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(11) **EP 1 138 919 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
04.10.2001 Bulletin 2001/40

(51) Int Cl.7: **F02D 41/38**, F02D 41/20,
H01L 41/04, F02M 51/06

(21) Application number: **00106967.3**

(22) Date of filing: **01.04.2000**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**
Designated Extension States:
AL LT LV MK RO SI

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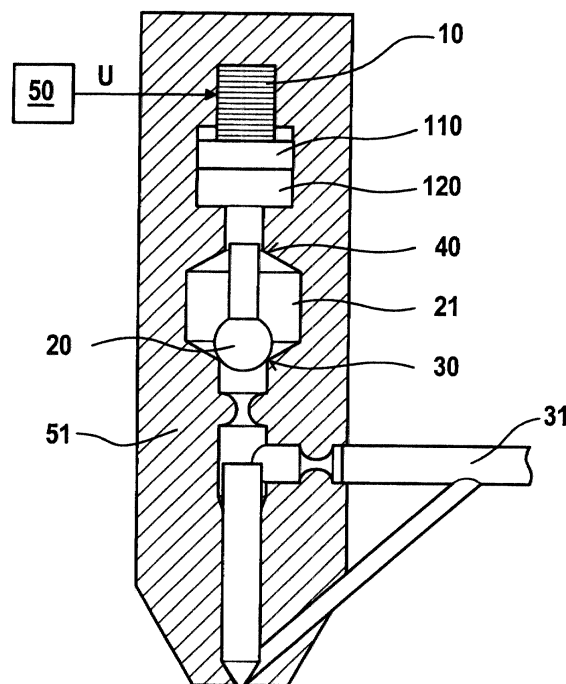
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(54) **Fuel injection system**

(57) Fuel injection system and method for operating the fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line by applying a voltage to said piezoelectric element,

wherein the voltage necessary to close the pressurized fuel supply line is determined based upon the gradient or the derivative over time of the pressure in the pressurized fuel supply line.

FIG. 1



Description

[0001] The present invention concerns a fuel injection system and a method for operating a fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line by applying a voltage to said piezoelectric element.

[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. As an example, piezoelectric elements may be used as piezoelectric elements for nozzles (in particular for common rail injectors) of an internal combustion engine. In this example, fuel injection is controlled by means of applying voltage to piezoelectric elements which expand or contract themselves as a function of the voltage applied.

[0003] Generally, for such applications it is of importance, to achieve predefined quantities of injected fuel. These predefined quantities need to be determined precisely. This holds especially true when small quantities of fuel are to be injected, e.g., during pre-injection. Accordingly, in order to achieve the aforementioned high accuracy of fuel injection with regard to timing and quantity, the valve needs to be positioned as accurately as possible. A deviating quantity of injected fuel has negative effects on the emissions. This problem arises specifically if a relatively small amount of fuel is to be injected.

[0004] It is an object of the present invention, to improve a fuel injection system in which a piezoelectric element drives a valve for closing a pressurized fuel supply line by applying a voltage to said piezoelectric element.

[0005] This object of the present invention is achieved by a method according to claim 1 and a fuel injection system according to claim 13, i.e., for operating the fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line, a voltage is applied to said piezoelectric element, wherein a minimal closing voltage necessary to close the pressurized fuel supply line is determined during or after an (normal) operation (within the life cycle) of the fuel injection system, in particular in the afterrun of a combustion engine which comprises the fuel injection system. The minimal closing voltage, which is necessary to close the pressurized fuel supply line, indicates the actual lift the piezoelectric element can perform. That means if the minimal voltage to close the valve is higher than a typical value (taking into account actual environmental data such as rail pressure) the piezoelectric element performs a lower lift than typically. The invention allows to use this minimal closing voltage to compensate for example aging effects of piezoelectric elements or sample

to sample deviations of the piezoelectric element or the injector itself. Furthermore, it can be used to indicate whether an piezoelectric element and/or injector has to be exchanged.

[0006] According to a preferred embodiment of the invention the minimal closing voltage necessary to close the pressurized fuel supply line is determined based upon the pressure in the fuel supply line.

[0007] According to a further preferred embodiment of the invention the minimal closing voltage necessary to close the pressurized fuel supply line is determined based upon the gradient or the derivative over time of the pressure in the fuel supply line.

[0008] An object of the present invention is preferably achieved by a method according to claim 5 and a fuel injection system according to claim 14, i.e., for operating the fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line, a voltage is applied to said piezoelectric element, wherein the minimal closing voltage necessary to close the pressurized fuel supply line is determined based upon the pressure in the fuel supply line. The invention allows to compensate for example the temperature dependency of fuel being injected and to compensate e.g. aging of the piezoelectric element and/or the injector.

[0009] An object of the present invention is advantageously achieved by a method according to claim 6 and a fuel injection system according to claim 15, i.e., for operating the fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line, a voltage is applied to said piezoelectric element, wherein the minimal closing voltage necessary to close the pressurized fuel supply line is determined based upon the gradient or the derivative over time of the pressure in the fuel supply line. The invention allows to compensate for example aging of the piezoelectric element and/or the injector.

[0010] An object of the present invention is alternatively achieved by a method according to claim 6 and a fuel injection system according to claim 16, i.e., for operating a fuel injection system, in which a piezoelectric element drives a valve for closing a pressurized fuel supply line a voltage is applied to said piezoelectric element, wherein the fuel injection system comprises a high pressure pump for controlling the pressure in the pressurized fuel supply line based upon a measurement of the pressure in the pressurized fuel supply line and wherein the minimal closing voltage necessary to close the pressurized fuel supply line is determined based upon the power consumption of the high pressure pump, the output of a controller controlling the high pressure pump and/or the difference between the measurement of the pressure in the pressurized fuel supply line and the desired value of the pressure in the pressurized fuel supply line. The invention allows to compensate for example aging of the piezoelectric element and/or the injector.

[0011] According to a further preferred embodiment

of the invention the pressurized fuel supply line is closed by applying a predetermined voltage on said piezoelectric element.

[0012] According to a further preferred embodiment of the invention said predetermined voltage is reduced, wherein said pressure in the pressurized fuel supply line or said gradient or said derivative over time of the pressure in the pressurized fuel supply line is monitored.

[0013] According to a further preferred embodiment of the invention said gradient or said derivative over time of the pressure in the pressurized fuel supply line is calculated based upon said pressure in the pressurized fuel supply line.

[0014] According to a further preferred embodiment of the invention said minimal closing voltage necessary to close the pressurized fuel supply line is assigned the actual value of the voltage applied on said piezoelectric element if the absolute value of said gradient or said derivative over time exceeds a predetermined limit.

[0015] According to a further preferred embodiment of the invention said valve is a double acting valve.

[0016] The above-described method can be applied during different operation situations. Preferably, the above-described method is applied during the after run of a combustion engine which comprises the fuel injection system. However, in another application of the inventive method, the method can also be applied during the starting phase of a combustion engine. The disadvantage of applying this method in the starting phase of the internal combustion engine is, that it would start with time delay. For this reason the application of this method during the after run of the combustion engine system is preferred. In addition, applying the above-described method during the after run bears the advantage that the pressure in the pressurized fuel supply line can be built to a certain predefined value and be held at this value with minimum interference of disturbing factors which otherwise might lead to different measuring results.

[0017] In a preferred embodiment of the invention the minimal closing voltage that needs to be applied is used to determine the change of lift of the piezoelectric element. Preferably, the aging process of piezoelectric elements is monitored this way, i.e., the minimal closing voltage is utilized to determine the aging of the piezoelectric element.

[0018] Implementing the invention in common rail systems allows to test each single piezoelectric element regardless of the number of control valves used within the common rail system. If implemented in a common rail system the pressure is preferably sensed by a single sensing device regardless of the number of piezoelectric elements implemented in a single fuel injection nozzle.

[0019] Within a preferred implementation of the inventive method the application of the method is repeated periodically. The advantage of the periodic repetition of the method is to be found in the possibility to receive

data over a longer time frame. These data are preferably utilized to determine the changes of the lift of the piezoelectric elements in said time frame. The intervals in which the method is applied can, e.g., be determined by the number of runs that are undertaken with the combustion engine and the number of piezoelectric elements that need to be tested. It is sufficient to apply the inventive method in each after run of the combustion engine with a different piezoelectric element. If, e.g., the method is applied in fuel injection systems with six fuel injection nozzles and each fuel injection nozzle is driven by one piezoelectric element acting on the control valve, the method would be applied once with each piezoelectric element and once without activating a piezoelectric element. Thus the repetition cycle would begin with the testing of the first piezoelectric element and again after seven applications of the inventive method.

[0020] The invention will be explained below in more detail with reference to exemplary embodiments, referring to the figures in which:

Fig. 1 shows a schematic representation of a fuel injection system with a double acting control valve;

Fig. 2 shows a further schematical presentation of the fuel injection system;

Fig. 3 shows an example for a flow chart implemented on the control unit shown in Fig. 1;

Fig. 4 shows voltage U versus time t ;

Fig. 5 shows pressure p_{rail} versus time t ;

Fig. 6 shows another example for a flow chart implemented on the control unit shown in Fig. 1; and

Fig. 7 shows another example for a flow chart implemented on the control unit shown in Fig. 1;

[0021] Fig. 1 and Fig. 2 show a fuel injection system as an exemplary embodiment of the invention. Reference number 51 refers to an injector with a double acting control valve 20. Reference number 40 refers to a first closed position and reference number 30 to a second closed position.

[0022] The fuel injection system as depicted in Fig. 1 comprises a hollow bore 21 in which a double acting control valve 20 can be moved up and down between the first closed position 40 and the second closed position 30. The control valve 20 is moved by applying a voltage U to a piezoelectric element 10 controlled by a control unit 50. The piezoelectric element 10 is driving the double acting control valve 20 by means of the transfer system. In the exemplary embodiment depicted in Fig. 1 the transfer system comprises a piston 110 and a hy-

draulic coupler 120. As shown in Fig. 1 the double acting control valve 20 can be positioned in a first closed position 40 and in a second closed position 30. In the shown example the double acting control valve 20 is in the second closed position 30. In this second closed position 30 the double-acting control valve 20 is closing the bore 21 against a fuel supply line 31, thus, not permitting any fuel entering the hollow bore 21. In this second closed position 30 pressure p_{rail} in the fuel supply line 31 applies a force against the control valve 20.

[0023] If the valve 20 opens the fuel supply line 31 a drop of the pressure p_{rail} or in the fuel supply line 31 occurs. This drop of the pressure p_{rail} in the pressured fuel supply line 31 opens the fuel injection nozzle and fuel is injected.

[0024] Fig. 2 shows a fuel injection system with four injectors 51, 52, 53, 54 connected via a common rail 62 containing fuel having a rail pressure p_{rail} . This rail pressure p_{rail} can be, for example, up to 500 bar. To maintain a high pressure in the common rail 62, the common rail 62 is connected to a high pressure pump 60 via a supply line 63. The high pressure pump 60 pumps fuel into the common rail 62. The high pressure pump 60 is (further connected via a connector 64) to a low pressure reservoir 80 containing fuel at a pressure which is lower than p_{rail} . The injectors 51, 52, 53, 54 are connected to the common rail 62 via fuel supply lines 31, 66, 67 and 68 respectively. With their so-called low pressure side, the injectors 51, 52, 53, 54 are connected to the low pressure reservoir 80 via low pressure lines 81, 82, 83, 84 respectively.

[0025] The control unit 50 is connected to the injectors 51, 52, 53, 54 via cables 85, 86, 87, 88 for applying a voltage to the piezoelectric elements of the injectors 51, 52, 53, 54. The control unit 50 is further connected to a pressure sensor 70 via a cable 89. The pressure sensor 70 measures the pressure p_{rail} in the common rail 62. Arrangements are also possible, wherein pressure sensors to measure the fuel pressure are located at the fuel supply lines 31, 66, 67, 68 or even within the injectors 51, 52, 53, 54. However, the example illustrated in Fig. 2, where one pressure sensor 70 is used to measure the pressure p_{rail} in the common rail 62, is a preferred embodiment.

[0026] The pressurized fuel supply line referred to in the claims include not only the fuel supply lines 31, 66, 67, 68 but also the common rail 62, the connector 63 or even fuel supply lines within the injectors 51, 52, 53, 54. The control unit 50 controls, in a preferred embodiment, the high pressure pump 60. In a preferred embodiment, the control unit 50, acts as a controller controlling the high pressure pump 60 based upon measured values of the rail pressure p_{rail} and the common rail 62 obtained by the pressure sensor 70. Power supply lines for supplying the high pressure pump 60 with electric power are not shown in Fig. 2.

[0027] Fig. 3 shows a flow chart which is implemented on the control unit 50. In a first step 90 a maximum volt-

age U_{max} is assigned to be the voltage U being applied to the piezoelectric element 10.

[0028] Applying this method in common rail systems with double acting control valves with a voltage U of about 180 - 200 V ($= U_{max}$) should be applied to move the control valve 20 to the second closed position 30. In such a system usually a voltage with a lower value of about 180 V is already sufficient to urge the control valve 20 to the second closed position 30. This value is normally even sufficient if the lift of the piezoelectric element is diminished due to aging.

[0029] Step 90 is followed by step 91. In step 91 the pressure p_{rail} of the common rail system is measured. The rail pressure, might for example be build up to about 500 bar. If utilized in a common rail system, it is advantageous to shut off the rail pressure control after the predefined pressure is reached in order to secure that a high pressure pump used for building up the rail pressure has no influence on the application of the method.

[0030] Step 91 is followed by a step 92 where the actual value of the pressure p_{rail} is stored by assigning its value to a variable

P_{rail_old} :

$$P_{rail_old} = P_{rail}$$

[0031] After a time Δt with

$$\Delta t = t_2 - t_1$$

wherein t_1 and t_2 are defined as shown in Fig. 4 a step 93 is carried out. In step 93 the voltage U applied on the piezoelectric element 10 is decreased by a predetermined voltage ΔU , i.e.

$$U = U - \Delta U$$

[0032] Step 93 is followed by a step 94 in which the pressure p_{rail} in the fuel supply line 31 is measured again. Step 94 is followed by a step 95 in which the gradient (or derivative over time) Δp_{rail} in the fuel supply line 31 is calculated via

$$\Delta p_{rail} = (p_{rail_old} - p_{rail}) / \Delta t$$

[0033] Of course other algorithms for calculating a gradient or derivative over time Δp_{rail} or a filtered derivative over time, e.g. a DT_1 filter might be used. In another alternative just the difference between p_{rail_old} and p_{rail} may be calculated, i.e.

$$\Delta p_{rail} = p_{rail_old} - p_{rail}$$

[0034] Step 95 is followed by a decision block 96 checking whether the absolute value of Δp_{rail} is greater than a predetermined limit T.

$$|\Delta p_{\text{rail}}| > T$$

[0035] If the condition

$$|\Delta p_{\text{rail}}| > T$$

is not fulfilled the decision block 96 is followed by step 92. This loop is indicated by the stepwise reduction of voltage U in Fig. 4.

[0036] If however the condition

$$|\Delta p_{\text{rail}}| > T$$

is fulfilled, decision block 96 is followed by a step 97 in which the minimal closing voltage U_{min} which is necessary to close the fuel supply line 31 is assigned the actual value of the voltage U applied to the piezoelectric element 10. Step 97 is followed by a step 98 in which the voltage U applied to the piezoelectric element 10 is reduced to 0 V as indicated also in Fig. 4. Reducing the value of the voltage U to 0 V moves the double acting control valve 20 into the first closing position 40 and also closes the fuel supply line 31. If this is done quick enough, it can be guaranteed that no fuel has entered into the cylinder while applying the inventive method. The pressure drop is only due to the leakage at the control valve when this is no longer closed the second closed position.

[0037] Fig. 4 and Fig. 5 illustrate the voltage U applied to the piezoelectric element 10 and the pressure p_{rail} in the common rail. At the time t_{open} the voltage U applied to the piezoelectric element 10 has reached a value U_{min} . At this minimal closing voltage U_{min} the piezoelectric element 10 is no longer capable of moving the double acting control valve 20 into the second closed position 30, i.e., the fuel supply line 31 is no longer closed. This leads to a drop in pressure p_{rail} in the common rail. This pressure drop, shown in Fig. 5, is sensed via the decision block 96 after the time interval Δt has expired, i.e., the drop of the pressure p_{rail} in the fuel supply line 31 is sensed at the time

$$t_{\text{open}} + \Delta t.$$

[0038] The decrease of the pressure p_{rail} shown in Fig. 5 before t_{open} and after $t_{\text{open}} + \Delta t$ is shown schematically only. It is much less than indicated in Fig. 5. This decrease of the pressure p_{rail} is due to leakage and forms preferably the basis for calculating the limit T. The limit T is preferably slightly higher than the absolute val-

ue of the slope of the decrease of the pressure p_{rail} before t_{open} .

[0039] Fig. 6 shows an alternative flow chart which can be implemented on the control unit 50. In a first step 130 a maximum voltage U_{max} is assigned to be the voltage U being applied to the piezoelectric element 10. Step 130 is followed by step 131 assigning the value of a voltage U_{old} to be U_{max} . Step 131 is followed by step 132. In step 132 the pressure p_{rail} of the common rail 62 (or in the fuel supply line 31) is measured. If utilized in a common rail system, it is advantageous to shut off the high pressure pump after a predefined pressure is reached in order to secure that the rail pressure is not biased.

[0040] Step 132 is followed by a step 133 where the actual value of the rail pressure p_{rail} is stored by assigning its value to a variable $p_{\text{rail_old}}$:

$$p_{\text{rail_old}} = p_{\text{rail}}$$

[0041] After a time Δt_x a step 134 is carried out. In step 134 a voltage U with

$$U = U_{\text{old}} - \Delta U$$

is applied on the piezoelectric element 10.

[0042] Step 134 is followed by a step 135 in which the rail pressure p_{rail} in the common rail is measured again. Step 135 is followed by a step 136 in which a gradient Δp_{rail} is calculated via

$$\Delta p_{\text{rail}} = (p_{\text{rail_old}} - p_{\text{rail}}) / \Delta t_x$$

wherein Δt_x is the time interval between the two measurements $p_{\text{rail_old}}$ and p_{rail} .

In another alternative just the difference between $p_{\text{rail_old}}$ and p_{rail} may be calculated, i.e.

$$\Delta p_{\text{rail}} = p_{\text{rail_old}} - p_{\text{rail}}$$

[0043] Step 136 is followed by a decision block 137 checking whether the absolute value of Δp_{rail} is greater than a predetermined limit T_x .

$$|\Delta p_{\text{rail}}| > T_x$$

[0044] If the condition

$$|\Delta p_{\text{rail}}| > T_x$$

is not fulfilled the decision block 137 is followed by a step 138. In step 138 U_{old} is assigned to have the actual

value of U:

$$U_{old} = U$$

[0045] Step 138 is followed by a step 139 reducing the voltage applied to the piezoelectric element to 0V:

$$U=0V$$

i. e. the piezoelectric element is discharged. Step 139 is followed by step 133.

[0046] If however the condition

$$|\Delta p_{rail}| > T_x$$

is fulfilled, decision block 137 is followed by a step 140 in which the minimal closing voltage U_{min} which is necessary to close the fuel supply line 31 is assigned the actual value of the voltage U applied to the piezoelectric element 10:

$$U_{min} = U$$

[0047] Step 140 is followed by a step 141 in which the voltage U applied to the piezoelectric element 10 is reduced to 0 V. Reducing the value of the voltage U to 0V moves the double acting control valve 20 into the first closing position 40 and also closes the fuel supply line 31. If this is done quick enough, it can be guaranteed that no fuel has entered into the cylinder while applying the inventive method. The pressure drop is only due to the leakage at the control valve when this is no longer closed the second closed position.

[0048] Fig. 7 shows an alternative flow chart which can be implemented on the control unit 50. In a first step 150 a maximum voltage U_{max} is assigned to be the voltage U being applied to the piezoelectric element 10. Step 151 is followed by a step 152 where the actual value of the power consumption P_{HPP} of the high pressure pump is stored by assigning its value to a variable P_{HPP_old} :

$$P_{HPP_old} = P_{HPP}$$

[0049] After a time Δt a step 152 is carried out. In step 153 the voltage U applied on the piezoelectric element 10 is decreased by a predetermined voltage ΔU , i.e.:

$$U = U - \Delta U$$

[0050] Step 153 is followed by a step 154 in which the power consumption P_{HPP} of the high pressure pump is

determined again. Step 154 is followed by a step 155 in which the difference

$$\Delta P_{HPP} = P_{HPP_old} - P_{HPP}$$

is calculated.

[0051] Step 155 is followed by a decision block 156 checking whether the absolute value of ΔP_{HPP} is greater than a predetermined limit T_{HPP} .

$$|\Delta P_{HPP}| > T_{HPP}$$

[0052] If the condition

$$|\Delta P_{HPP}| > T_{HPP}$$

is not fulfilled the decision block 156 is followed by step 152.

[0053] If, however, the condition

$$|\Delta P_{HPP}| > T_{HPP}$$

is fulfilled, decision block 156 is followed by a step 157 in which the minimal closing voltage U_{min} which is necessary to close the fuel supply line 31 is assigned the actual value of the voltage U applied to the piezoelectric element 10. Step 157 is followed by a step 158 in which the voltage U applied to the piezoelectric element 10 is reduced to 0V. Reducing the value of the voltage U to 0V moves the double acting control valve 20 into the first closing position 40 and also closes the fuel supply line 31.

[0054] The example in Fig. 7 can be also carried out using the output of a controller controlling the high pressure pump 60 or the difference between the measurement of the pressure in the pressurized fuel supply line (e. g. the common rail) and the desired value of the pressure in the pressurized fuel supply line (e. g. the common rail) instead of using the power consumption of the high pressure pump.

[0055] The above described implementations of the inventive method and apparatus are exemplary only. For example, it is also possible to implement the invention with other types of control valve arrangements, e. g., single acting control valves.

Claims

1. Method for operating a fuel injection system, in which a piezoelectric element (10) drives a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a voltage (U) to said piezoelectric element (10),

characterized in that

a minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined during or after an operation of the fuel injection system.

2. Method according to claim 1,

characterized in that

a minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

3. Method according to claims 1 or 2,

characterized in that

the minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the gradient or the derivative over time (Δp_{rail}) of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

4. Method according to claims 1, 2 or 3, wherein the fuel injection system comprises a high pressure pump for controlling the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon a measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68),**characterized in that**

the minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the power consumption of the high pressure pump, the output of a controller controlling the high pressure pump and/or the difference between the measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) and the desired value of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

5. Method for operating a fuel injection system, in which a piezoelectric element (10) drives a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a voltage (U) to said piezoelectric element (10),

characterized in that

a minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

6. Method for operating a fuel injection system, in which a piezoelectric element (10) drives a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a voltage (U) to said

piezoelectric element (10),

characterized in that

a minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the gradient or the derivative over time (Δp_{rail}) of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

7. Method according to claims 2, 3, 4, 5 or 6,

characterized in that

said pressurized fuel supply line (31, 62, 63, 66, 67, 68) is closed by applying a predetermined voltage ($U_{\max}$) on said piezoelectric element (10).

8. Method according to claim 7,

characterized in that

said predetermined voltage ($U_{\max}$) applied on said piezoelectric element (10) is reduced, wherein said pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) or said gradient or said derivative over time (Δp_{rail}) of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is monitored.

9. Method according to claim 8,

characterized in that

said gradient or said derivative over time (Δp_{rail}) of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is calculated based upon said pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68).

10. Method according to claim 8 or 9,

characterized in that

said minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is assigned the actual value of the voltage (U) applied on said piezoelectric element (10) if the absolute value of said gradient or said derivative over time (Δp_{rail}) exceeds a predetermined limit.

11. Method for operating a fuel injection system, in which a piezoelectric element (10) drives a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a voltage (U) to said piezoelectric element (10), wherein the fuel injection system comprises a high pressure pump for controlling the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon a measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68),**characterized in that**

the minimal closing voltage ($U_{\min}$) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is determined based upon the power consumption of the high pressure pump, the output

of a controller controlling the high pressure pump and/or the difference between the measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) and the desired value of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68). 5

12. Method according to claim 11,

characterized in that

following consecutive steps are carried out: 10

- closing said pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a predetermined voltage (U_{max}) on said piezoelectric element (10) 15
- reducing said predetermined voltage (U_{max}) applied on said piezoelectric element (10), wherein the power consumption of the high pressure pump, the output of a controller controlling the high pressure pump and/or the difference between the measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) and the desired value of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) is monitored. 20 25

13. Fuel injection system, in which a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) can be driven by a piezoelectric element (10) by applying a voltage (U) to said piezoelectric element (10), in particular using a method according to one of the claims 1, 2, 3, 4, 7, 8, 9, or 10,

characterized in that

said fuel injection system comprises a control unit (50) for determining the minimal closing voltage (U_{min}) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) during or after an operation of the fuel injection system. 30 35

14. Fuel injection system, in which a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) can be driven by a piezoelectric element (10) by applying a voltage (U) to said piezoelectric element (10), in particular using a method according to one of the claims 5, 7, 8, 9 or 10,

characterized in that

said fuel injection system comprises a control unit (50) for determining the minimal closing voltage (U_{min}) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68). 40 45 50

15. Fuel injection system, in which a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) can be driven by a piezoelectric element (10) by applying a voltage (U) to said piezoelectric element (10), in particular using a method accord-

ing to one of the claims 3 or 6 through 10,

characterized in that

said fuel injection system comprises a control unit (50) for determining the minimal closing voltage (U_{min}) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon the gradient or the derivative over time (Δp_{rail}) of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68). 5

16. Fuel injection system, in which a piezoelectric element (10) drives a valve (20) for closing a pressurized fuel supply line (31, 62, 63, 66, 67, 68) by applying a voltage (U) to said piezoelectric element (10), in particular using a method according to one of the claims 4 through 12 wherein the fuel injection system comprises a high pressure pump for controlling the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon a measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68),

characterized in that

said fuel injection system comprises a control unit (50) for determining the minimal closing voltage (U_{min}) necessary to close the pressurized fuel supply line (31, 62, 63, 66, 67, 68) based upon the power consumption of the high pressure pump, the output of a controller controlling the high pressure pump and/or the difference between the measurement of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68) and the desired value of the pressure (p_{rail}) in the pressurized fuel supply line (31, 62, 63, 66, 67, 68), 15 20 25 30 35

17. Fuel injection system according to claim 13, 14 or 15 or 16,

characterized in that

said valve (20) is a double-acting valve. 40 45 50 55

FIG. 1

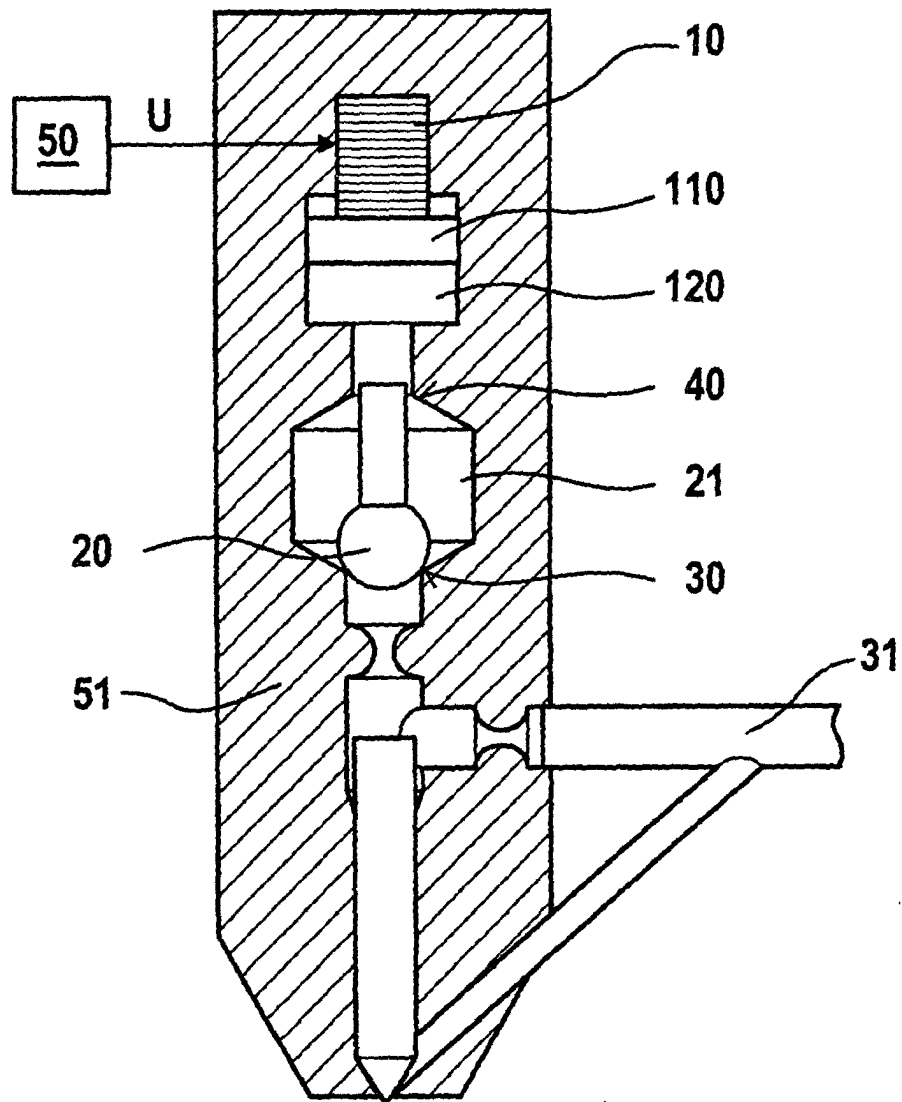


FIG. 2

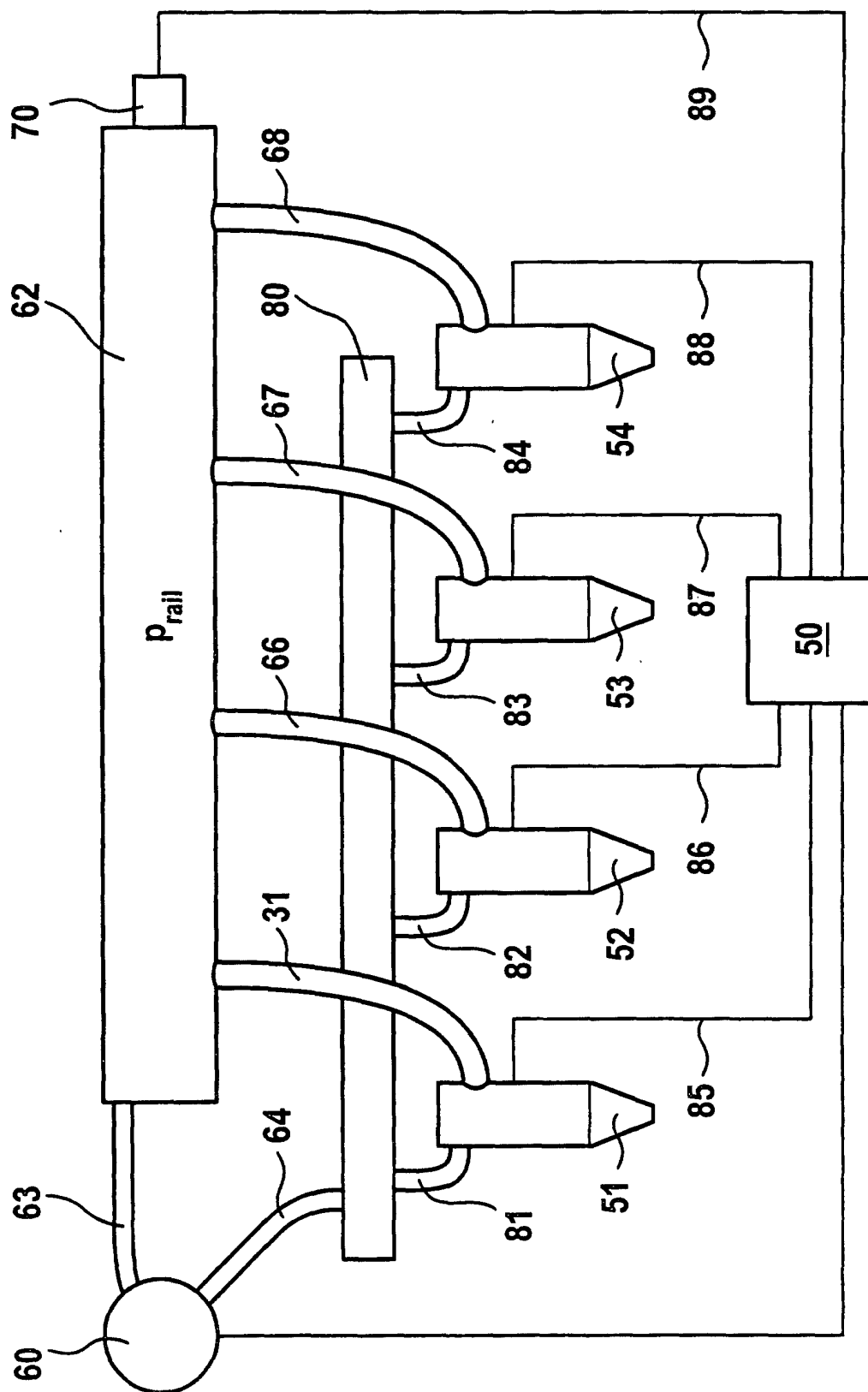
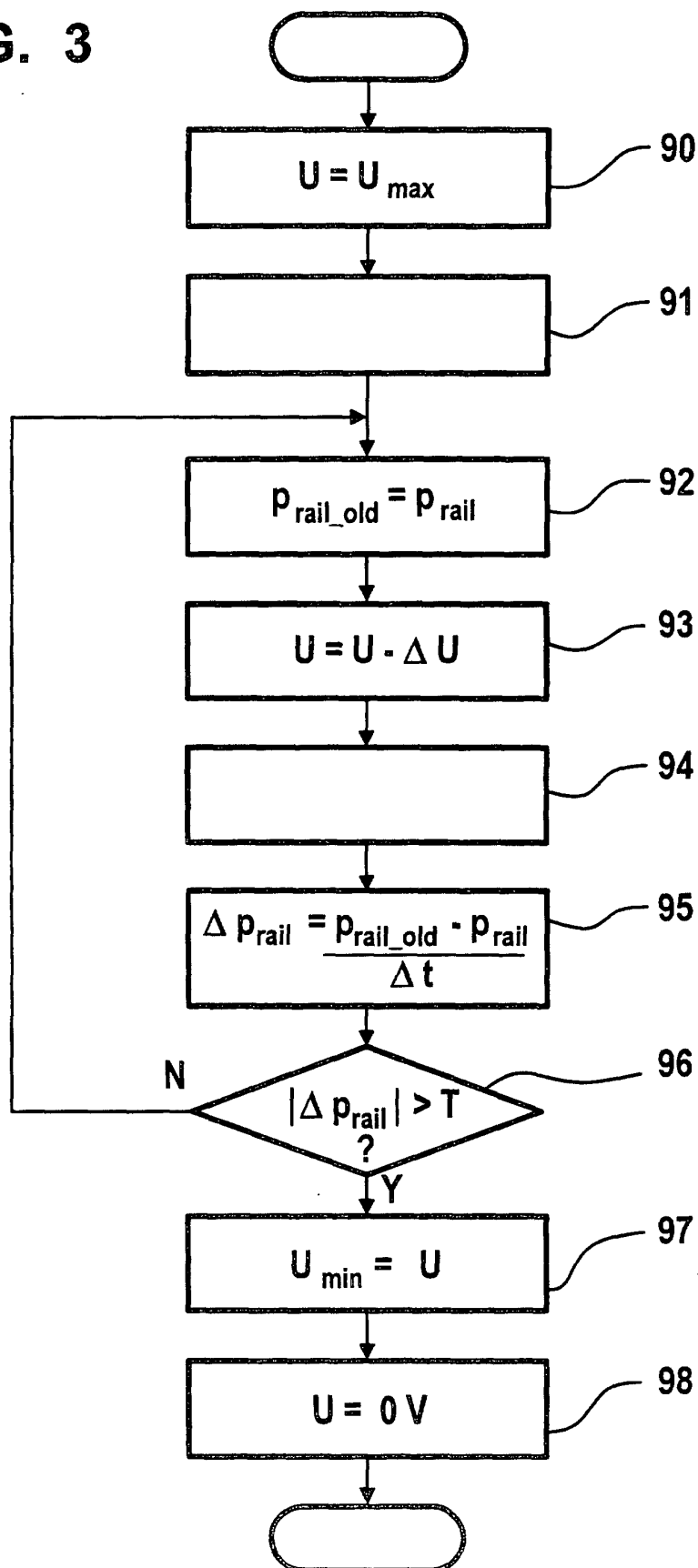


FIG. 3



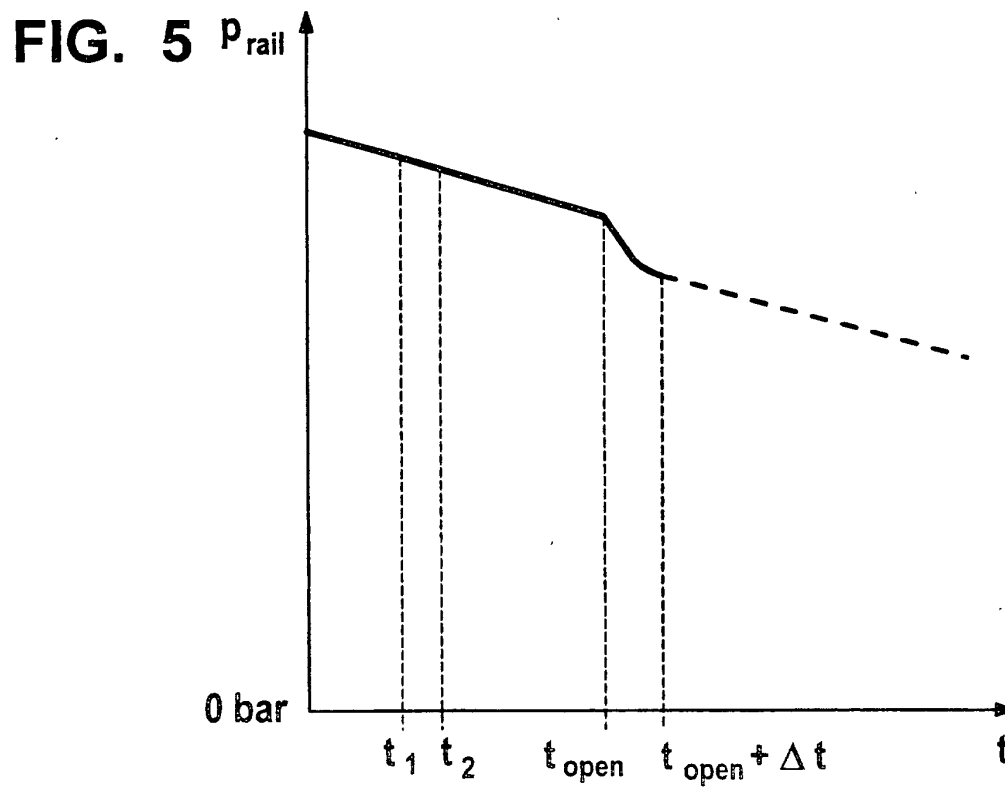
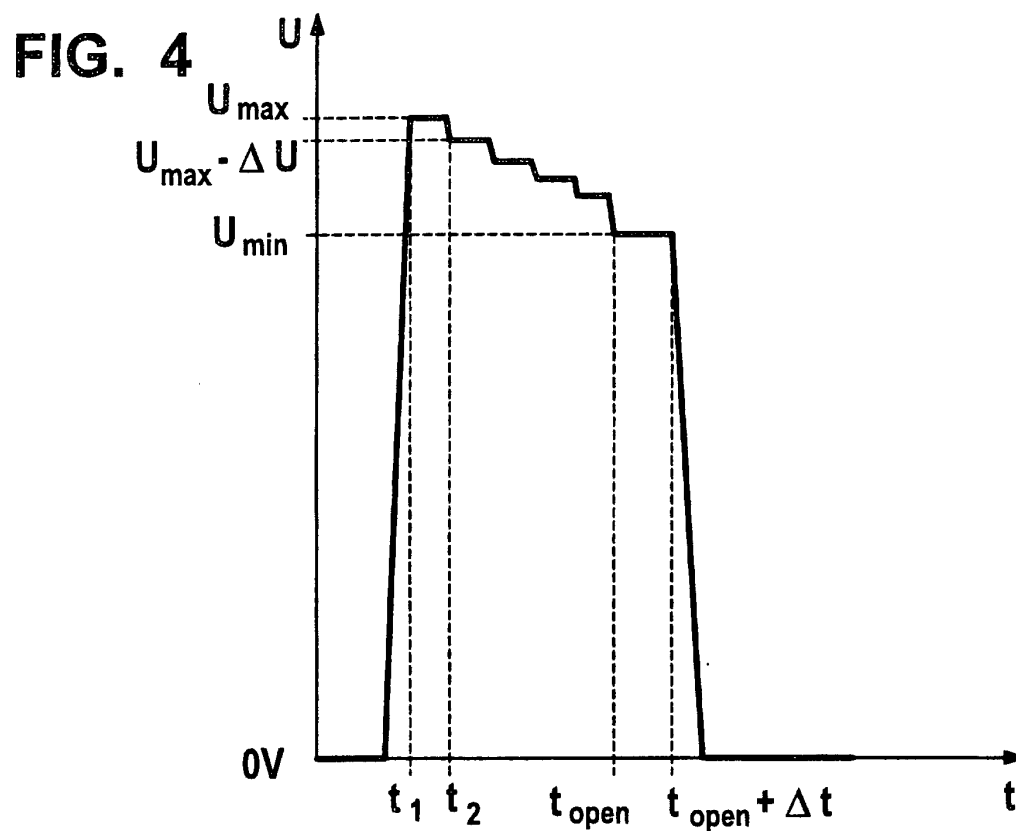


FIG. 6

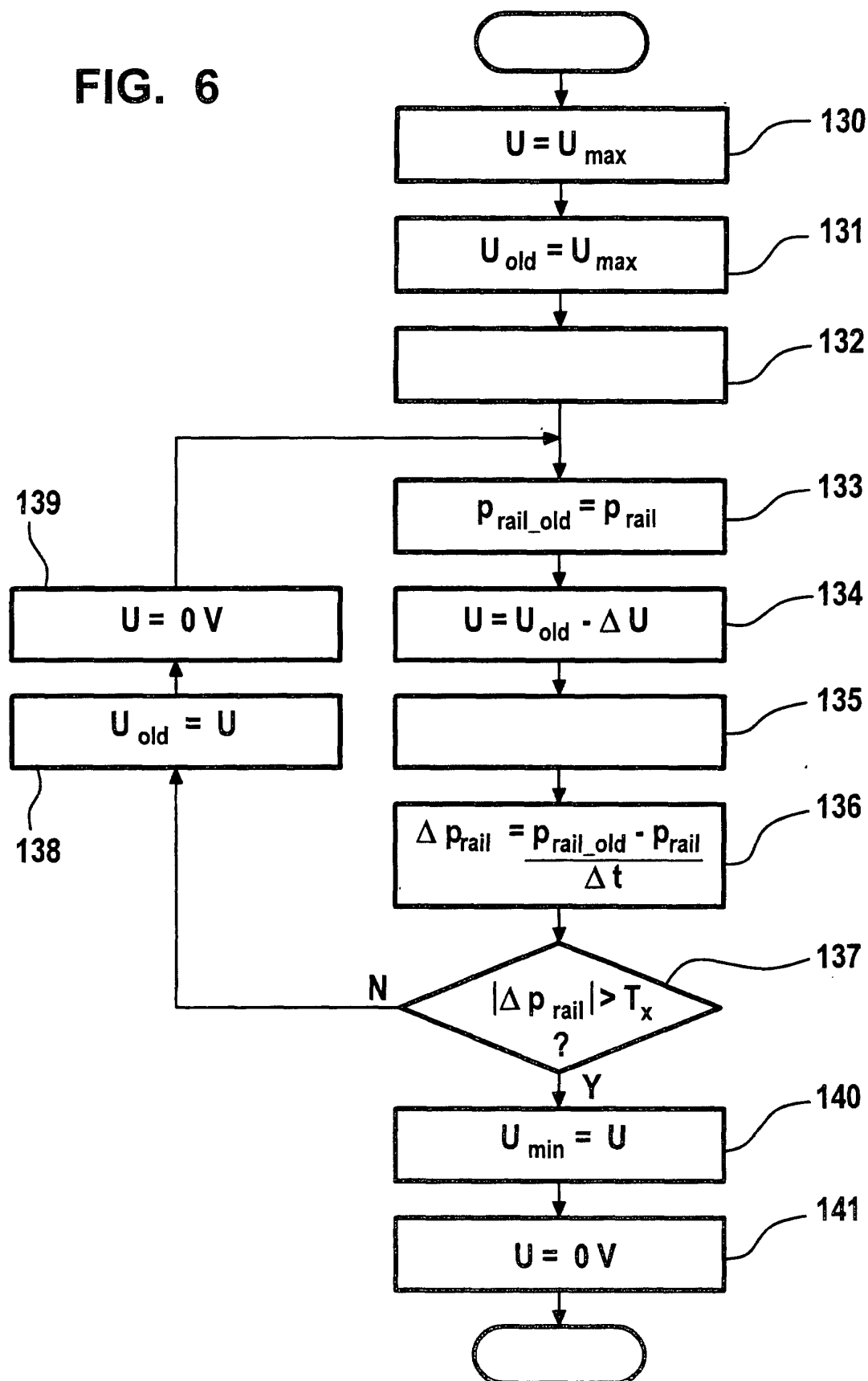
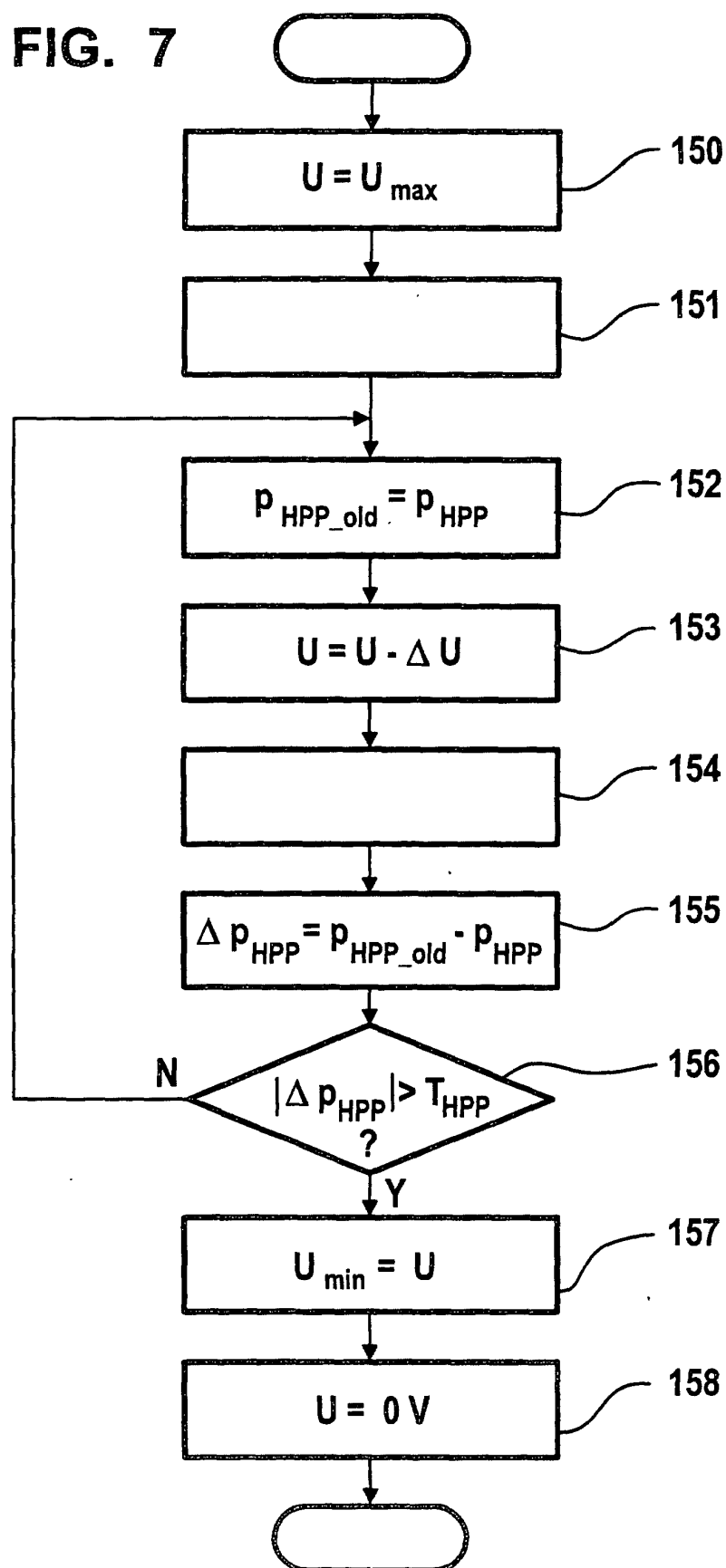


FIG. 7





European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 00 10 6967

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