixes with the air and a spark plug 10 is also provided which cyclically gives off sparks for igniting the air-fuel mixture so as to obtain the combustion which heats the air. The combustion chamber 7 of the heating device 6 ends with an outlet duct 11 which engages in the exhaust duct 3 (immediately upstream of the treatment device 5).

[0019] The heating device 6 comprises a tubular body 12 (for example with a cylindrical shape and having a circular or elliptical cross-section) in which the fuel injector 9 and the spark plug 10 are assembled; through the tubular body 12 (at least) an inlet opening 13 is obtained which is connected to the fan 8 by means of an inlet duct 14 for receiving an air flow which is directed into the combustion chamber 7 and is mixed with the fuel injected by the fuel injector 9.

[0020] According to a possible embodiment illustrated in Figure 1, the heating device 6 comprises a temperature sensor 15 which is arranged along the outlet duct 11 for measuring the temperature of the hot air that flows through the outlet duct 11; alternatively, the temperature sensor 15 could be arranged along the exhaust duct 3 downstream of the engaging point of the outlet duct 11 (and upstream of the treatment device 5) for measuring the temperature of the mixture of exhaust gas and hot air that flows through the exhaust duct 3.

[0021] The heating device 6 comprises a tank 16 containing the fuel and a low-pressure pump 17 which draws from the tank 16 for supplying the fuel under pressure towards the fuel injector 9 through a supply duct 18. According to a preferred embodiment, the tank 16 is not exclusively dedicated to the heating device 6 but is (mainly) dedicated to the internal combustion engine 2; i.e. the heating device 6 uses for its operation a (small) part of the fuel contained in the tank 16 and destined to the operation of the internal combustion engine 2. Consequently, also a high-pressure pump 19 is provided which receives the fuel from the low-pressure pump 17 and supplies the fuel to a fuel injection system of the internal combustion engine 2.

[0022] The fuel injector 9 is designed to inject the atomized fuel into the combustion chamber 7 and is fixed to a bottom wall of the tubular body 12. Furthermore, the fuel injector 9 is of passive type, i.e. it totally lacks actuators that can be controlled and capable of generating movement and is controlled only under pressure: when the pressure of the fuel entering the fuel injector 9 is smaller than a predetermined pressure threshold value the fuel injector 9 remains closed, whereas when the pressure of the fuel entering the fuel injector 9 is greater than the pressure threshold value the fuel injector 9 opens spontaneously exploiting the hydraulic thrust generated

by the fuel under pressure.

[0023] According to what is illustrated in Figures 2-5, the fuel injector 9 is of passive type, i.e. lacks actuators that can be controlled, and comprises an injection nozzle 20 (provided with a mechanical atomizer), through which the fuel is injected and atomized inside the combustion chamber 7. Furthermore, the passive fuel injector 9 comprises a shutter 21 assembled movable so as to move between a closing position, in which the shutter 21 prevents fuel from flowing through the injection nozzle 20, and an opening position, in which the shutter 21 allows fuel to flow through the injection nozzle 20. Finally, the passive fuel injector 9 comprises an elastic body 22 which presses against the shutter 21 in order to hold the shutter 21 in its closing position with a predetermined force. The passive fuel injector 9 is manufactured so that the pressure of the fuel present inside the passive fuel injector 9 tends to press the shutter 21 in the opening position against the action of the elastic body 22. Consequently, when the pressure of the fuel is sufficiently high (i.e. greater than the pressure threshold value) it manages to overcome the elastic force generated by the elastic body 22 and thus moves the shutter 21 in the opening position; similarly, when the pressure of the fuel decreases (i.e. goes below the pressure threshold value) the elastic force generated by the elastic body 22 prevails and thus the shutter 21 is pressed in the closing position.

[0024] In other words, the passive fuel injector 9 is pressure-controlled, since when the pressure of the fuel supplied to the passive fuel injector 9 is greater than the pressure threshold value, the passive fuel injector 9 carries out the injection of fuel into the combustion chamber 7, whereas when the pressure of the fuel supplied to the passive fuel injector 9 is smaller than the pressure threshold value, the passive fuel injector 9 does not carry out the injection of fuel into the combustion chamber 7.

[0025] Being the passive fuel injector 9 of passive type, i.e. lacking actuators that can be controlled and in particular lacking electric conductors insulated with plastic materials or the like, the passive fuel injector 9 is only made of metal components (in particular steels) which are particularly resistant to heat and can bear particularly high temperatures (also above 250°-300° C) without damage. Furthermore, being the fuel injector 9 of passive type, i.e. lacking actuators that can be controlled, inside the passive fuel injector 9 there is no heat generation and thus it is not necessary to provide for any disposal of the heat generated inside the passive fuel injector 9. Finally, the internal structure of the passive fuel injector 9 is simple and only composed of mechanical pieces having a relatively large dimension (unlike a traditional electromagnetic injector) which can tolerate without any problems an also very high heating; in this manner, the passive fuel injector 9 is capable of tolerating particularly high temperatures (also above 250°-300° C).

[0026] According to what is illustrated in Figure 1, the heating device 6 further comprises a shut-off solenoid valve 23, which can be electrically controlled and is ar-

ranged along the supply duct 18 between the low-pressure pump 17 and the passive fuel injector 9; in use, the shut-off solenoid valve 23 is controlled in order to control the supply of fuel under pressure from the low-pressure pump 17 to the passive fuel injector 9 and thus to control when to carry out the injection of fuel into the combustion chamber 7. The shut-off solenoid valve 23 is arranged at a suitable distance from the passive fuel injector 9 (and thus from the combustion chamber 7 and from the exhaust duct 3) so as to be naturally screened from the heat present in the exhaust duct 3 and in the combustion chamber 7 and thus so as not to be subject to an excessive heating by effect of the heat present in the exhaust duct 3 and in the combustion chamber 7.

[0027] The heating device 6 comprises a control unit 24 (schematically illustrated in Figure 1) which is configured to control the entire operation of the heating device 6, i.e. to control the fan 8, the injector 9 (through the shut-off solenoid valve 23), and the spark plug 10 in a coordinated manner in order to reach in the most efficient and effective manner possible the target objective (i.e. to quickly heat the treatment device 5 without damaging due to excess of temperature the treatment device 5 and minimizing the production of pollutant substances). The control unit 24 could exploit the reading of the temperature sensor 15 in order to control (possibly in feedback) the combustion in the combustion chamber 7 so as to quickly heat the treatment device 5 without damaging due to excess of temperature the treatment device 5.

[0028] The control unit 24 is also connected to a pressure sensor 25 which measures the fuel pressure P along the supply duct 18 downstream of the low-pressure pump 17 and upstream of the shut-off solenoid valve 23 (i.e. between the low-pressure pump 17 and the shut-off solenoid valve 23). The pressure sensor 25 is generally already present since it is an essential component of the supply system of the fuel to the internal combustion engine 2. The control unit 24 could also be connected to a pressure sensor 26 (in addition to the pressure sensor 25) which measures the fuel pressure P along the supply duct 18 downstream of the shut-off solenoid valve 23 and upstream of the passive fuel injector 9 (i.e. between the shut-off solenoid valve 23 and the passive fuel injector 9); the pressure sensor 26 is exclusively dedicated to the heating device 6 and could thus not be present so as to reduce the costs of the heating device 6.

[0029] In use, the control unit 24 receives (for example through a BUS of the vehicle in which the exhaust system 1 is installed) the request to carry out a use cycle of the heating device 6 for pre-heating the treatment device 5.

[0030] During the use cycle of the heating device 6, the control unit 24 actuates the fan 8 for supplying air into the combustion chamber 7, actuates the solenoid valve 23 which activates (opens) the passive fuel injector 9 so as to inject fuel into the combustion chamber 7, and cyclically activates the spark plug 10 so as to give off sparks which determine the hitting of the air-fuel mixture present in the combustion chamber 7. In particular, the

control unit 24 establishes a target air flow rate which has to be supplied by the fan 8, establishes a target mixture ratio (i.e. a ratio between air and fuel), and determines a target fuel flow rate depending on the target air flow rate and on the target mixture ratio (and thus controls the solenoid valve 23 which activates the passive fuel injector 9 so as to inject the target fuel flow rate).

[0031] Depending on the target fuel flow rate and depending on the fuel pressure P in the supply duct 18 (measured by the pressure sensor 25), the control unit 24 generally determines the target duty cycle of the passive fuel injector 9 (i.e. of the shut-off solenoid valve 23 which controls the passive fuel injector 9), i.e. the control unit 24 determines the fraction of time for which the passive fuel injector 9 has to remain open in proportion to the total time considered. Therefore, the control unit 24 actuates the target duty cycle controlling the shut-off solenoid valve 23 by means of a Pulse Width Modulation (PWM).

[0032] The control in Pulse Width Modulation of the shut-off solenoid valve 23 (which provides for a cyclic opening and closing of the shut-off solenoid valve 23) is preferable when the internal combustion engine 2 is running and thus the low-pressure pump 17 has to be controlled in order to satisfy (also and especially) the needs of the internal combustion engine 2; by way of example, the control frequency F of the shut-off solenoid valve 23 could be comprised between 50 and 150 Hz and the opening time of the shut-off solenoid valve 23 at each period could be comprised between 2 and 20 ms. Whereas, when the internal combustion engine 2 is not running, the low-pressure pump 17 is used only by the heating device 6 and thus it is simpler to keep the shut-off solenoid valve 23 always open varying the fuel pressure P in the supply duct 18 acting on the control of the low-pressure pump 17.

[0033] In other words, when the internal combustion engine 2 is running, the fuel pressure P in the supply duct 18 is at least in part set by the internal combustion engine 2 and thus the target fuel flow rate of the passive fuel injector 9 is preferably obtained by modulating the opening and the closing of the shut-off solenoid valve 23; instead, when the internal combustion engine 2 is not running, it is also possible to obtain the target fuel flow rate of the passive fuel injector 9 by keeping the shut-off solenoid valve 23 always open and by modulating (acting on the low pressure pump 17) the fuel pressure P in the supply duct 18. By way of example, when the internal combustion engine 2 is running, the fuel pressure P in the supply duct 18 can vary between 4 and 7 bar (in order to prevent malfunctions of the high-pressure pump 19) whereas when the internal combustion engine 2 is not running, the fuel pressure P in the supply duct 18 can change between 2 and 7 bar.

[0034] In use, the control unit 24 can use the reading of the fuel pressure P along the supply duct 18 (upstream of the shut-off solenoid valve 23 and thus read by the pressure sensor 25 or downstream of the shut-off sole-

noid valve 23 and thus read by the pressure sensor 26) in order to determine (diagnose) a possible malfunction of the shut-off solenoid valve 23 and/or of the passive fuel injector 9. Obviously, a malfunction of the shut-off solenoid valve 23 is more likely as it is an active component (i.e. provided with an electric actuator which produces a movement) with respect to a malfunction of the passive fuel injector 9 as it is a passive component and thus with many less parts which can be subject to breakdowns (however, also the passive fuel injector 9 can break or get stuck and thus its malfunction, although less likely, is not anyway totally excluded a priori).

[0035] The control unit 24 uses the fuel pressure P measured by the pressure sensor 25 or 26 for carrying out a diagnosis of the correct operation of the shut-off solenoid valve 23 and of the passive fuel injector 9 (which in the absence of malfunctions follows with a small time delay the corresponding opening/closing of the shut-off solenoid valve 23). In particular, when the shut-off solenoid valve 23 and the passive fuel injector 9 open/close regularly with a certain control frequency F (as said in the foregoing comprised between 50 and 150 Hz), they generate an oscillation in the fuel pressure P measured by the pressure sensor 25 or 26 and such oscillation can be searched by the control unit 24 as proof of the regular opening/closing of the shut-off solenoid valve 23 and of the passive fuel injector 9.

[0036] In other words, when the shut-off solenoid valve 23 is controlled to open (consequently causing the opening of the passive fuel injector 9) the fuel pressure between the shut-off solenoid valve 23 and the passive fuel injector 9 has to change if the shut-off solenoid valve 23 and the passive fuel injector 9 open in sequence and subsequently close in sequence (first the shut-off solenoid valve 23 opens and closes and then with a small time delay the passive fuel injector 9 opens and closes); therefore, by observing the fuel pressure P read by the pressure sensor 25 or 26 it is possible to realize if such fuel pressure P has oscillations at the control frequency F of the shut-off solenoid valve 23.

[0037] The diagnosis of the operation of the assembly composed of the shut-off solenoid valve 23 and of the passive fuel injector 9 is simpler by using the reading of the fuel pressure P along the supply duct 18 downstream of the shut-off solenoid valve 23 and thus carried out by the pressure sensor 26, since the oscillation at the control frequency F in the fuel pressure P measured by the pressure sensor 26 is greater (more evident) than the oscillation in the fuel pressure P measured by the pressure sensor 25; in fact, the fuel pressure P measured by the pressure sensor 26 is directly and essentially influenced by the openings of the shut-off solenoid valve 23 and of the fuel injector 9 whereas the fuel pressure P measured by the pressure sensor 25 is significantly influenced also by the actuations of the high pressure pump 19.

[0038] According to a preferred embodiment, the control unit 24 analyses the harmonic content of the fuel pressure P read by the pressure sensor 25 or 26 and thus

carries out an FFT (Fast Fourier Transform) or another type of transformation (for example a DFT - Discrete Fourier Transform) for determining the harmonic content of the fuel pressure P read by the pressure sensor 25 or 26. In particular, the control unit 24 determines the amplitude A of the harmonic content of the fuel pressure P (read by the pressure sensor 25 or 26) at the control frequency F of the shut-off solenoid valve 23 and compares such amplitude A of the harmonic component with thresholds TH1 and TH2 (the threshold TH2 is smaller than the threshold TH1).

[0039] When the amplitude A of the harmonic component of the fuel pressure P (read by the pressure sensor 25 or 26) at the control frequency F of the shut-off solenoid valve 23 is greater than the threshold TH1, the control unit 24 establishes that the shut-off solenoid valve 23 and the passive fuel injector 9 open/close regularly.

[0040] When the amplitude A of the harmonic component of the fuel pressure P (read by the pressure sensor 25 or 26) at the control frequency F of the shut-off solenoid valve 23 is smaller than the first threshold TH1 but greater than the threshold TH2 (i.e. when the amplitude A of the harmonic component is comprised between the two thresholds TH1 and TH2), the control unit 24 establishes that the shut-off solenoid valve 23 opens/closes regularly, whereas the passive fuel injector 9 is stuck in a closing position.

[0041] When the amplitude A of the harmonic component of the fuel pressure P (read by the pressure sensor 25 or 26) at the control frequency F of the shut-off solenoid valve 23 is greater than the threshold TH2 (and thus also at the threshold TH1 which is greater than the threshold TH2), the control unit 24 establishes that the shut-off solenoid valve 23 is stuck in an opening position or in a closing position. From the analysis of the harmonic content of the fuel pressure P read by the pressure sensor 25 or 26 it is not possible to distinguish the cases in which the shut-off solenoid valve 23 remains stuck open from the cases in which the shut-off solenoid valve 23 remains stuck closed; in the case in which the problem is of electric nature, a distinction could be made through electric tests (for example a check of the continuity or of the short circuit of the electric circuit of a control coil of the shut-off solenoid valve 23).

[0042] From the analysis of the harmonic content of the fuel pressure P read by the pressure sensor 25 or 26 it is not possible to diagnose the case of the passive fuel injector 9 stuck in an opening position and it is not possible to diagnose the presence of a fuel loss along the supply duct 18.

[0043] Instead, the case of the passive fuel injector 9 stuck in an opening position and the presence of a fuel loss along the supply duct 18 can be diagnosed by the control unit 24 by observing the fuel pressure P read by the pressure sensor 26 when the shut-off solenoid valve 23 is closed: in this situation and in the absence of problems, the fuel pressure P read by the pressure sensor 26 should remain approximately constant (since the hy-

draulic system should be sealed and thus totally static). If, when the shut-off solenoid valve 23 is closed, the fuel pressure P read by the pressure sensor 26 goes below a threshold TH3, the control unit 24 diagnoses the presence of a (undesired) fuel loss which can be due to the presence of a fuel loss along the supply duct 18 or to the fact that the passive fuel injector 9 is stuck in an opening position. Generally, the threshold TH3 (for example 1.5 bars) is less than half of a typical working pressure value (for example 3-5 bars).

[0044] Alternatively or additionally, the control unit 24 could consider not the fuel pressure P read by the pressure sensor 26, but the gradient (i.e. the derivative first in time) of the fuel pressure P read by the pressure sensor 26: if, when the shut-off solenoid valve 23 is closed, the gradient (i.e. the first derivative in time) of the fuel pressure P read by the pressure sensor 26 is greater (in absolute value) than a threshold TH4, then the control unit 24 diagnoses the presence of a (undesired) fuel loss which can be due to the presence of a fuel loss along the supply duct 18 or to the fact that the passive fuel injector 9 is stuck in an opening position.

[0045] In any case, it is not possible to discriminate between the case in which a fuel loss is present along the supply duct 18 and the case in which the passive fuel injector 9 is stuck in an opening position.

[0046] According to a possible embodiment, the control frequency F of the shut-off solenoid valve 23 and the physical features of the supply duct 18 (length and diameter) could be chosen (dimensioned) so as to trigger hydraulic resonance phenomena when the shut-off solenoid valve 23 and the passive fuel injector 9 cyclically open and close so as to amplify (i.e. make more easily identifiable) the alteration in the harmonic content of the fuel pressure read by the pressure sensor 25 caused by the cyclic opening of the shut-off solenoid valve 23 and of the passive fuel injector 9. In other words, the physical characteristics of the supply duct 18 are chosen (dimensioned) so that it has its own resonance frequencies that are substantially equal to the control frequency F of the shut-off solenoid valve 23.

[0047] It is important to highlight that the fuel contained in the tank 16 and which is thus used both by the internal combustion engine 2, and by the heating device 6 can be liquid (petrol, diesel, ethanol...) or also gaseous (LPG, methane, hydrogen...) .

[0048] The embodiments described herein can be combined to one another without departing from the scope of protection of the present invention.

[0049] The above-described heating device 6 has numerous advantages.

[0050] Firstly, the above-described heating device 6 is simple and cost-effective to manufacture as regards the component destined to provide the injection of fuel into the combustion chamber 7. In fact, the passive fuel injector 9 is, by its nature, capable of bearing high temperatures and does not generate inside it any heat and thus it does not require neither a particular thermal insulation

from the combustion chamber 7, nor a heat dissipation; furthermore, the shut-off solenoid valve 23 (much more sensible to the heat of the passive fuel injector 9) is arranged at a suitable distance from the combustion chamber 7 and thus does not require any particular thermal protection requirements.

[0051] Furthermore, the above-described heating device 6 allows carrying out a diagnosis, which is effective (i.e. without false negatives) and efficient (i.e. without false positives), of the correct functioning of the injection of fuel inside the combustion chamber 7 also using only the reading of the pressure sensor 25 which is already present (i.e. is not added in combination with the heating device 6) since it is necessary for the correct functioning of the injection plant of the fuel into the internal combustion engine 2.

LIST OF THE REFERENCE NUMERAL OF THE FIGURES

[0052]

- | | | |
|----|----------------------------|--|
| 1 | exhaust system | |
| 2 | internal combustion engine | |
| 3 | exhaust duct | |
| 4 | silencer | |
| 5 | treatment device | |
| 6 | heating device | |
| 7 | combustion chamber | |
| 8 | fan | |
| 9 | fuel injector | |
| 10 | spark plug | |
| 11 | outlet duct | |
| 12 | tubular body | |
| 13 | inlet opening | |
| 14 | inlet duct | |
| 15 | temperature sensor | |
| 16 | tank | |
| 17 | low pressure pump | |
| 18 | supply duct | |
| 19 | high pressure pump | |
| 20 | injection nozzle | |
| 21 | shutter | |
| 22 | elastic body | |
| 23 | shut-off solenoid valve | |
| 24 | control unit | |
| 25 | pressure sensor | |
| 26 | pressure sensor | |

Claims

1. A heating device (6) for an exhaust system (1) of an internal combustion engine (2); the heating device (6) comprises:
- a tubular body (12), which contains a combustion chamber (7) ;

a fuel injector (9), which is coupled to the tubular body (12) in order to inject, into the combustion chamber (7), fuel to be mixed with air, is passive, namely it lacks actuators that can be electrically controlled to generate a movement, and has a movable shutter (21), which is pressure-controlled in order to inject fuel only when the fuel pressure inside the injector (9) is greater than a predetermined pressure threshold value;

a supply duct (18), which is designed to connect the injector (9) to a pump (17), which is configured to supply fuel under pressure;

a shut-off solenoid valve (23), which can be electrically controlled and is arranged along the supply duct (18) between the pump (17) and the passive injector (9);

a control unit (24) configured to electrically control the opening and the closing of the shut-off solenoid valve (23), thus consequently determining the opening and the closing of the passive injector (9); and

a spark plug (10) is coupled to the tubular body (12) so as to trigger the combustion of a mixture of air and fuel;

the heating device (6) is **characterized in that:**

the tubular body (12) has at least one inlet opening (13), which can be connected to a fan (8) in order to receive an air flow;

it is provided at least one pressure sensor (25, 26) arranged along the supply duct (18) upstream of the passive injector (9); and

the control unit (24) is configured to diagnose the correct operation of the shut-off solenoid valve (23) and/or of the passive injector (9) depending on a fuel pressure (P) in the supply duct (18) read by the pressure sensor (25, 26) .

2. The heating device (6) according to claim 1, wherein the control unit (24) is configured to obtain a target fuel flow rate through the passive injector (9) by controlling the shut-off solenoid valve (23) by means of a cyclic opening and closing and by applying a pulse width modulation.
3. The heating device (6) according to claim 1, wherein the control unit (24) is configured to obtain a target fuel flow rate through the passive injector (9) by keeping the shut-off solenoid valve (23) always open and by controlling the pump (17) so as to change a fuel pressure in the supply duct (18).
4. The heating device (6) according to claim 1, 2 or 3, wherein the pressure sensor (25) is arranged along the supply duct (18) upstream of the shut-off solenoid valve (23).

5. The heating device (6) according to claim 1, 2 or 3, wherein the pressure sensor (26) is arranged along the supply duct (18) between the shut-off solenoid valve (23) and the passive injector (9).

6. The heating device (6) according to one of the claims from 1 to 5, wherein the control unit (24) is configured to:

control the shut-off solenoid valve (23) so as to cyclically open and close the shut-off solenoid valve (23) with a predetermined control frequency (F);

analyse a harmonic content of the fuel pressure (P) read by the pressure sensor (25, 26) in order to determine an amplitude (A) of the harmonic component of the fuel pressure (P) at the control frequency (F) of the shut-off solenoid valve (23); and

compare the amplitude (A) of the harmonic component with at least one threshold (TH1, TH2).

7. The heating device (6) according to claim 6, wherein, when the amplitude (A) of the harmonic component is greater than a first threshold (TH1), the control unit (24) establishes that the shut-off solenoid valve (23) and the passive fuel injector (9) open and close regularly.

8. The heating device (6) according to claim 7, wherein:

when the amplitude (A) of the harmonic component is smaller than the first threshold (TH1) and greater than a second threshold (TH2), the control unit (24) establishes that the shut-off solenoid valve (23) opens/closes regularly, whereas the passive fuel injector (9) is stuck in a closing position; and

when the amplitude (A) of the harmonic component is smaller than the second threshold (TH2), the control unit (24) establishes that the shut-off solenoid valve (23) is stuck in an opening position or in a closing position.

9. The heating device (6) according to claim 6, 7 or 8, wherein a control frequency (F) of the shut-off solenoid valve (23) and the physical features of the supply duct (18) are chosen so as to favour hydraulic resonance phenomena when the shut-off solenoid valve (23) and the passive injector (9) cyclically open and close at the control frequency (F).

10. The heating device (6) according to one of the claims from 1 to 9, wherein the control unit (24) is configured to establish that the passive fuel injector (9) is stuck in an opening position or there is a fuel leak along the supply duct (18), if the fuel pressure (P) read by the pressure sensor (26) arranged downstream of

the shut-off solenoid valve (23) decreases when the shut-off solenoid valve (23) is closed.

11. A method to control the heating device (6) according to one of the claims from 1 to 10; the control method comprises the steps of:

measuring a fuel pressure (P) in the supply duct (18) by means of a pressure sensor (25, 26); and diagnosing the correct operation of the shut-off solenoid valve (23) and/or of the passive fuel injector (9) depending on the fuel pressure read by the pressure sensor (25, 26).

12. The control method according to claim 11 and comprising the steps of:

controlling the shut-off solenoid valve (23) so as to cyclically open and close the shut-off solenoid valve (23) with a predetermined control frequency (F);

analysing a harmonic content of the fuel pressure (P) read by the pressure sensor (25, 26) in order to determine an amplitude (A) of the harmonic component of the fuel pressure (P) at the control frequency (F) of the shut-off solenoid valve (23); and

comparing the amplitude (A) of the harmonic component with thresholds (TH1, TH2).

13. The control method according to claim 12 and comprising the further step of establishing that the shut-off solenoid valve (23) and the passive fuel injector (9) open/close regularly, when the amplitude (A) of the harmonic component is greater than a first threshold (TH1).

14. The control method according to claim 13 and comprising the further steps of:

establishing that the shut-off solenoid valve (23) opens/closes regularly, whereas the passive fuel injector (9) is stuck in a closing position, when the amplitude (A) of the harmonic component is smaller than the first threshold (TH1) and greater than a second threshold (TH2); and establishing that the shut-off solenoid valve (23) is stuck in an opening position or in a closing position, when the amplitude (A) of the harmonic component is smaller than the second threshold (TH2).

15. The control method according to claim 12, 13 or 14, wherein a control frequency (F) of the shut-off solenoid valve (23) and the physical features of the supply duct (18) are chosen so as to favour hydraulic resonance phenomena when the shut-off solenoid valve (23) and the passive injector (9) cyclically open

and close at the control frequency (F).

16. The control method according to one of the claims from 11 to 15 and comprising the further step of establishing that the passive fuel injector (9) is stuck in an opening position or there is a fuel leak along the supply duct (18), if the fuel pressure (P) read by the pressure sensor (26) arranged downstream of the shut-off solenoid valve (23) decreases when the shut-off solenoid valve (23) is closed.

Amended claims in accordance with Rule 137(2) EPC.

1. A heating device (6) for an exhaust system (1) of an internal combustion engine (2); the heating device (6) comprises:

a tubular body (12), which contains a combustion chamber (7) ending with an outlet duct (11) configured to engage in an exhaust duct (3) of the exhaust system (1) upstream of a treatment device (5);

a fuel injector (9), which is coupled to the tubular body (12) in order to inject, into the combustion chamber (7), fuel to be mixed with air, is passive, namely it lacks actuators that can be electrically controlled to generate a movement, and has a movable shutter (21), which is pressure-controlled in order to inject fuel only when the fuel pressure inside the injector (9) is greater than a predetermined pressure threshold value;

a supply duct (18), which is designed to connect the injector (9) to a pump (17), which is configured to supply fuel under pressure;

a shut-off solenoid valve (23), which can be electrically controlled and is arranged along the supply duct (18) between the pump (17) and the passive injector (9);

a control unit (24) configured to electrically control the opening and the closing of the shut-off solenoid valve (23), thus consequently determining the opening and the closing of the passive injector (9); and

a spark plug (10) coupled to the tubular body (12) so as to trigger the combustion of a mixture of air and fuel;

the heating device (6) is **characterized in that:**

the tubular body (12) has at least one inlet opening (13), which can be connected to a fan (8) in order to receive an air flow;

it is provided at least one pressure sensor (25, 26) arranged along the supply duct (18) upstream of the passive injector (9); and the control unit (24) is configured to diagnose the correct operation of the shut-off

solenoid valve (23) and/or of the passive injector (9) depending on a fuel pressure (P) in the supply duct (18) read by the pressure sensor (25, 26) .

2. The heating device (6) according to claim 1, wherein the control unit (24) is configured to obtain a target fuel flow rate through the passive injector (9) by controlling the shut-off solenoid valve (23) by means of a cyclic opening and closing and by applying a pulse width modulation.

3. The heating device (6) according to claim 1, wherein the control unit (24) is configured to obtain a target fuel flow rate through the passive injector (9) by keeping the shut-off solenoid valve (23) always open and by controlling the pump (17) so as to change a fuel pressure in the supply duct (18).

4. The heating device (6) according to claim 1, 2 or 3, wherein the pressure sensor (25) is arranged along the supply duct (18) upstream of the shut-off solenoid valve (23).

5. The heating device (6) according to claim 1, 2 or 3, wherein the pressure sensor (26) is arranged along the supply duct (18) between the shut-off solenoid valve (23) and the passive injector (9).

6. The heating device (6) according to one of the claims from 1 to 5, wherein the control unit (24) is configured to:

control the shut-off solenoid valve (23) so as to cyclically open and close the shut-off solenoid valve (23) with a predetermined control frequency (F);

analyse a harmonic content of the fuel pressure (P) read by the pressure sensor (25, 26) in order to determine an amplitude (A) of the harmonic component of the fuel pressure (P) at the control frequency (F) of the shut-off solenoid valve (23); and

compare the amplitude (A) of the harmonic component with at least one threshold (TH1, TH2).

7. The heating device (6) according to claim 6, wherein, when the amplitude (A) of the harmonic component is greater than a first threshold (TH1), the control unit (24) establishes that the shut-off solenoid valve (23) and the passive fuel injector (9) open and close regularly.

8. The heating device (6) according to claim 7, wherein:

when the amplitude (A) of the harmonic component is smaller than the first threshold (TH1) and greater than a second threshold (TH2), the con-

- control unit (24) establishes that the shut-off solenoid valve (23) opens/closes regularly, whereas the passive fuel injector (9) is stuck in a closing position; and
when the amplitude (A) of the harmonic component is smaller than the second threshold (TH2), the control unit (24) establishes that the shut-off solenoid valve (23) is stuck in an opening position or in a closing position.
9. The heating device (6) according to claim 6, 7 or 8, wherein a control frequency (F) of the shut-off solenoid valve (23) and the physical features of the supply duct (18) are chosen so as to favour hydraulic resonance phenomena when the shut-off solenoid valve (23) and the passive injector (9) cyclically open and close at the control frequency (F).
10. The heating device (6) according to one of the claims from 1 to 9, wherein the control unit (24) is configured to establish that the passive fuel injector (9) is stuck in an opening position or there is a fuel leak along the supply duct (18), if the fuel pressure (P) read by the pressure sensor (26) arranged downstream of the shut-off solenoid valve (23) decreases when the shut-off solenoid valve (23) is closed.
11. A method to control the heating device (6) according to one of the claims from 1 to 10; the control method comprises the steps of:
- measuring a fuel pressure (P) in the supply duct (18) by means of a pressure sensor (25, 26); and
diagnosing the correct operation of the shut-off solenoid valve (23) and/or of the passive fuel injector (9) depending on the fuel pressure read by the pressure sensor (25, 26).
12. The control method according to claim 11 and comprising the steps of:
- controlling the shut-off solenoid valve (23) so as to cyclically open and close the shut-off solenoid valve (23) with a predetermined control frequency (F);
analysing a harmonic content of the fuel pressure (P) read by the pressure sensor (25, 26) in order to determine an amplitude (A) of the harmonic component of the fuel pressure (P) at the control frequency (F) of the shut-off solenoid valve (23); and
comparing the amplitude (A) of the harmonic component with thresholds (TH1, TH2).
13. The control method according to claim 12 and comprising the further step of establishing that the shut-off solenoid valve (23) and the passive fuel injector (9) open/close regularly, when the amplitude (A) of the harmonic component is greater than a first threshold (TH1).
14. The control method according to claim 13 and comprising the further steps of:
- establishing that the shut-off solenoid valve (23) opens/closes regularly, whereas the passive fuel injector (9) is stuck in a closing position, when the amplitude (A) of the harmonic component is smaller than the first threshold (TH1) and greater than a second threshold (TH2); and
establishing that the shut-off solenoid valve (23) is stuck in an opening position or in a closing position, when the amplitude (A) of the harmonic component is smaller than the second threshold (TH2).
15. The control method according to claim 12, 13 or 14, wherein a control frequency (F) of the shut-off solenoid valve (23) and the physical features of the supply duct (18) are chosen so as to favour hydraulic resonance phenomena when the shut-off solenoid valve (23) and the passive injector (9) cyclically open and close at the control frequency (F).
16. The control method according to one of the claims from 11 to 15 and comprising the further step of establishing that the passive fuel injector (9) is stuck in an opening position or there is a fuel leak along the supply duct (18), if the fuel pressure (P) read by the pressure sensor (26) arranged downstream of the shut-off solenoid valve (23) decreases when the shut-off solenoid valve (23) is closed.

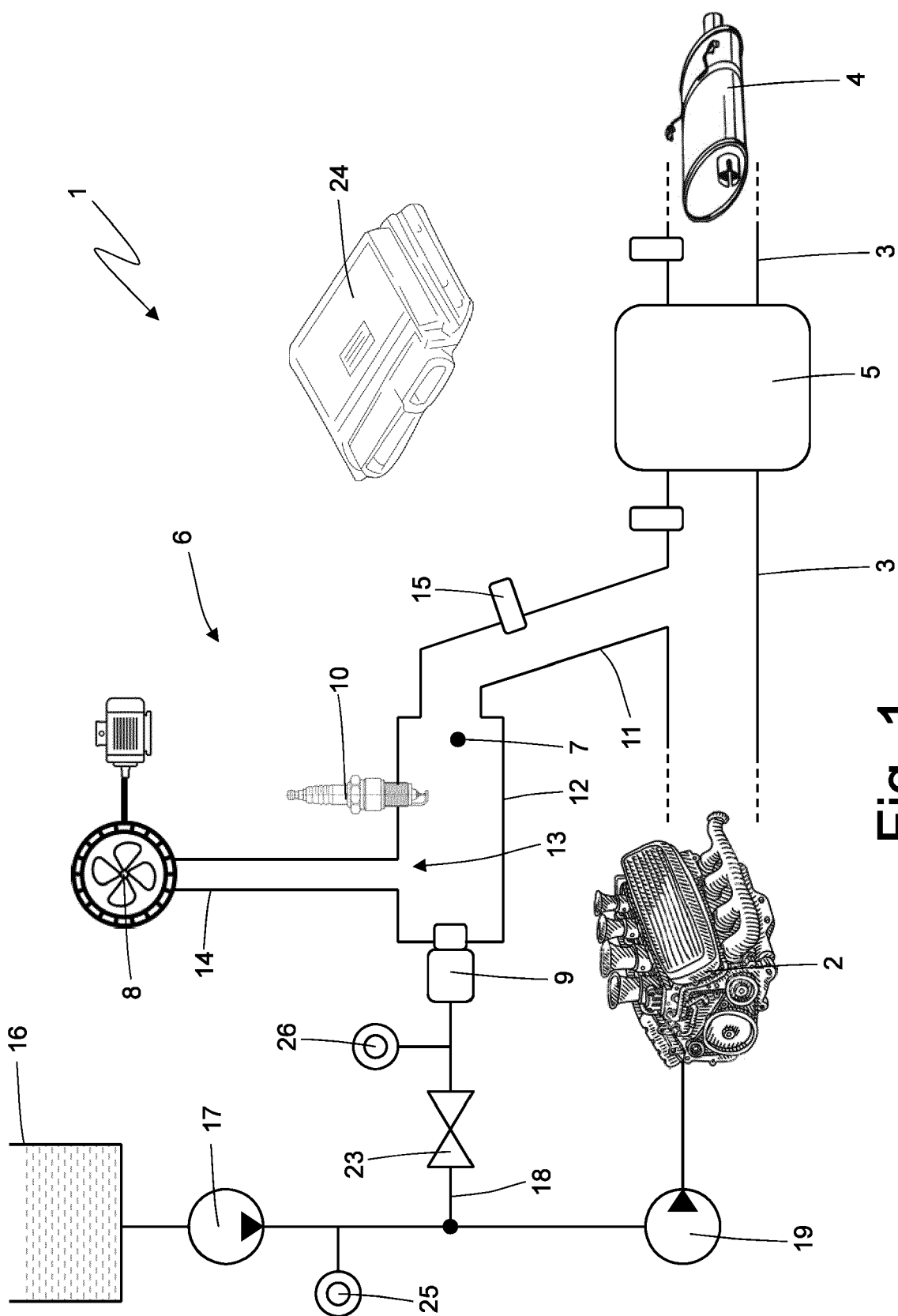


Fig. 1

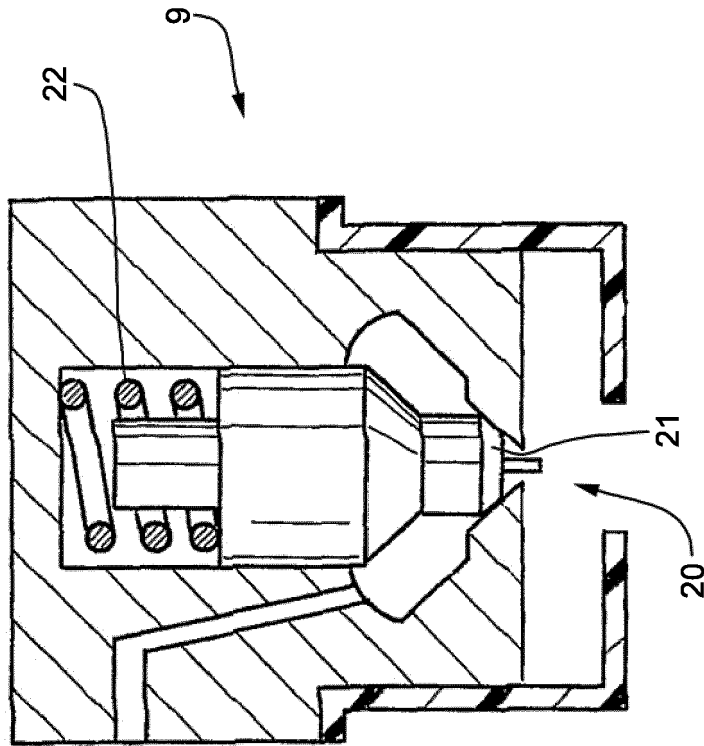


Fig. 3

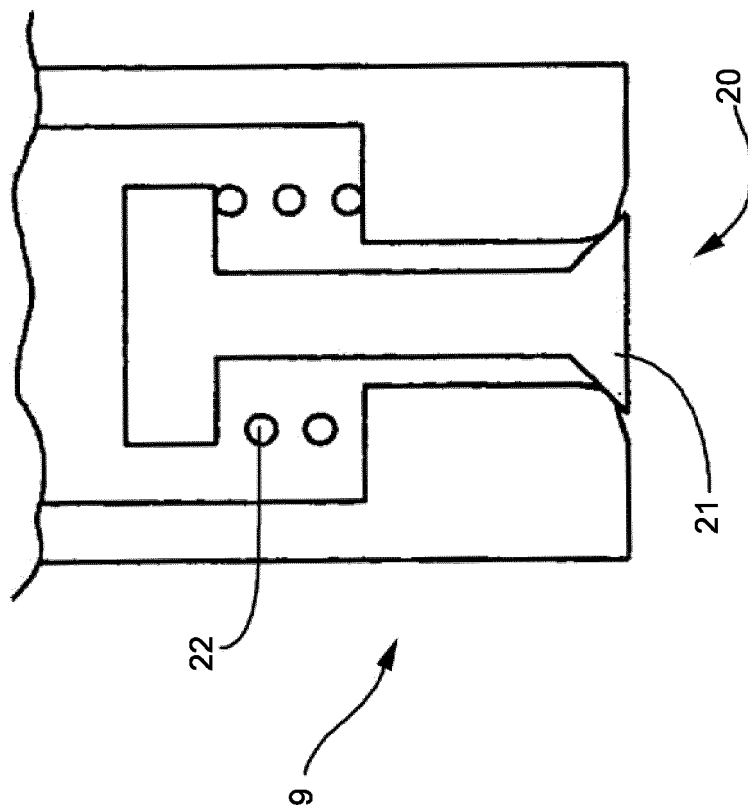
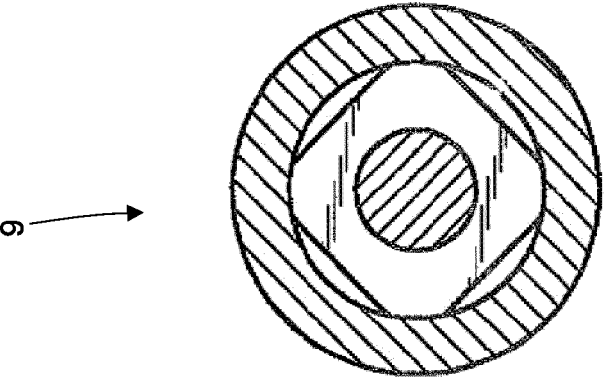
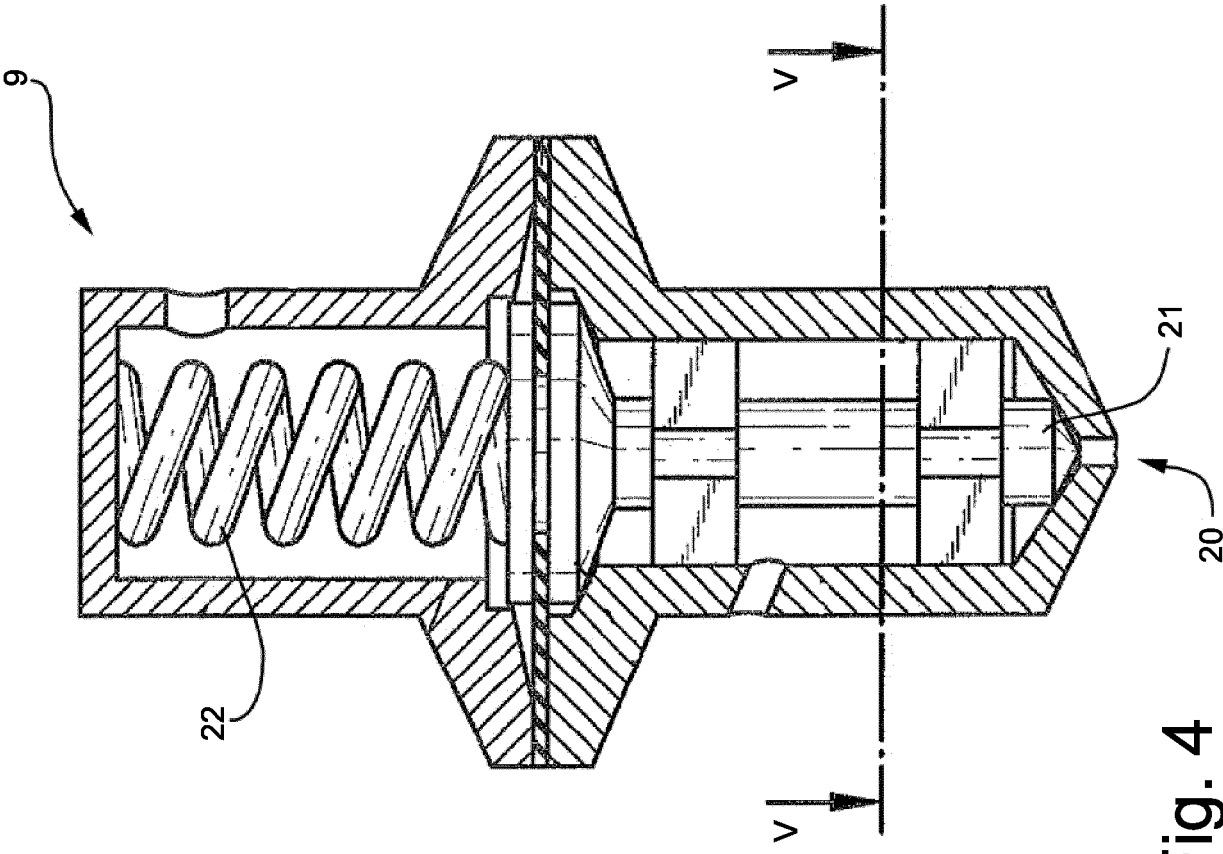


Fig. 2





EUROPEAN SEARCH REPORT

Application Number

EP 22 21 3887

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EPO FORM 1503 03.82 (P04C01)

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A	EP 2 151 559 A1 (MAGNETI MARELLI POWERTRAIN SPA [IT]) 10 February 2010 (2010-02-10) * paragraph [0019]; claim 1; figure 1 *	1-16	
			TECHNICAL FIELDS SEARCHED (IPC)
			F01N
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 22 January 2023	Examiner Seifert, Marco
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	

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

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5 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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22-01-2023

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