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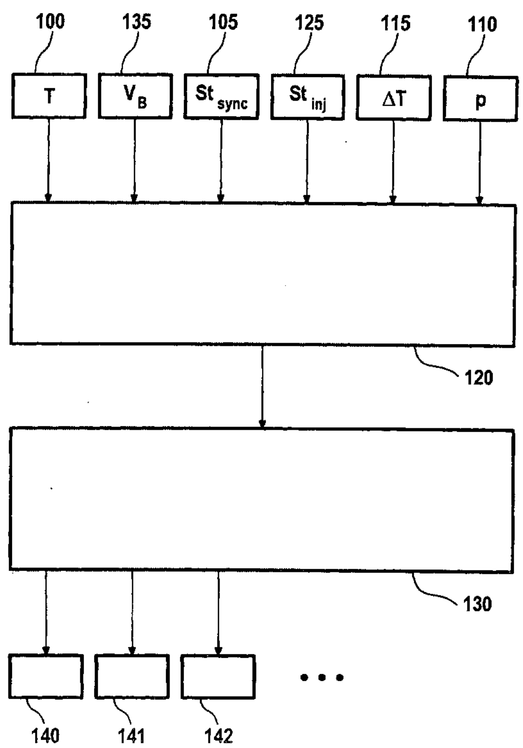
(54) **Control method and control apparatus for a multiple-acting valve within a fuel injection system**

(57) A control method and a control apparatus for a multiple-acting valve (10) within a fuel injection system are described. The method is characterized in that the multiple-acting valve (10) is controlled by a control unit (120) as according to a predefined control scheme. At least one system parameter (p, T, V_B, St_{sync}, ΔT, St_{inj}) is monitored. The predefined control scheme and therefore the control of the multiple-acting valve is modified in case at least one of the monitored system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}) and/or combination of two or more of the parameters match predefined conditions. The apparatus is characterized in that a control unit (120) is implemented for control of the multiple-acting valve (10) as according to a predefined control scheme. Monitoring means (100, 105, 110, 115, 125, 135) are implemented for monitoring the system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}). Modification means (120) are implemented for modification of the predefined control scheme and therefore the control of the multiple-acting valve in case at least one of the monitored system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}) match predefined conditions.

FIG. 4



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Description

[0001] The present invention concerns a method as defined in the preamble of claim 1 and an apparatus as defined in the preamble of claim 23, i.e. a control method and a control apparatus for a multiple-acting valve within a fuel injection system.

[0002] Fuel injection systems are essential components of internal combustion engines. They may be implemented either with individual or with shared fuel supply lines for each fuel injection nozzle (the second alternative is also referred to as common rail systems, shortly: CR systems). In each case, fuel injections are controlled by means of opening and closing fuel injection nozzles in a predefined way.

[0003] In case of a fuel injection system with multiple-acting valves, the multiple-acting valves are used to execute the opening and the closing of the fuel injection nozzles. A piezoelectric element may be used to actuate the multiple-acting valve.

[0004] Fig. 5 is a schematic representation of a fuel injection system using a piezoelectric element 2010 as an actuator. Referring to Fig. 1, piezoelectric element 2010 is electrically energized to expand and contract in response to a given activation voltage. Piezoelectric element 2010 is coupled to a piston 2015. In the expanded state, piezoelectric element 2010 causes piston 2015 to protrude into hydraulic adapter 2020 which contains a hydraulic fluid, for example fuel. As a result of the piezoelectric element's expansion, double-acting control valve 2025 is hydraulically pushed away from hydraulic adapter 2020 and valve plug 1000 is extended away from first closed position, or seat, 1. The combination of double-acting control valve 2025 and hollow bore 2050 is often referred to as double-acting, double seat valve for the reason that when piezoelectric element 2010 is in an unexcited state, double-acting control valve plug 1000 rests in first closed position 1. On the other hand, when piezoelectric element 2010 is fully extended, valve plug 1000 rests in second closed position, or seat, 2. The later position of valve plug 1000 is schematically represented with ghost lines in Fig. 5.

[0005] The fuel injection system comprises an injection needle 2070 allowing for injection of fuel from a pressurized fuel supply line 2060 at a pressure p into the cylinder (not shown). When the piezoelectric element 2010 is unexcited or when it is fully extended, the double-acting control valve plug 1000 rests respectively in its first closed position 1 or in its second closed position 2. In either case, the hydraulic rail pressure p maintains injection needle 2070 at a closed position. Thus, the fuel mixture does not enter into the cylinder (not shown). Conversely, when the piezoelectric element 2010 is excited such that double-acting control valve plug 1000 is in the so-called midposition M with respect to the hollow bore 2050, then there is a pressure drop in the pressurized fuel supply line 2060. This pressure drop results in a pressure differential in the pressurized fuel supply line 2060 between the top and the bottom of the injection needle 2070 so that the injection needle 2070 is lifted allowing for fuel injection into the cylinder (not shown). Midposition M is schematically represented with ghost lines in Fig. 5.

[0006] Hence, in this example, fuel injection is controlled by means of applying voltages to the piezoelectric actuator which expands or contracts itself as a function of the voltage applied. Resulting thereof (but possibly with further use of transmission elements), the valve plug 1000 moves a corresponding distance $\Delta 1$ between the first seat 1 and the open position M, and a distance $\Delta 2$ between the open position M and the second seat 2, respectively. A more detailed description of a corresponding system can be found at German patent application Nos. DE 197 42 073 A1 and DE 1976 29 844 A1, which are hereby incorporated by reference herein in their entirety. These patent applications disclose piezoelectric elements with double-acting, double seat valves for controlling injection needles in a fuel injection system.

[0007] Generally, for such applications it is of importance, to achieve predefined quantities of injected fuel with high accuracy. Hence, it is of importance to have an accurate control of the system. However, occurring system conditions may oppose this aim.

[0008] It is an object of the present invention, to provide an improved control method and control apparatus for a multiple-acting valve within a fuel injection system.

[0009] This object of the present invention is achieved by an object of method claim 1, i.e. by a control method for a multiple-acting valve within a fuel injection system, characterized in that the multiple-acting valve is controlled by a control unit as according to a predefined control scheme. At least one system parameter is monitored. The predefined control scheme and therefore the control of the multiple-acting valve is modified in case one or more of the monitored system parameters match predefined conditions.

[0010] This object of the present invention is further achieved by an object of the apparatus claim 23, i.e. a control apparatus for a multiple-acting valve within a fuel injection system, characterized in that a control unit is implemented for control of the multiple-acting valve as according to a predefined control scheme. Monitoring means are implemented for monitoring at least one system parameter. Modification means are implemented for modification of the predefined control scheme and therefore the control of the multiple-acting valve in case one or more of the monitored system parameters match predefined conditions.

[0011] Generally, it is the aim of any predefined control scheme to allow an optimized system control. However, even though a predefined control scheme might generally match this purpose, it might be better to have a different control scheme under certain system conditions. Hence, a corresponding modification is advantageous.

[0012] The modification of any predefined control scheme and therefore the control of the multiple-acting valve can be done on several ways. For example, an existing control scheme which is "stored" (i.e. the information of which is physically located) in any suitable storage of a control unit can be modified by means of replacing parts of it with new parts. However, the same result is obtained by means of replacing the whole scheme with a new scheme, for example comprising the in the first case remaining old parts as well as the new parts. Moreover, it is possible, to modify the treatment and therefore the meaning of the control scheme instead of the scheme as it is stored itself (for example, the control unit could move the double-acting control valve 2025 into its first seat 1 no matter if the control scheme requires either the first seat 1 or the second seat 2). Furthermore, any other suitable way of obtaining a modified control of the fuel injection system can be used with the invention. Hence, by terms of "modification of a predefined control scheme" any measure is addressed which results in a system control which is different from what it would be without the measure.

[0013] As according to claim 2, the multiple-acting control valve is a double-acting control valve which has a first seat corresponding to a first closed position, a second seat corresponding to a second closed position and an open position.

[0014] For the control of a corresponding control valve the inventive method is particular advantageous.

[0015] Furthermore, as according to claim 3, the multiple-acting control valve is actuated by means of a piezoelectric element. The first seat corresponds to a first voltage applied to the piezoelectric element. The second seat corresponds to a second voltage applied to the piezoelectric element which is larger than the first voltage. The open position corresponds to a medium voltage applied to the piezoelectric element which is in between the first and the second voltage.

[0016] Within a corresponding system, full advantage can be taken out of the invention.

[0017] Advantageously, the fuel pressure is monitored and the predefined control scheme is modified in case the monitored pressure exceeds a predefined threshold (claim 4).

[0018] This allows to compensate for pressure dependencies of the control valve. Since pressure dependencies are likely to occur within a fuel injections system dealing with pressurized fuel a corresponding compensation is particular advantageous.

[0019] Furthermore, the number and kind of injections (St_{inj}) are monitored and the predefined control scheme is modified if no pre-injections are to be performed (claim 5).

[0020] As according to a further advantageous implementation, according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve from the first seat into the open position and instead of doing so, the multiple-acting control valve is moved from the second seat into the open position in case the monitored pressure exceeds a predefined threshold (claim 6).

[0021] For example, in case of a double-acting control valve as described above, the double-acting control valve 2025 is moved from its first seat 1 to the open position M against the pressure force but from its second seat 2 to the open position M with the pressure force. Hence, in case of very high pressures it is advantageous to open the double-acting control valve 2025 from the second seat 2 rather than from the first seat 1. This is because a relatively large force would be required to move the double-acting control valve 2025 from its first seat 1 against the pressure p into its open position M and hence it is difficult to accurately stop the movement when the double-acting control valve 2025 is in its open position M. If the movement from seat 1 to seat 2 is fast enough, there will be no injection during this operation.

[0022] As according to claim 6, according to the predefined control scheme an injection is executed by means of moving the multiple-acting valve from the first seat into the open position, the multiple-acting control valve is placed in its first seat, but, however, in order to execute the injection, the multiple-acting control valve is firstly moved from the first seat into the second seat before it is moved into the open position in case the monitored pressure exceeds a predefined threshold (claim 7).

[0023] This allows to improve the accuracy of an injection even in case the double-acting control valve 2025 is in its less eligible seat before.

[0024] Advantageously, according to the predefined control scheme two pre-injections are executed before a main injection takes place and the multiple-acting valve is moved into the first seat between the two pre-injections and instead, the multiple-acting control valve is moved into the second seat between the two pre-injections (claim 8).

[0025] If high pressures occur, it is especially advantageous to apply a corresponding modification to the predefined control scheme between the two pre-injections.

[0026] Advantageously, the system temperature is monitored and the predefined control scheme is modified in case the monitored temperature is below a predefined threshold (claim 9).

[0027] This allows to compensate for temperature dependencies of the fuel injection system.

[0028] Additionally, the time gap between injections is monitored; and the predefined control scheme is modified in case the time gap between injections exceeds a predefined value (claim 10).

[0029] Advantageously, the status of the synchronicity of the system with respect to the camshaft and the crankshaft signal is monitored and the predefined control scheme is modified in case the system is not finally synchronized (claim 11).

[0030] Furthermore, according to the predefined control scheme the multiple-acting control valve is moved into the second seat after an injection is executed and instead of doing so, the multiple-acting control valve is moved into the first seat in case the monitored temperature and/or the time gap between these injections exceeds a predefined value and/or the system is not finally synchronized (claim 12).

[0031] This is particularly advantageous in case of a system with piezoelectric actuators, since in case of very low temperatures the lifting ability of piezoelectric elements might be reduced. Hence, for example in case of a double-acting control valve 2025, it is easier to move the double-acting control valve 2025 into its first seat 1 than into its second seat 2 with a sufficient accuracy and security.

[0032] Advantageously, according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve from the second seat into the open position and instead of doing so, the multiple-acting control valve is moved from the first seat into the open position in case the monitored temperature and/or the time gap between these injections exceeds a predefined value and/or the system is not finally synchronized (claim 13).

[0033] This is advantageous, because it might be more difficult to achieve a sufficient accuracy while starting with the second seat 2 in case of low temperatures.

[0034] Advantageously, according to the predefined control scheme there is a pre-injection before a main injection and the multiple-acting control valve is moved into the second seat between the pre-injection and the main injection and instead of doing so, the multiple-acting control valve is moved into the first seat between the pre-injection and the main injection in case the monitored temperature and/or the time gap between these injections exceeds a predefined value and/or the system is not finally synchronized (claim 14).

[0035] This is advantageous, since in particular while starting a car low temperatures may be relevant and hence the main injections should be executed while starting from the first seat 1.

[0036] Advantageously, both the fuel pressure and the system temperature are monitored and in case the pressure exceeds the predefined threshold and at the same time the temperature is below the predefined threshold the multiple-acting valve is controlled as if the pressure would not exceed the predefined threshold (claim 15).

[0037] In a corresponding case, the temperature dependency might be of major importance than the pressure dependency is. This in particular holds, in case the reduction of the lifting ability of the piezoelectric element is too large to safely have the double-acting control valve 2025 in its second seat 2. Hence, it is advantageous to ignore the exceeding of the pressure threshold which would lead to a preferred use of the second seat 2 without this rule.

[0038] According to claims 16-21, the multiple-acting control valve is actuated by means of a piezoelectric element. In an advantageous implementation according to claims 16-21, the buffer voltage in the charging circuit of the piezoelectric element is monitored and the control of the double-acting control valve is accordingly modified.

[0039] Advantageously, as long as the system is not finally synchronized with respect to the engine speed signals of the crankshaft and the camshaft, any injection is executed by moving the valve from first seat 1 to the midway portion and back to first seat 1 instead of moving it to second seat 2. This rule has priority over other rules.

[0040] When the time between the pre-injection and the main injection or the time in any other situation between two injection events during which the valve is moved to the second seat exceeds a predefined value the valve is moved to first seat 1 instead of second seat 2.

[0041] According to claim 22, the monitored system parameters and/or any combination of two or more of the monitored system parameters are ranked in a priority ordering and the predefined control scheme and therefore the control of the multiple-acting valve is modified based on the monitored system parameter or combination of the monitored system parameters having the highest priority ranking.

[0042] The invention will be explained below in more detail with reference to exemplary embodiments, referring to the figures in which:

- Fig. 1 shows a depiction of four graphs illustrating the inventive method;
- Fig. 2 shows a depiction of two graphs illustrating the inventive method;
- Fig. 3 shows a depiction of two further graphs illustrating the inventive method;
- Fig. 4 shows a block diagram of an exemplary embodiment of a control system in which the invention is implemented; and
- Fig. 5 shows a schematic representation of an exemplary fuel injection system using a piezoelectric element as an actuator;
- Fig. 6 shows a schematic representation of an exemplary piezoelectric element control system for a fuel injection system;
- Fig. 7a shows a schematic circuit diagram for explaining a first charging phase (charging switch 220 closed) in the apparatus of Fig. 6;
- Fig. 7b shows a schematic circuit diagram for explaining a second charging phase (charging switch 220 open) in the apparatus of Fig. 6;

Fig. 7c shows a schematic circuit diagram for explaining a first discharging phase (discharging switch 230 closed) in the apparatus of Fig. 6; and

Fig. 7d shows a schematic circuit diagram for explaining a second discharging phase (discharging switch 230 open) in the apparatus of Fig. 6.

[0043] Fig. 6, which shows a schematic diagram of an exemplary piezoelectric element control system for a fuel injection system. In Fig. 6 there is a detailed area A and a non-detailed area B, the separation of which is indicated by a dashed line c. The detailed area A comprises a circuit for charging and discharging piezoelectric elements 10, 20, 30, 40, 50 and 60. In the example being considered, these piezoelectric elements 10, 20, 30, 40, 50, 60 are actuators in fuel injection nozzles (in particular in so-called common rail injectors) of an internal combustion engine. Piezoelectric elements can be used for such purposes because, as is known, they possess the property of contracting or expanding as a function of a voltage applied thereto or occurring therein. The non-detailed area B comprises a control unit D and an activation IC E by both of which the elements within the detailed area A are controlled, as well as measuring components F for measuring occurring rail pressures.

[0044] As mentioned above, the circuit within the detailed area A comprises six piezoelectric elements 10, 20, 30, 40, 50, 60. The reason to take six piezoelectric elements 10, 20, 30, 40, 50, 60 in the embodiment described is to independently control six cylinders within a combustion engine; hence, any other number of piezoelectric elements might match any other purpose.

[0045] The piezoelectric elements 10, 20, 30, 40, 50, 60 are distributed into a first group, or bank, G1 and a second group, or bank, G2, each comprising three piezoelectric elements (i.e., piezoelectric elements 10, 20 and 30 in the first group G1 and piezoelectric elements 40, 50 and 60 in the second group G2). Groups G1 and G2 are constituents of circuit parts connected in parallel with one another. Group selector switches 310, 320 can be used to establish which of the groups G1, G2 of piezoelectric elements 10, 20 and 30 and 40, 50 and 60, respectively, will be discharged in each case by a common charging and discharging apparatus (however, the group selector switches 310, 320 are meaningless for charging procedures, as is explained in further detail below).

[0046] The group selector switches 310, 320 are arranged between a coil 240 and the respective groups G1 and G2 (the coil-side terminals thereof) and are implemented as transistors. Side drivers 311, 321 are implemented which transform control signals received from the activation IC E into voltages which are eligible for closing and opening the switches as required.

[0047] Diodes 315 and 325 (referred to as group selector diodes), respectively, are provided in parallel with the group selector switches 310, 320. If the group selector switches 310, 320 are implemented as MOSFETs or IGBTs, for example, these group selector diodes 315, 325 can be constituted by the parasitic diodes themselves. The diodes 315, 325 bypass the group selector switches 310, 320 during charging procedures. Hence, the functionality of the group selector switches 310, 320 is reduced to select a group G1, G2 of piezoelectric elements 10, 20 and 30, resp. 40, 50 and 60 for a discharging procedure only.

[0048] Within each group Gl resp. G2 the piezoelectric elements 10, 20 and 30, resp. 40, 50 and 60 are arranged as constituents of piezo branches 110, 120 and 130 (group G1) and 140, 150 and 160 (group G2) that are connected in parallel. Each piezo branch comprises a series circuit made up of a first parallel circuit comprising a piezoelectric element 10, 20, 30, 40, 50 resp. 60 and a resistor 13, 23, 33, 43, 53 resp. 63 (referred to as branch resistors) and a second parallel circuit made up of a selector switch implemented as a transistor 11, 21, 31, 41, 51 resp. 61 (referred to as branch selector switches) and a diode 12, 22, 32, 42, 52 resp. 62 (referred to as branch diodes).

[0049] The branch resistors 13, 23, 33, 43, 53 resp. 63 cause each corresponding piezoelectric element 10, 20, 30, 40, 50 resp. 60 during and after a charging procedure to continuously discharge themselves, since they connect both terminals of each capacitive piezoelectric element 10, 20, 30, 40, 50, resp. 60 one to another. However, the branch resistors 13, 23, 33, 43, 53 resp. 63 are sufficiently large to make this procedure slow compared to the controlled charging and discharging procedures as described below. Hence, it is still a reasonable assumption to consider the charge of any piezoelectric element 10, 20, 30, 40, 50 or 60 as unchanging within a relevant time after a charging procedure (the reason to nevertheless implement the branch resistors 13, 23, 33, 43, 53 and 63 is to avoid remaining charges on the piezoelectric elements 10, 20, 30, 40, 50 and 60 in case of a breakdown of the system or other exceptional situations). Hence, the branch resistors 13, 23, 33, 43, 53 and 63 may be neglected in the following description.

[0050] The branch selector switch/branch diode pairs in the individual piezo branches 110, 120, 130, 140, 150 resp.160, i.e., selector switch 11 and diode 12 in piezo branch 110, selector switch 21 and diode 22 in piezo branch 120, and so on, can be implemented using electronic switches (i.e., transistors) with parasitic diodes, for example MOSFETs or IGBTs (as stated above for the group selector switch/diode pairs 310 and 315 resp. 320 and 325). The branch selector switches 11, 21, 31, 41, 51 resp. 61 can be used to establish which of the piezoelectric elements 10, 20, 30, 40, 50 or 60 will be charged in each case by a common charging and discharging apparatus: in each case, the piezoelectric elements 10, 20, 30, 40, 50 or 60 that are charged are all those whose branch selector switches 11, 21, 31, 41, 51 or 61 are closed during the charging procedure which is described below.

[0051] The branch diodes 12, 22, 32, 42, 52 and 62 serve for bypassing the branch selector switches 11, 21, 31, 41, 51 resp. 61 during discharging procedures. Hence, in the example considered for charging procedures any individual piezoelectric element can be selected, whereas for discharging procedures either the first group Gl or the second group G2 of piezoelectric elements 10, 20 and 30 resp. 40, 50 and 60 or both have to be selected.

[0052] Returning to the piezoelectric elements 10, 20, 30, 40, 50 and 60 themselves, the branch selector piezo terminals 15, 25, 35, 45, 55 resp. 65 may be connected to ground either through the branch selector switches 11, 21, 31, 41, 51 resp. 61 or through the corresponding diodes 12, 22, 32, 42, 52 resp. 62 and in both cases additionally through resistor 300.

[0053] The purpose of resistor 300 is to measure the currents that flow during charging and discharging of the piezoelectric elements 10, 20, 30, 40, 50 and 60 between the branch selector piezo terminals 15, 25, 35, 45, 55 resp. 65 and the ground. A knowledge of these currents allows a controlled charging and discharging of the piezoelectric elements 10, 20, 30, 40, 50 and 60. In particular, by closing and opening charging switch 220 and discharging switch 230 in a manner dependent on the magnitude of the currents, it is possible to set the charging current and discharging current to predefined average values and/or to keep them from exceeding or falling below predefined maximum and/or minimum values as is explained in further detail below.

[0054] In the example considered, the measurement itself further requires a voltage source 621 which supplies a voltage of, for example, 5 V DC and a voltage divider implemented as two resistors 622 and 623. This is in order to prevent the activation IC E (by which the measurements are performed) from negative voltages which might otherwise occur on measuring point 620 and which cannot be handled by means of activation IC E: such negative voltages are changed into positive voltages by means of addition with a positive voltage setup which is supplied by said voltage source 621 and voltage divider resistors 622 and 623.

[0055] The other terminal of each piezoelectric element 10, 20, 30, 40, 50 and 60, i.e. the group selector piezo terminal 14, 24, 34, 44, 54 resp. 64, may be connected to the plus pole of a voltage source via the group selector switch 310 resp. 320 or via the group selector diode 315 resp. 325 as well as via a coil 240 and a parallel circuit made up of a charging switch 220 and a charging diode 221, and alternatively or additionally connected to ground via the group selector switch 310 resp. 320 or via diode 315 resp. 325 as well as via the coil 240 and a parallel circuit made up of a discharging switch 230 or a discharging diode 231. Charging switch 220 and discharging switch 230 are implemented as transistors which are controlled via side drivers 222 resp. 232.

[0056] The voltage source comprises an element having capacitive properties which, in the example being considered, is the (buffer) capacitor 210. Capacitor 210 is charged by a battery 200 (for example a motor vehicle battery) and a DC voltage converter 201 downstream therefrom. DC voltage converter 201 converts the battery voltage (for example, 12 V) into substantially any other DC voltage (for example 250 V), and charges capacitor 210 to that voltage. DC voltage converter 201 is controlled by means of transistor switch 202 and resistor 203 which is utilized for current measurements taken from a measuring point 630.

[0057] For cross check purposes, a further current measurement at a measuring point 650 is allowed by activation IC E as well as by resistors 651, 652 and 653 and a, for example, 5 V DC voltage source 654; moreover, a voltage measurement at a measuring point 640 is allowed by activation IC E as well as by voltage dividing resistors 641 and 642.

[0058] Finally, a resistor 330 (referred to as total discharging resistor), a stop switch implemented as a transistor 331 (referred to as stop switch), and a diode 332 (referred to as total discharging diode) serve to discharge the piezoelectric elements 10, 20, 30, 40, 50 and 60 (if they happen to be not discharged by the "normal" discharging operation as described further below). Stop switch 331 is preferably closed after "normal" discharging procedures (cycled discharging via discharge switch 230). It thereby connects piezoelectric elements 10, 20, 30, 40, 50 and 60 to ground through resistors 330 and 300, and thus removes any residual charges that might remain in piezoelectric elements 10, 20, 30, 40, 50 and 60. The total discharging diode 332 prevents negative voltages from occurring at the piezoelectric elements 10, 20, 30, 40, 50 and 60, which might in some circumstances be damaged thereby.

[0059] Charging and discharging of all the piezoelectric elements 10, 20, 30, 40, 50 and 60 or any particular one is accomplished by way of a single charging and discharging apparatus (common to all the groups and their piezoelectric elements). In the example being considered, the common charging and discharging apparatus comprises battery 200, DC voltage converter 201, capacitor 210, charging switch 220 and discharging switch 230, charging diode 221 and discharging diode 231 and coil 240.

[0060] The charging and discharging of each piezoelectric element works the same way and is explained in the following while referring to the first piezoelectric element 10 only.

[0061] The conditions occurring during the charging and discharging procedures are explained with reference to Figs. 3a through 3d, of which Figs. 7a and 7b illustrate the charging of piezoelectric element 10, and Figs. 7c and 7d the discharging of piezoelectric element 10.

[0062] The selection of one or more particular piezoelectric elements 10, 20, 30, 40, 50 or 60 to be charged or discharged, the charging procedure as described in the following as well as the discharging procedure are driven by activation IC E and control unit D by means of opening or closing one or more of the above introduced switches 11, 21, 31, 41, 51, 61; 310, 320; 220, 230 and 331. The interactions between the elements within the detailed area A on the on hand and activation IC E and control unit D on the other hand are described in detail further below.

[0063] Concerning the charging procedure, firstly any particular piezoelectric element 10, 20, 30, 40, 50 or 60 which is to be charged has to be selected. In order to exclusively charge the first piezoelectric element 10, the branch selector switch 11 of the first branch 110 is closed, whereas all other branch selector switches 21, 31, 41, 51 and 61 remain opened. In order to exclusively charge any other piezoelectric element 20, 30, 40, 50, 60 or in order to charge several ones at the same time they would be selected by closing the corresponding branch selector switches 21, 31, 41, 51 and/or 61.

[0064] Then, the charging procedure itself may take place:

[0065] Generally, within the example considered, the charging procedure requires a positive potential difference between capacitor 210 and the group selector piezo terminal 14 of the first piezoelectric element 10. However, as long as charging switch 220 and discharging switch 230 are open no charging or discharging of piezoelectric element 10 occurs. In this state, the circuit shown in Fig. 6 is in a steady-state condition, i.e., piezoelectric element 10 retains its charge state in substantially unchanged fashion, and no currents flow.

[0066] In order to charge the first piezoelectric element 10, charging switch 220 is closed. Theoretically, the first piezoelectric element 10 could become charged just by doing so. However, this would produce large currents which might damage the elements involved. Therefore, the occurring currents are measured at measuring point 620 and switch 220 is opened again as soon as the detected currents exceed a certain limit. Hence, in order to achieve any desired charge on the first piezoelectric element 10, charging switch 220 is repeatedly closed and opened whereas discharging switch 230 remains open.

[0067] In more detail, when charging switch 220 is closed, the conditions shown in Fig. 7a occur, i.e., a closed circuit comprising a series circuit made up of piezoelectric element 10, capacitor 210, and coil 240 is formed, in which a current $i_{LE}(t)$ flows as indicated by arrows in Fig. 7a. As a result of this current flow both positive charges are brought to the group selector piezo terminal 14 of the first piezoelectric element 10 and energy is stored in coil 240.

[0068] When charging switch 220 opens shortly (for example, a few μs) after it has closed, the conditions shown in Fig. 7b occur: a closed circuit comprising a series circuit made up of piezoelectric element 10, charging diode 221, and coil 240 is formed, in which a current $i_{LA}(t)$ flows as indicated by arrows in Fig. 7b. The result of this current flow is that energy stored in coil 240 flows into piezoelectric element 10. Corresponding to the energy delivery to the piezoelectric element 10, the voltage occurring in the latter, and its external dimensions, increase. Once energy transport has taken place from coil 240 to piezoelectric element 10, the steady-state condition of the circuit, as shown in Fig. 6 and already described, is once again attained.

[0069] At that time, or earlier, or later (depending on the desired time profile of the charging operation), charging switch 220 is once again closed and opened again, so that the processes described above are repeated. As a result of the re-closing and re-opening of charging switch 220, the energy stored in piezoelectric element 10 increases (the energy already stored in the piezoelectric element 10 and the newly delivered energy are added together), and the voltage occurring at the piezoelectric element 10, and its external dimensions, accordingly increase.

[0070] If the aforementioned closing and opening of charging switch 220 are repeated numerous times, the voltage occurring at the piezoelectric element 10, and the expansion of the piezoelectric element 10, rise in steps.

[0071] Once charging switch 220 has closed and opened a predefined number of times, and/or once piezoelectric element 10 has reached the desired charge state, charging of the piezoelectric element is terminated by leaving charging switch 220 open.

[0072] Concerning the discharging procedure, in the example considered, the piezoelectric elements 10, 20, 30, 40, 50 and 60 are discharged in groups (G1 and/or G2) as follows:

[0073] Firstly, the group selector switch(es) 310 and/or 320 of the group or groups G1 and/or G2 the piezoelectric elements of which are to be discharged are closed (the branch selector switches 11, 21, 31, 41, 51, 61 do not affect the selection of piezoelectric elements 10, 20, 30, 40, 50, 60 for the discharging procedure, since in this case they are bypassed by the branch diodes 12, 22, 32, 42, 52 and 62). Hence, in order to discharge piezoelectric element 10 as a part of the first group G1, the first group selector switch 310 is closed.

[0074] When discharging switch 230 is closed, the conditions shown in Fig. 7c occur: a closed circuit comprising a series circuit made up of piezoelectric element 10 and coil 240 is formed, in which a current $i_{EE}(t)$ flows as indicated by arrows in Fig. 7c. The result of this current flow is that the energy (a portion thereof) stored in the piezoelectric element is transported into coil 240. Corresponding to the energy transfer from piezoelectric element 10 to coil 240, the voltage occurring at the piezoelectric element 10, and its external dimensions, decrease.

[0075] When discharging switch 230 opens shortly (for example, a few µs) after it has closed, the conditions shown in Fig. 7d occur: a closed circuit comprising a series circuit made up of piezoelectric element 10, capacitor 210, discharging diode 231, and coil 240 is formed, in which a current i_{EA} (t) flows as indicated by arrows in Fig. 7d. The result of this current flow is that energy stored in coil 240 is fed back into capacitor 210. Once energy transport has taken place from coil 240 to capacitor 210, the steady-state condition of the circuit, as shown in Fig. 6 and already described, is once again attained.

[0076] At that time, or earlier, or later (depending on the desired time profile of the discharging operation), discharging switch 230 is once again closed and opened again, so that the processes described above are repeated. As a result of the re-closing and re-opening of discharging switch 230, the energy stored in piezoelectric element 10 decreases further, and the voltage occurring at the piezoelectric element, and its external dimensions, also accordingly decrease.

[0077] If the aforementioned closing and opening of discharging switch 230 are repeated numerous times, the voltage occurring at the piezoelectric element 10, and the expansion of the piezoelectric element 10, decrease in steps.

[0078] Once discharging switch 230 has closed and opened a predefined number of times, and/or once the piezoelectric element has reached the desired discharge state, discharging of the piezoelectric element 10 is terminated by leaving discharging switch 230 open.

[0079] In the following, by way of example, a fuel injection system with a double-acting control valve 10 as described above (while referring to Fig. 5) is considered. Hence, the double-acting control valve 10 has a first seat 1 corresponding to a first closed position, a second seat 2 corresponding to a second closed position and an open position M. However, any other multiple-acting control valve may be used with the invention. For example, instead of having two closed positions and one open position, a further double-acting control valve might have one closed position and two open positions; or, generally, the multiple-acting valve might have more open and/or closed positions.

[0080] Moreover, in the example considered, the double-acting control valve 2025 is actuated by means of a piezoelectric element (not shown). Hence, the first seat 1 corresponds to a first voltage applied to the piezoelectric element; the second seat 2 corresponds to a second voltage applied to the piezoelectric element which is larger than the first voltage; and the open position corresponds to a medium voltage applied to the piezoelectric element which is in between the first and the second voltage.

[0081] Reference is now had to Figs. 1 to 3.

[0082] Within Fig. 1, four graphs (1), (2), (3) and (4) are shown. In each graph (1), (2), (3) and (4) quantities are depicted as functions of the time during the same time slot. Hence, the base axis of each graph (1), (2), (3) and (4) is a time axis t, with the time axes t of the four graphs (1), (2), (3) and (4) being equal one to another. Moreover, within the first graph (1), the remaining axis is a amount-of-injection axis I and injections are depicted. Furthermore, within the three remaining graphs (2),(3) and (4), the remaining axes are a voltage axes and voltages applied to the piezoelectric actuators are depicted.

[0083] In more detail, within graph (1) an exemplary injection profile is depicted, which comprises a first pre-injection starting at a first time t_1 and terminated at a second time t_2, a second pre-injection starting at a third time t_3 and terminated at a fourth time t_4, a main injection starting at a fifth time t_5 and terminated at a sixth time t_6, and a post-injection starting at a seventh time t_7 and terminated at a eighth time t_8. Each injection is indicated by means of an injection amount I_M which corresponds to the injection occurring while the double-acting control valve 2025 is in its open position M and which, for simplicity, is depicted as constant during the starting time and the termination time. However, any other injection profile as well as any function of the injection amount I over the time can be used without any effect to the invention.

[0084] Within graph (2), by way of example, a predefined control scheme for the double-acting control valve 2025 is depicted, which is eligible to execute the above described injection profile. According hereto, initially the double-acting control valve 2025 is in its first seat 1 and a corresponding low voltage V_1 is applied to the piezoelectric actuator. At the first time t_1, the double-acting control valve 2025 is moved into its open position M and a corresponding medium voltage V_M is applied to the piezoelectric actuator. At the second time t_2 the double-acting control valve 2025 is moved back into its first seat 1 and the corresponding low voltage V_1 is applied to the piezoelectric actuator. At the third time t_3 the double-acting control valve 2025 is moved into its open position M and a corresponding medium voltage V_M is applied to the piezoelectric actuator. At the fourth time t_4 the double-acting control valve 2025 is moved into its second seat 2 and a corresponding high voltage V_2 is applied to the piezoelectric actuator. At the fifth time t_5 the double-acting control valve 2025 is moved into its open position M and a corresponding medium voltage V_M is applied to the piezoelectric actuator. At the sixth time t_6 the double-acting control valve 2025 is moved into its first seat 1 and the corresponding low voltage V_1 is applied to the piezoelectric actuator. At the seventh time t_7 the double-acting control valve 2025 is moved into its open position M and a corresponding medium voltage V_M is applied to the piezoelectric actuator. Finally, at the eighth time t_8 the double-acting control valve 2025 is moved back into its first seat 1 and the corresponding low voltage V_1 is applied to the piezoelectric actuator.

[0085] It is to be understood, that any other suitable predefined control scheme for the double-acting control valve 2025 may be used with the invention. Moreover, the voltages applied to the piezoelectric actuator may be obtained immediately or in accordance with any suitable function of the voltage over the time without any effect to the invention. For example, the voltages may be obtained in steps. Moreover, the voltages applied to the actuator to realize an injection may differ depending on whether the valve is moved from seat 1 or seat 2 into the midway position.

[0086] Within graph (3), a first modification of the afore described predefined control scheme is shown. In this example, at the second time t_2 the double-acting control valve 2025 is not returned into its first seat 1 as described above, but it is moved into the second seat 2. As a result, at the third time t_3 the double-acting control valve 2025 is moved into its open position M from the second seat 2 instead of the first seat 1.

[0087] Within the example considered, the corresponding modification is executed because the fuel pressure within the fuel injection system, which is monitored for this purpose, exceeds a predefined threshold ($p>p\text{-}_{max}$). Hence, in case the fuel pressure p exceeds the predefined threshold p_{max}, the double-acting control valve 2025 is moved from the open position M into the second seat 2 instead of first seat 1 and into the open position M from the second seat 2 instead the of first seat 1.

[0088] The reason for a corresponding rule is as follows: As can be seen from Fig. 5, the double-acting control valve 2025 opens from its first seat 1 against the fuel pressure p but from its second seat 2 with the fuel pressure p. However, the fuel pressure p is changing over the time in dependence of the operating point of the system. Hence, there is a corresponding asymmetry in the system performance. Generally, this asymmetry increases in accordance with a raise of the fuel pressure p. In more detail, for high pressures p large forces (and corresponding large medium voltages V_M across the piezoelectric actuator) are required in order to move the double-acting control valve 2025 out of its first seat 1. However, with large forces it is rather difficult to precisely move the double-acting control valve 2025 into its open position M and not to move it further away and back again first. As a result, starting with a threshold p_{max} of, for example, about 1600 bar in a common fuel injection system, sufficiently precise results are better obtained while opening the double-acting control valve 2025 from its second seat 2 (and therefore with the pressure force) instead of its first seat 1.

[0089] As a further reason, it has to be considered, that large forces are obtained by means of applying relatively large medium voltages V_M to the piezoelectric actuator. If, for example, for the first seat 1 a zero voltage and for the second seat 2 a maximum voltage of 200 V is applied to the piezoelectric actuator, in case of high pressures p for moving and holding the double-acting control valve 2025 in its open position M, a medium voltage V_M is required which is much larger than 100 V. Resulting thereof, the voltage difference between the high voltage V_2 of 200 V and the medium voltage V_M is much smaller than the corresponding difference between the medium voltage V_M and the low voltage V_1 of 0 V. Hence, a smaller amount of currents is required in order to charge the piezoelectric actuator from the medium voltage V_M to the high voltage V_2 than it would be required in order to charge it from the low voltage V_1 to the medium voltage V_M. For this reason, in total a less amount of currents is required while performing an injection by means of discharging the piezoelectric actuator from the high voltage V_2 to the medium voltage V_M and charging it again from the medium voltage V_M to the high voltage V_2 than it would be required while starting from the first seat 1. Hence, the inventive modification of the predefined control scheme helps to reduce the energy consumption of the system. Moreover, the times necessary for charging and discharging the piezoelectric element are reduced. Hence, the ability of the system to quickly afterwards charge another piezoelectric element for another double-acting control valve (not shown) within the system in order to partly drive two (or more) cylinders of the engine in parallel is increased.

[0090] Within graph (4), a second modification of the afore described predefined control scheme is shown. In this example, at the fourth time t_4 the double-acting control valve 2025 is not moved into its second seat 2 as described above, but it is moved into its first seat 1. As a result, at the fifth time t_5 the double-acting control valve 2025 is moved into its open position M from the first seat 1 instead of the second seat 2. Hence, the double-acting control valve is driven like a single-acting valve which only has one open and one closed position.

[0091] The reason for a corresponding modification of the control scheme can be a temperature of the system which is below a predefined threshold. This is because the lifting ability of piezoelectric actuators is reduced for low temperatures (for example temperatures which are significantly below 0° C). Hence, it is difficult to properly expand piezoelectric elements to the length required for having the double-acting control valve 2025 in its second seat 2 and for this reason it might be better to switch the double-acting control valve between its first seat 1 and its open position M only. Corresponding situations particularly occur when a car engine is started when the environmental temperature is low. Other reasons for such a control scheme include: 1) the system not being fully synchronized, and 2) the time gap between two injection events, e.g., pre-injection and main injection exceeding a predefined threshold.

[0092] Within Fig.2, three graphs (1), (2) and (3) are shown. In each graph (1), (2) and (3) quantities are depicted as functions of the time during the same time slot. Hence, the base axis of each graph (1), (2) and (3) is a time axis t and the time axes t of the three graphs (1), (2) and (3) are equal one to another. Moreover, within the first graph (1), the remaining axis is a amount-of-injection axis I and injections are depicted. Furthermore, within the two remaining graphs (2) and (3), the remaining axes are a voltage axes and voltages applied to the piezoelectric actuators are depicted.

[0093] In more detail, within graph (1) an exemplary injection profile is depicted, which comprises one injection starting at a first time t_1 and terminated at a second time t_2. The injection is indicated by means of an injection amount I_M which corresponds to the injection occurring while the double-acting control valve 2025 is in its open position M and which, for simplicity, is depicted as constant during the starting time and the termination time. However, any other injection profile as well as any occurring function of the injection amount I over the time can be used without any effect to the invention.

[0094] Within graph (2), by way of example, a predefined control scheme for the double-acting control valve 2025 is depicted, which is eligible to execute the above described injection profile. According hereto, before the first time t_1 the low voltage V_1 is applied to the piezoelectric element and hence the double-acting control valve 2025 is in its first seat 1. At the first time t_1 a medium voltage V_M is applied to the piezoelectric element and hence the double-acting control valve 2025 is moved into its open position M. Finally, at the second time t_2 the low voltage V_1 is applied to the piezoelectric element and hence is returned into its first seat 1.

[0095] Withing graph 3 the predefined control scheme is modified as follows: the double-acting control valve 2025 is moved from its first seat 1 into its second seat 2 at a time t_0 which is in advance to the first time t_1 and hence the high voltage V_2 is applied to the piezoelectric element which initially was on the low voltage V_1. However, since this happens immediately and with no or no substantial time in which the voltage remains on the level of the medium voltage V_M, no (or basically no) injection occurs while doing so. Then, the injection is executed by means of reducing the high voltage V_2 to the medium voltage V_M at the first time t_1 and therefore moving the double-acting control valve 2025 into its open position M.

[0096] The reason to do so would be that a high pressure p occurred according to which it would be difficult to move the double-acting control valve 2025 from its first seat 1 into its open position M with sufficiently high accuracy as described above. Hence, it might be desired to move the double-acting control valve 2025 from its second seat 2 into its open position M only. However, since the double-acting control valve 2025 initially was in its first seat 1 it is therefore required to move the double-acting control valve 2025 from its first seat 1 into its second seat 2 first.

[0097] Another reason for the profile depicted in Fig. 3 may be when, in contrast to the usual profile, a main injection with no pre-injection is to be performed. This may be desirable in certain situations. In such a case, in order to leave unchanged conditions for the main injection, it may also be desirable to realize a profile as shown in Fig. 3.

[0098] Within Fig.3, again three graphs (1), (2) and (3) are shown. In each graph (1), (2) and (3) quantities are depicted as functions of the time during the same time slot. Hence, the base axis of each graph (1), (2) and (3) is a time axis t and the time axes t of the three graphs (1), (2) and (3) are equal one to another. Moreover, within the first graph (1), the remaining axis is a amount-of-injection axis I and injections are depicted. Furthermore, within the two remaining graphs (2) and (3), the remaining axes are a voltage axes and voltages applied to the piezoelectric actuators are depicted.

[0099] In more detail, within graph (1) an exemplary injection profile is depicted, which comprises one injection starting at a first time t_1 and terminated at a second time t_2. The injection is indicated by means of an injection amount I_M which corresponds to the injection occurring while the double-acting control valve 2025 is in its open position M and which, for simplicity, is depicted as constant during the starting time and the termination time. However, any other injection profile as well as any occurring function of the injection amount I over the time can be used without any effect to the invention.

[0100] Within graph (2), by way of example, a predefined control scheme for the double-acting control valve 2025 is depicted, which is eligible to execute the above described injection profile. According hereto, before the first time t_1 the high voltage V_2 is applied to the piezoelectric element and hence the double-acting control valve 2025 is in its second seat 2. At the first time t_1 a medium voltage V_M is applied to the piezoelectric element and hence the double-acting control valve 2025 is moved into its open position M. Finally, at the second time t_2 the high voltage V_2 is applied to the piezoelectric element and hence is returned into its second seat 2.

[0101] Withing graph (3) the predefined control scheme is modified as follows: the double-acting control valve 2025 is moved from its second seat 2 into its 1 at a time t_0 which is in advance to the first time t_1 and hence the low voltage V_1 is applied to the piezoelectric element which initially was on the high voltage V_2. However, since this happens immediately and with no or no substantial time in which the voltage remains on the level of the medium voltage V_M, no (or basically no) injection occurs while doing so. Then, the injection is executed by means of increasing the low voltage V_1 to the medium voltage V_M at the first time t_1 and therefore moving the double-acting control valve 2025 into its open position M. Finally, the double-acting control valve 2025 is returned into its first seat 1 at the second time t_2 while applying the low voltage V_1 to the piezoelectric element.

[0102] The reason to do so would be that a low temperature occurred according to which it would be difficult to hold and/or move the double-acting control valve 2025 in its second seat 2 with sufficiently high accuracy as described above. Hence, it might be desired to switch the double-acting control valve 2025 between its first seat 1 and its second seat 2 only. However, since the double-acting control valve 2025 initially was in its second seat 2 it is therefore required to move the double-acting control valve 2025 from its second seat 2 into its first seat 1 first.

[0103] In similar fashion, other system parameters may be monitored and the control of the double-acting control valve accordingly modified. For example, the voltage (V_B) across a buffer capacitor in the charging circuit for the piezoelectric element used to actuate the double-acting control valve may be monitored. See the description above regarding the piezoelectric element control system with reference to Figs. 6 and 7a to d.

[0104] Fig. 4, as mentioned above, shows a block diagram of an exemplary embodiment of a control system in which the invention is implemented. Hence, there are first determination components 100 for the determination and monitoring of the system temperature, particularly for the determination of the temperature occurring at piezoelectric elements 140, 141 and 142. A second determination component 105 provided for indicating the status of synchronicity St_{sync} of the system. Moreover, a third determination component 110 is provided for determination and monitoring of the fuel pressure occurring in the fuel injection system. Furthermore, there are a fourth determination component 135 for monitoring buffer capacitor voltage V_B, a fifth determination component 115 for monitoring the time gap between two injections ΔT and a sixth determination component 125 for monitoring the kind of injections to be realized at the actual operating point of the fuel injection system. St_{inj} describes this actual status of injections. All determination components 100, 105,110, 115, 125 and 135 are connected to a control unit 120 which may control piezoelectric elements according to a predefined control scheme as well modify the control scheme in response to values of the determination components, either alone or in combination, mentioned above. The control scheme may be modified, for example, if: 1) the status of synchronicity St_{sync} indicates that the system is not finally synchronized; 2) the status of injections (St_{inj}) indicates that no pre-injection is to be performed; and/or 3) the time gap between injections (ΔT) exceeds a predefined value (ΔT_{MAX}) and/or values of any of the other determination components mentioned above exceeding a threshold value. The control unit 120 immediately controls an activation IC 130 which again activates the piezoelectric elements 140, 141 and 142.

[0105] It is to be understood, that any other control system and any other control scheme may be used with the present invention. Moreover, any further system parameter of interest may by monitored.

Claims

1. Control method for a multiple-acting valve (10) within a fuel injection system, **characterized in that**

   a) the multiple-acting valve (10) is controlled by a control unit (120) as according to a predefined control scheme;

   b) at least one system parameter (p, T, V_B, St_{sync}, ΔT, St_{inj}) is monitored; and

   c) the predefined control scheme and therefore the control of the multiple-acting valve is modified in case one or more of the monitored system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}) match predefined conditions.

2. Control method as according to claim 1, **characterized in that** the multiple-acting control valve (10) is a double-acting control valve which has a first seat (1) corresponding to a first closed position, a second seat (2) corresponding to a second closed position and an open position (M).

3. Control method as according to one of the foregoing claims, **characterized in that**

   a) the multiple-acting control valve (10) is actuated by means of a piezoelectric element (140, 141, 142);

   b) the first seat (1) corresponds to a first voltage (V_1) applied to the piezoelectric element (140, 141, 142);

   c) the second seat (2) corresponds to a second voltage (V_2) applied to the piezoelectric element (140, 141, 142) which is larger than the first voltage (V_1) ; and

   d) the open position (M) corresponds to a medium voltage (V_M) applied to the piezoelectric element (140, 141, 142) which is in between the first and the second voltage (V_2, V_1).

4. Control method as according to one of the foregoing claims, **characterized in that**

   a) the fuel pressure (p) is monitored; and

   b) the predefined control scheme is modified in case the monitored pressure (p) exceeds a predefined threshold (p_{max}).

5. Control method as according to one of the foregoing claims, **characterized in that**

   a) the number and kind of injections (St_{inj}) are monitored; and

   b) the predefined control scheme is modified if no pre-injections are to be performed.

6. Control method as according to one of the foregoing claims, **characterized in that**

   a) according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve (10) from the first seat (1) into the open position (M); and

b) instead of doing so, the multiple-acting control valve (10) is moved from the second seat (2) into the open position (M) in case the monitored pressure (p) exceeds the predefined threshold (p_{max}).

7. Control method as according to one of the foregoing claims, **characterized in that**

a) according to the predefined control scheme an injection is executed by means of moving the multiple-acting valve (10) from the first seat (1) into the open position (M) ;
b) the multiple-acting control valve (10) is placed in its
c) in order to execute the injection, the multiple-acting control valve (10) is firstly moved from the first seat (1) into the second seat (2) before it is moved into the open position (M) in case the monitored pressure (p) exceeds a predefined threshold (p_{max}).

8. Control method as according to one of the foregoing claims, **characterized in that**

a) according to the predefined control scheme two pre-injections are executed before a main injection takes place and the multiple-acting valve (10) is moved into the first seat (1) between the two pre-injections; and
b) instead, the multiple-acting control valve (10) is moved into the second seat (2) between the two pre-injections.

9. Control method as according to one of the foregoing claims, **characterized in that**

a) the system temperature (T) is monitored; and
b) the predefined control scheme is modified in case the monitored temperature (T) is below a predefined threshold (T_{min}).

10. Control method as according to one of the foregoing claims, **characterized in that**

a) the time gap between injections (ΔT) is monitored; and
b) the predefined control scheme is modified in case the time gap between injections (ΔT) exceeds a predefined value.

11. Control method as according to one of the foregoing claims, **characterized in that**

a) the status of the synchronicity of the system with respect to the camshaft and the crankshaft signal (St_{sync}) is monitored; and
b) the predefined control scheme is modified in case the system is not finally synchronized.

12. Control method as according to one of the foregoing claims, **characterized in that**

a) according to the predefined control scheme the multiple-acting control valve (10) is moved into the second seat (2) after an injection is executed; and
b) instead of doing so, the multiple-acting control valve (10) is moved into the first seat (1) in case the monitored temperature (T) is below a predefined threshold (T_{min}) and/or the time gap (ΔT) between these injections exceeds a predefined value (ΔT_{MAX}) and/or the system is not finally synchronized.

13. Control method as according to one of the foregoing claims, **characterized in that**

a) according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve (10) from the second seat (2) into the open position (M); and
b) instead of doing so, the multiple-acting control valve (10) is moved from the first seat (1) into the open position (M) in case the monitored temperature (T) is below a predefined threshold (T_{min}) and/or the time gap (ΔT) between these injections exceeds a predefined value (ΔT_{MAX}) and/or the system is not finally synchronized.

14. Control method as according to one of the foregoing claims, **characterized in that**

a) according to the predefined control scheme there is a pre-injection before a main injection and the multiple-acting control valve (10) is moved into the second seat (2) between the pre-injection and the main injection; and
b) instead of doing so, the multiple-acting control valve (10) is moved into the first seat (1) between the pre-injection and the main injection in case the monitored temperature (T) is below the predefined threshold (T_{min}) and/or the time gap (ΔT) between these injections exceeds a predefined value (ΔT_{MAX}) and/or the system is not finally synchronized.

15. Control method as according to one of the foregoing claims, **characterized in that**

a) both the fuel pressure (p) and the system temperature (T) are monitored; and
b) in case the pressure (p) exceeds the predefined threshold (p_{max}) and at the same time the temperature (T) is below the predefined threshold (T_{min}) the multiple-acting valve (10) is con-

trolled as if the pressure (p) would not exceed the predefined threshold (p_{max}).

16. Control method as according to one of claims 1, 2 and 4 through 12, **characterized in that**

a) the multiple-action control valve (10) is actuated by means of a piezoelectric element;
b) the buffer voltage (V_B) in the charging circuit of the piezoelectric element is monitored; and
c) the predefined control scheme is modified in case the monitored buffer voltage (V_B) is below a predefined threshold ($V_{B\ min}$).

17. Control method as according to one of claims 1, 2 and 4 through 12, **characterized in that**

a) the multiple-action control valve (10) is actuated by means of a piezoelectric element;
b) according to the predefined control scheme the multiple-acting control valve (10) is moved into the second seat (2) after an injection is executed; and
c) instead of doing so, the multiple-acting control valve (10) is moved into the first seat (1) in case the monitored buffer voltage (V_B) is below a predefined threshold (V_{Bmin}).

18. Control method as according to one of claims 1, 2 and 4 through 12, **characterized in that**

a) the multiple-action control valve (10) is actuated by means of a piezoelectric element;
b) according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve (10) from the second seat (2) into the open position (M); and
c) instead of doing so, the multiple-acting control valve (10) is moved from the first seat (1) into the open position (M) in case the monitored buffer voltage (V_B) is below a predefined threshold (V_{Bmin}).

19. Control method as according to claim 3, **characterized in that**

a) the buffer voltage (V_B) in the charging circuit of the piezoelectric element is monitored; and
b) the predefined control scheme is. modified in case the monitored buffer voltage (V_B) is below a predefined threshold (V_{Bmin}).

20. Control method as according to claim 3, **characterized in that**

a) according to the predefined control scheme the multiple-acting control valve (10) is moved into the second seat (2) after an injection is executed; and
b). instead of doing so, the multiple-acting control valve (10) is moved into the first seat (1) in case the monitored buffer voltage (V_B) is below a predefined threshold (V_{Bmin}).

21. Control method as according to claim 3, **characterized in that**

a) according to the predefined control scheme an injection is executed by means of moving the multiple-acting control valve (10) from the second seat (2) into the open position (M); and
b) instead of doing so, the multiple-acting control valve (10) is moved from the first seat (1) into the open position (M) in case the monitored buffer voltage (V_B) is below a predefined threshold ($V_{B\ min}$).

22. Control method as according to one of the foregoing claims, **characterized in that**

a) the monitored system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}) and/or any combination of two or more of the monitored system parameters are ranked in a priority ordering; and
b) the predefined control scheme and therefore the control of the multiple-acting valve is modified based on the monitored system parameter (p, T, V_B, St_{sync}, ΔT, St_{inj}) or combination of the monitored system parameters having the highest priority ranking.

23. Control apparatus for a multiple-acting valve within a fuel injection system, **characterized in that**

a) a control unit (120) is implemented for control of the multiple-acting valve (10) as according to a predefined control scheme;
b) monitoring means (100, 110) are implemented for monitoring at least one system parameter (p, T, V_B, St_{sync}, ΔT, St_{inj}); and
c) modification means (120) are implemented for modification of the predefined control scheme and therefore the control of the multiple-acting valve in case at least one of the monitored system parameters (p, T, V_B, St_{sync}, ΔT, St_{inj}) match predefined conditions.

FIG. 1

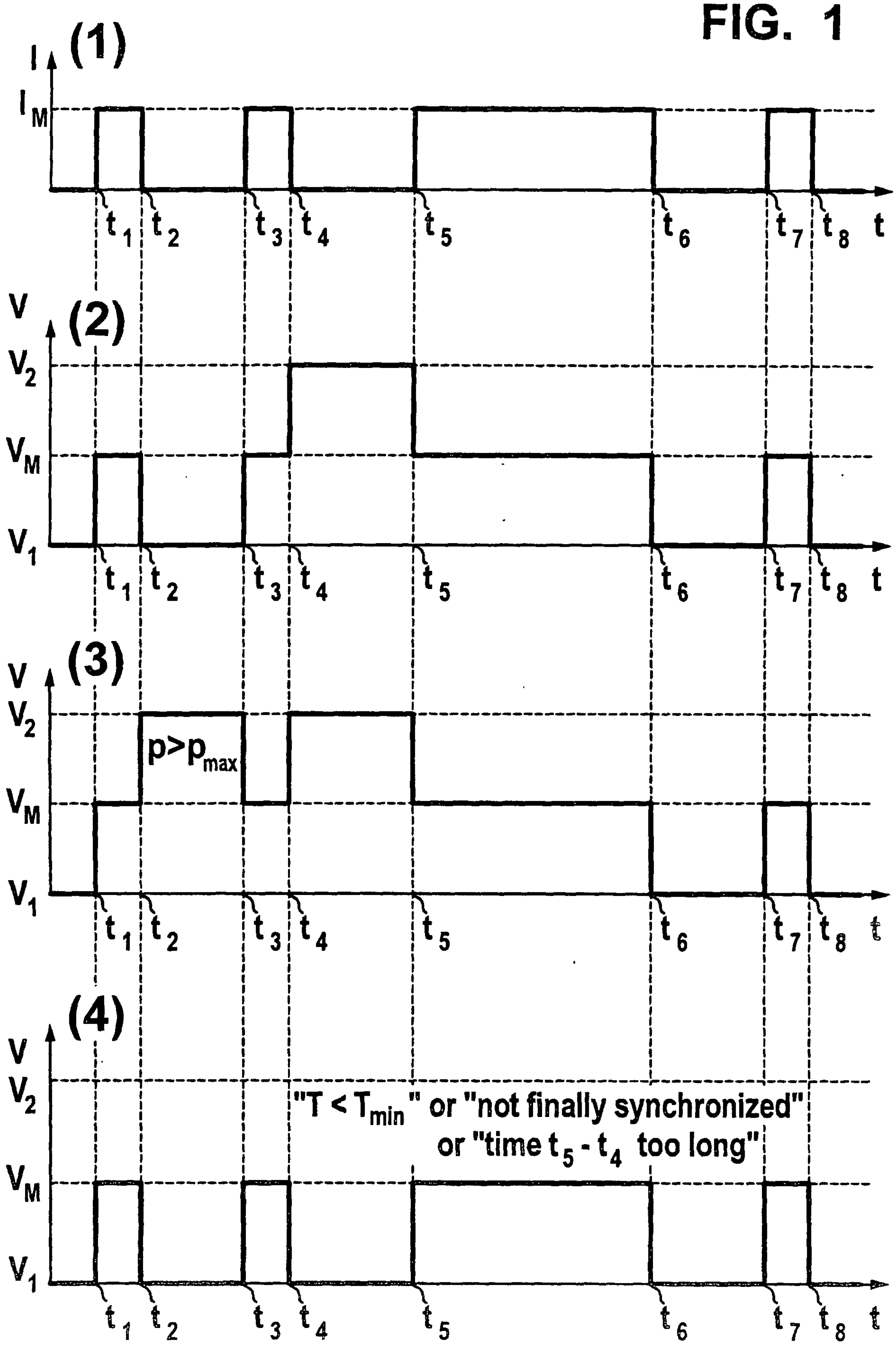

(1)
I
I_M
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t
(2)
V
V_2
V_M
V_1
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t
(3)
V
V_2
$p>p_{max}$
V_M
V_1
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t
(4)
V
V_2
"$T < T_{min}$" or "not finally synchronized"
or "time $t_5 - t_4$ too long"
V_M
V_1
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t

FIG. 2

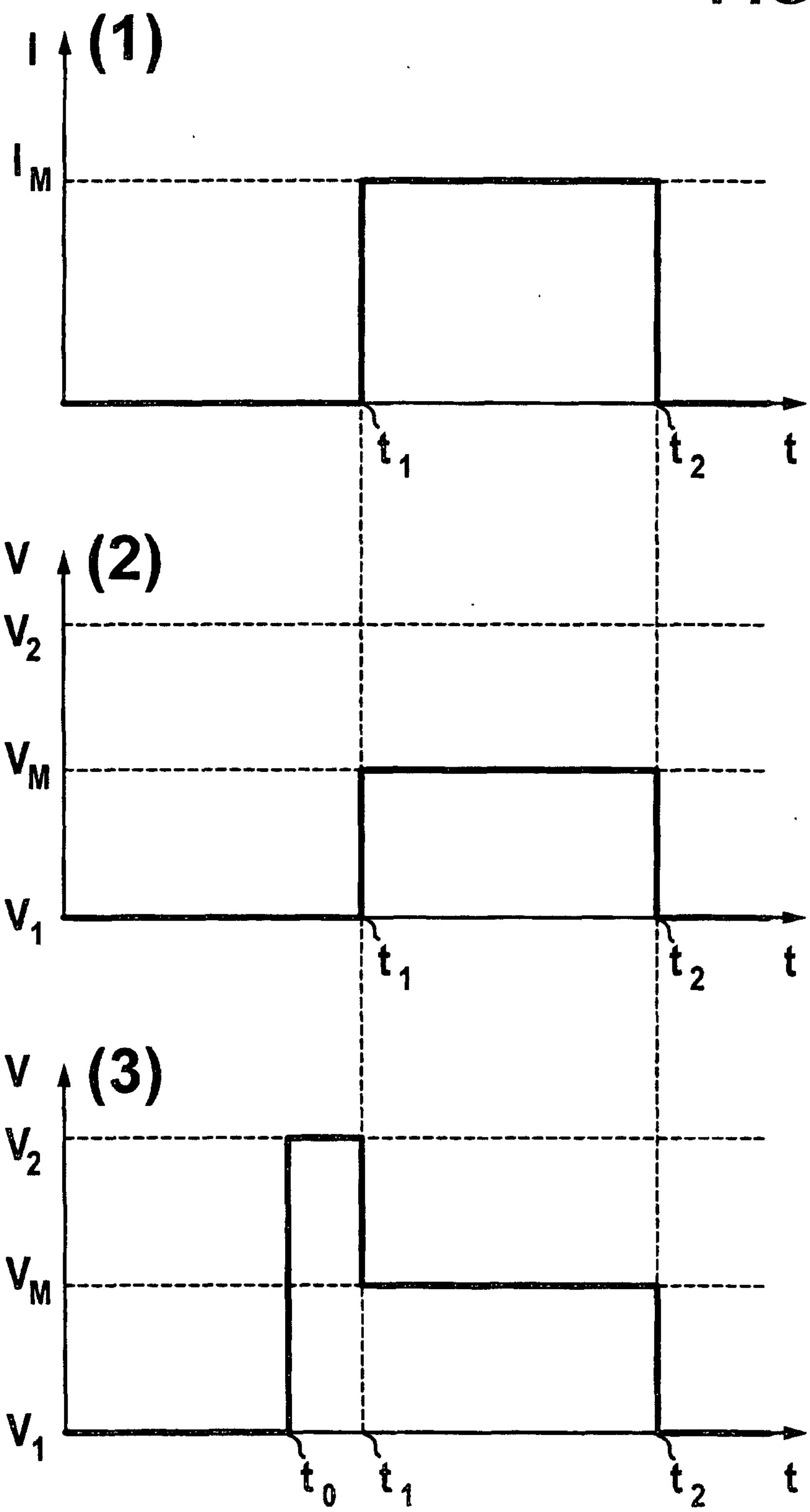


FIG. 3

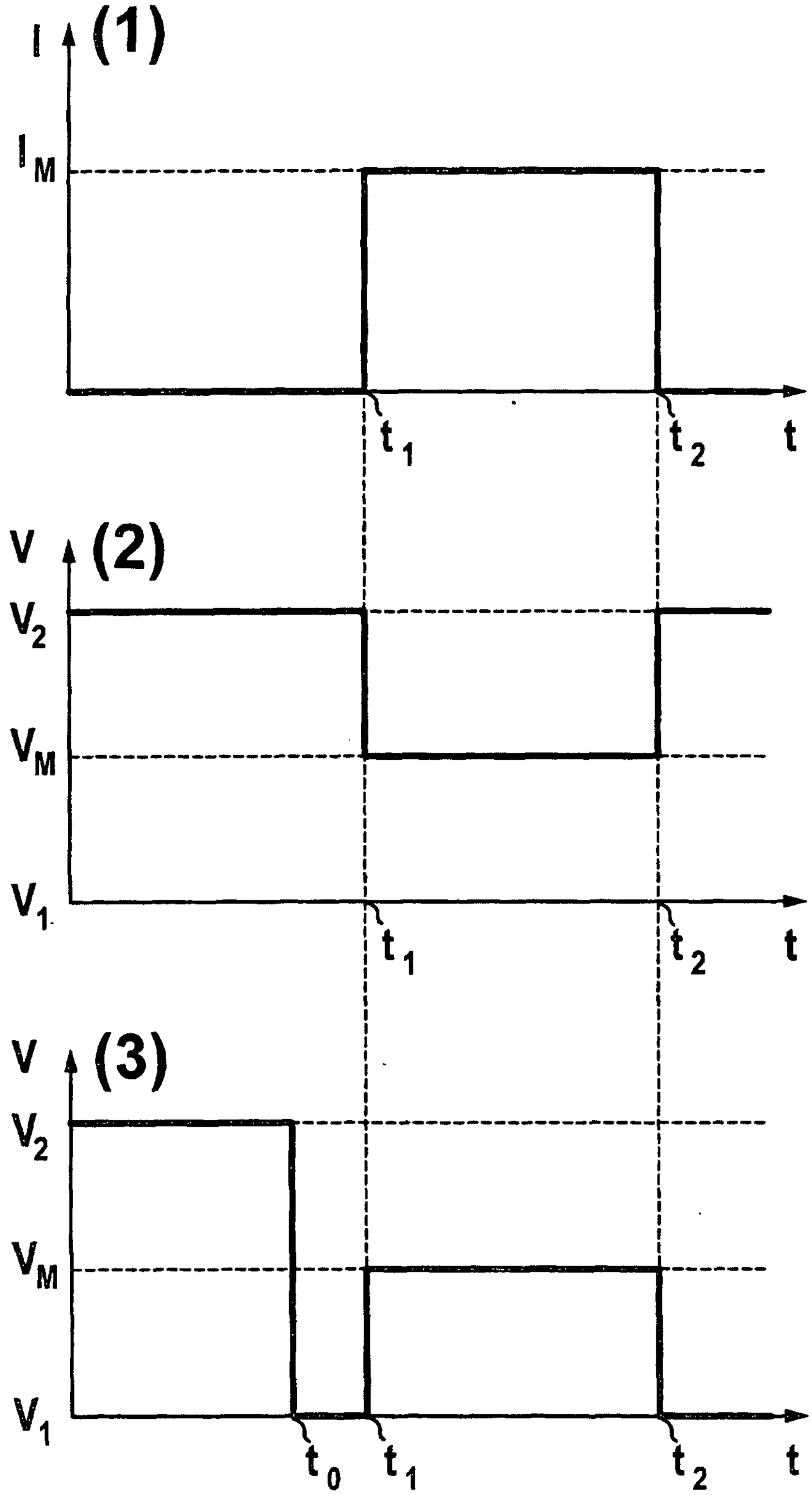


FIG. 4

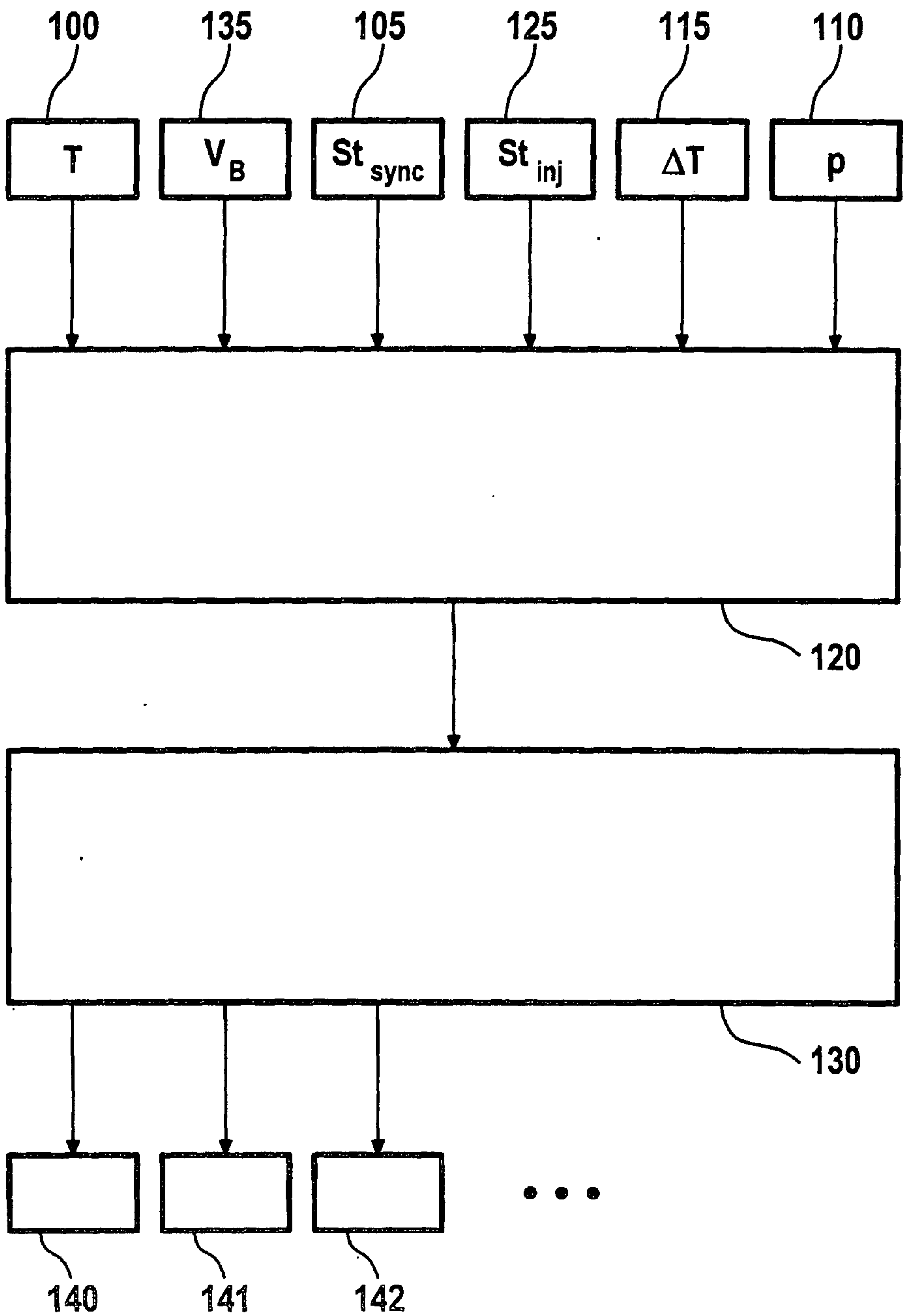
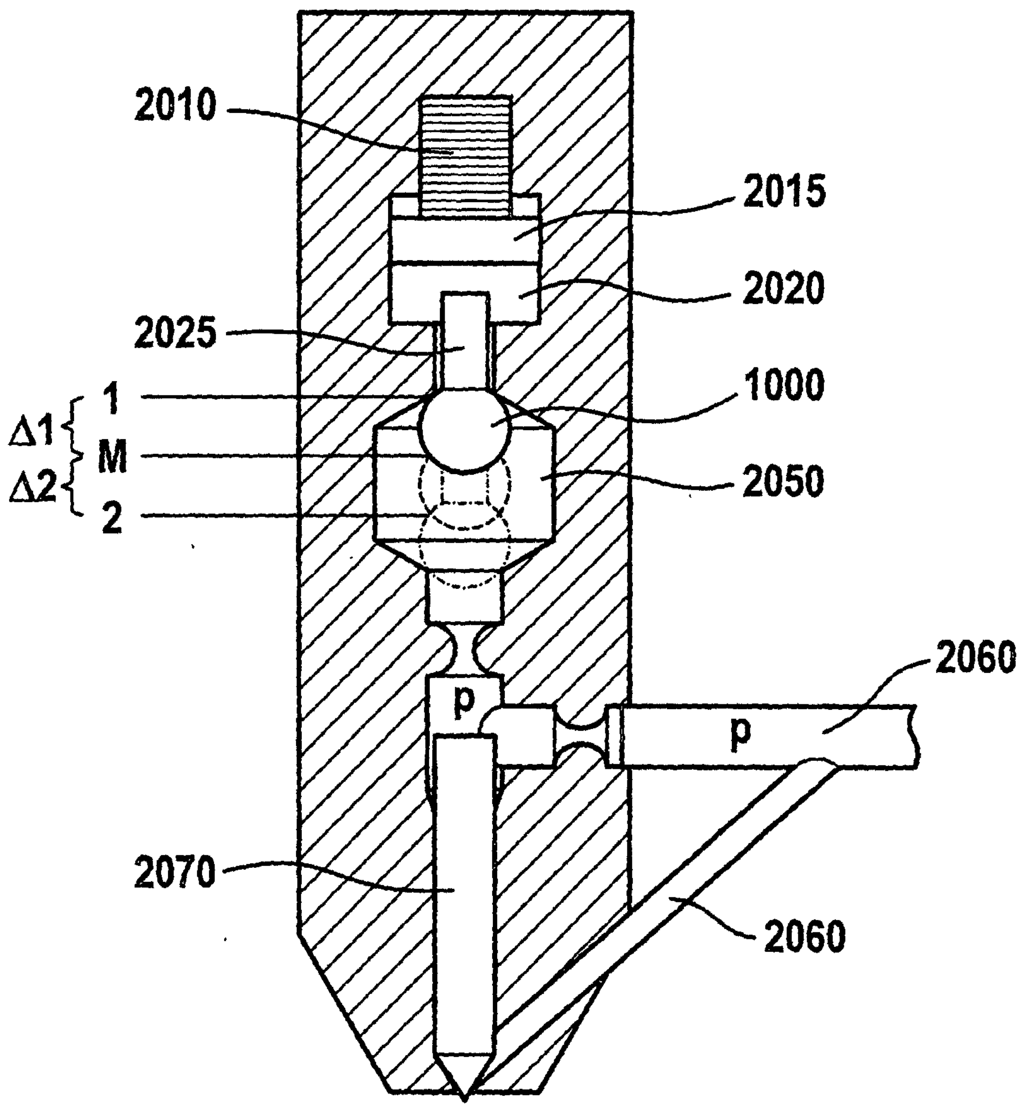
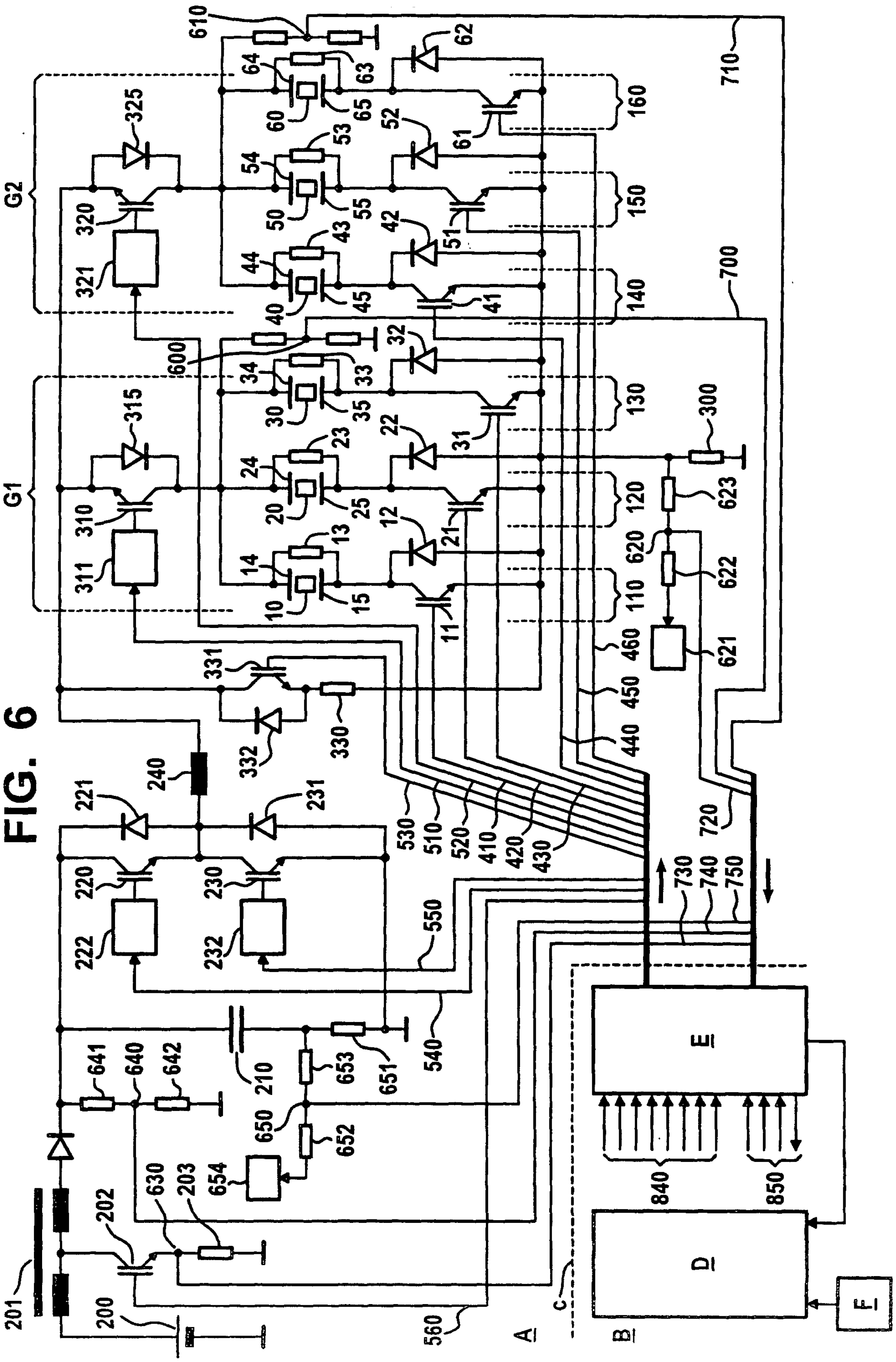

100
135
105
125
115
110
T
V_B
St_{sync}
St_{inj}
ΔT
p
120
130
140
141
142

FIG. 5




G1
G2
610
62
710
64
63
60
65
160
325
54
53
52
50
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150
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320
44
43
42
51
321
40
45
41
140
700
600
34
33
32
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35
130
315
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23
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300
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25
31
120
623
310
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12
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15
21
620
622
311
110
11
621
460
331
450
440
332
330
221
240
231
530
510
520
410
420
430
720
220
230
730
740
750
222
232
550
540
E
641
640
642
210
653
651
650
652
654
840
850
202
630
203
201
200
D
F
560
A
c
B

FIG. 6

FIG. 7a

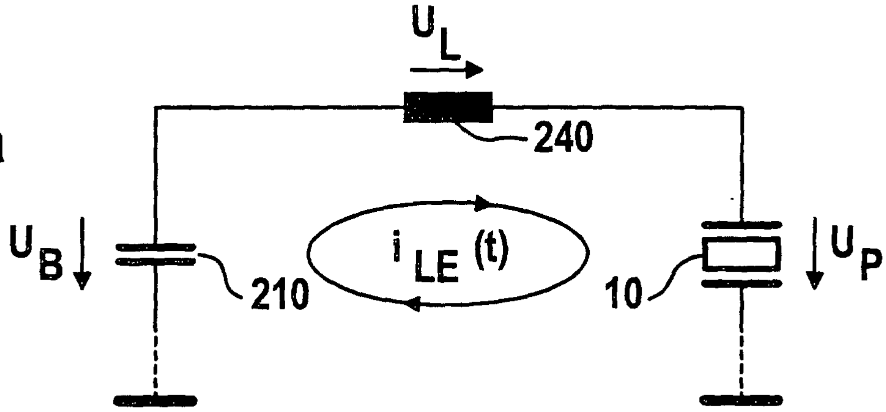


FIG. 7b

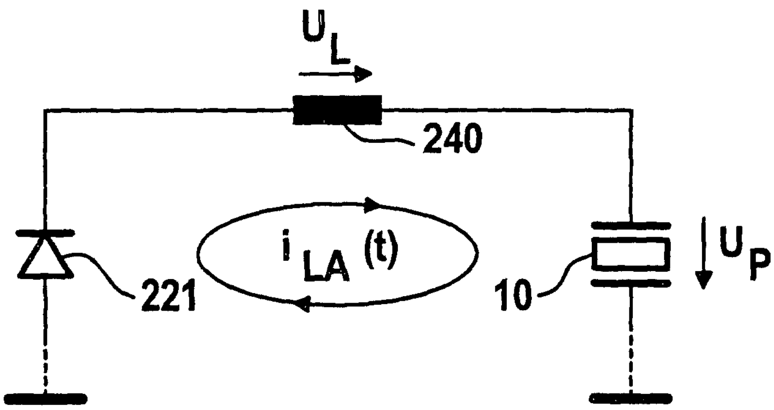


FIG. 7c

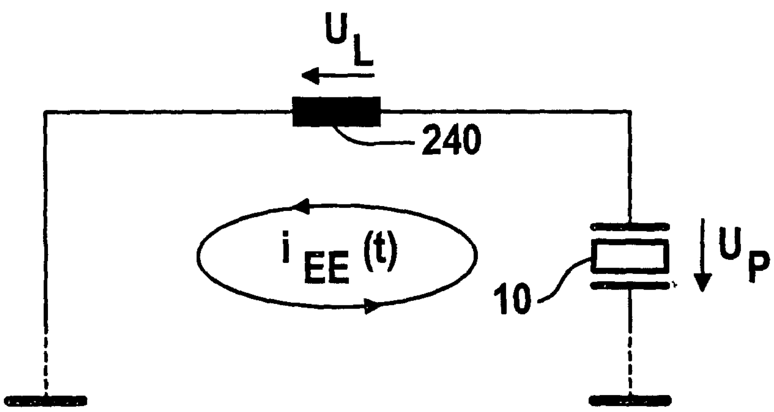
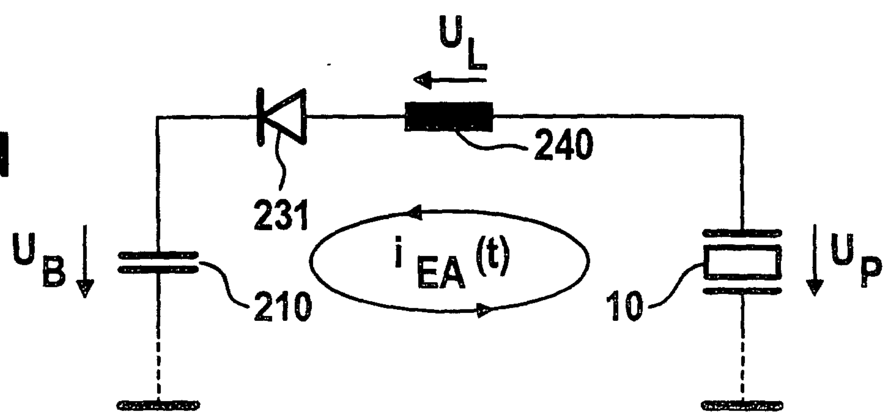


FIG. 7d



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 10 6987

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	US 5 924 403 A (THOMAS ERIC D) 20 July 1999 (1999-07-20) * figures 2-6 * * column 1, line 31 - column 2, line 10 * * column 3, line 51 - column 4, line 11 * * column 5, line 21 - line 45 * * column 6, line 7 - line 30 * * column 7, line 15 - column 8, line 54 * ---	1,4,5, 10,23	F02D41/38 F02M51/06 F02D41/20
D,A	DE 197 42 073 A (BOSCH GMBH ROBERT) 25 March 1999 (1999-03-25) * column 1, line 44 - column 2, line 9 * * column 3, line 46 - column 5, line 48 * * figures * ---	1-3,7,8, 23	
D,A	DE 197 29 844 A (BOSCH GMBH ROBERT) 14 January 1999 (1999-01-14) * column 1, line 20 - line 45 * * column 2, line 55 - column 5, line 33 * * figures 2-4 * -----	1-3	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

F02D
H01L
G01D
G01R
F02M
F02P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 July 2000	Lapeyronnie, P

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The members are as contained in the European Patent Office EDP file on
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