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(54) **Fuel injection valve**

(57) A fuel injection valve (1) provided with a control valve (8) which is displaced in order to control a pressure within a pressure chamber (5) acting upon a jet hole valve (4), an actuator (17) which generates an operation force for displacing the control valve (8), and elastic support means (22) which elastically supports the control valve in resistance to the operation force. The actuator (17) can change the operation force by controlling a control amount, and the elastic support means (22) is displaced along with the control valve (8) in accordance with increase of the operation force. When the control valve (8) is displaced to a chosen intermediate position it abuts with an abutting member (23). This abutting member (23) is pushed by a set pushing force, generated by a elastic member (24) which is separate from the elastic support means (23), which acts in the opposite direction to the operation force prior to the displacement of the abutting member (23). By structuring the fuel injection valve (1) in this way, it is possible to accurately control the control valve (8) such that it has the chosen intermediate displacement.

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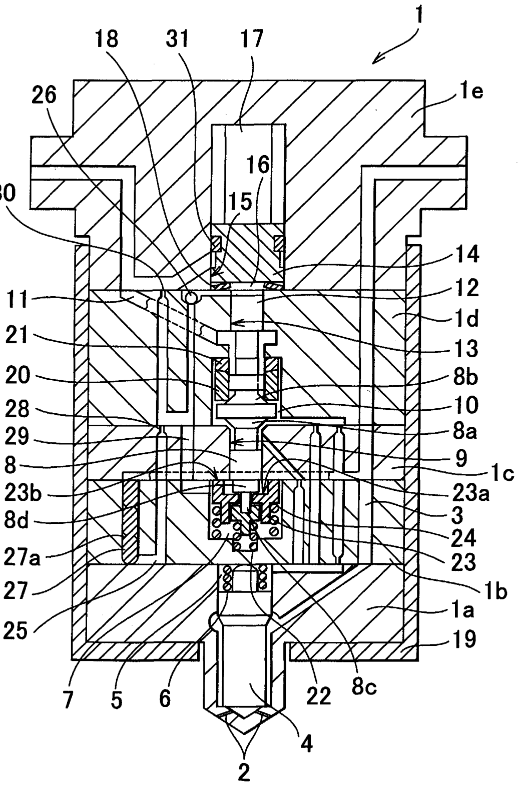


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## Description

### BACKGROUND OF THE INVENTION

1. Field of the Invention

**[0001]** The invention relates to a fuel injection valve.

2. Description of Related Art

**[0002]** A fuel injection valve is used to supply fuel to an internal combustion engine, or the like. Generally, the fuel injection valve is provided with a jet hole valve which can move in an axial direction within the fuel injection valve. This jet hole valve has an end portion for opening and closing the jet hole, and a base portion positioned on the opposite side to the end portion. When the valve is closed, a high fuel pressure within a pressure chamber is applied to the base portion.

**[0003]** When opening the jet hole using the jet hole valve, first, the fuel pressure within the pressure chamber is reduced. As a result, in contrast to the high fuel pressure which is still applied to the end portion of the jet hole valve, the pressure applied to the base portion of the jet hole valve falls. Due to this pressure difference, the jet hole valve is energized in an opening direction resisting a closing spring which energizes the jet hole valve in a closing direction. Thus, the jet hold valve is moved in the opening direction and the jet hole is opened.

**[0004]** When closing the jet hole using the jet hole valve, first, the fuel pressure within the pressure chamber is raised. When the pressure difference of the respective fuel pressures applied to the end portion and the base portion of the jet hole valve is eliminated, the jet hole valve is moved in a closing direction by the closing spring, and the jet hole is closed.

**[0005]** In a normal fuel injection valve, a control valve is necessary to control the fuel pressure within the pressure chamber in order to open and close the jet hole valve as described above. The control valve disclosed in USP 5779149 is operated by an electrostrictive actuator. In this related art, the control valve is not operated directly by extension of the electrostrictive actuator. Instead, a fluid chamber is interposed between a large diameter piston disposed on the electrostrictive actuator side and a small diameter piston disposed on the control valve side. An extension amount of the electrostrictive actuator is converted in the fluid chamber into a pushing force which acts as an operation force. This pushing force is then transmitted to the control valve.

**[0006]** It should be noted that if this type of fuel injection valve is modified when used in a diesel engine such that a lift speed of the jet hole valve is varied so as to have at least two steps. By doing so, it is possible to change the injection rate when injecting fuel, and thus it is possible to achieve appropriate fuel injections in accordance with driving condition. When opening the jet hole valve, this can be achieved if the pressure within the pressure chamber is reduced in two steps. In order to reduce the pressure of the pressure chamber in this way, it is necessary to devise changes to the fuel outflow passage from the pressure chamber, and control the displacement of the control valve such that there is a displacement when the valve is closed, and two-stepped displacement when the valve is opened. In other words, the control valve must be controlled such that there are three-stepped displacements.

**[0007]** Related art disclosed up until now has shown that displacing a control valve in two-stepped displacements between zero and maximum displacements is easily achieved, by respectively abutting the control valve against two facing seat portions. Accordingly, if modification were conducted such that the control valve could be maintained at an intermediate displacement at which the control valve did not abut with either of the seat portions, three-stepped displacements could be realized.

**[0008]** An electrostrictive actuator or magnetic actuator can change an operation force by changing a control amount. However, the generated operation force is easily changed depending on temperature conditions and the like. As a result, it is not possible to accurately execute control such that the control valve has an intermediate displacement, by using control of the control amount of the actuator alone.

### SUMMARY OF THE INVENTION

**[0009]** Accordingly, it is an object of the invention to provide a fuel injection valve which can accurately control a control valve to have a chosen intermediate displacement.

**[0010]** According to an exemplary embodiment of the invention a fuel injection valve is provided which includes a control valve, an actuator and elastic support means. In this fuel injection valve, the control valve is displaced in order to control a pressure within a pressure chamber acting upon a jet hole valve, the actuator generates an operation force for displacing the control valve, and the elastic support means elastically supports the control valve in resistance to the operation force. Furthermore, the actuator is capable of changing the operation force by controlling a control amount, and the elastic support means is displaced along with the control valve in accordance with increase of the operation force. Moreover, the control valve abuts with an abutting member when the control valve is displaced to a chosen intermediate displacement. The abutting member is pushed by a set pushing force generated by a elastic member separate from the elastic support means, this pushing force acting in the opposite direction to the operation force prior to the displacement of the abutting member.

**[0011]** According to a further embodiment of the invention, in the fuel injection valve, the actuator is preferably an electrostrictive actuator. Furthermore, a fluid chamber for converting an extension amount of the electrostrictive actuator into a pushing force which acts as the operation force is preferably provided between the control valve and the electrostrictive actuator. In addition, the fluid chamber and a high pressure fuel passage of the fuel injection valve are preferably communicated by a communication passage and a check valve which only permits flow of fuel toward the fluid chamber is preferably disposed in the communication passage.

**[0012]** According to a further embodiment of the invention, in the fuel injection valve, a pin member is preferably inserted in the communication passage, and high pressure fuel within the high pressure fuel passage, which has reduced pressure due to passing around the pin member, is preferably supplied to the fluid chamber. Furthermore, a groove is preferably formed so as to extend around a circumference of the pin member in a circumferential direction.

**[0013]** According to a further embodiment of the invention, in the fuel injection valve, a first fluid chamber and a second fluid chamber which mutually face each other are preferably provided. Furthermore, the actuator is preferably the electrostrictive actuator, and the second fluid chamber is preferably disposed between the electrostrictive actuator, for converting the extension amount of the electrostrictive actuator into the pushing force which acts as the operation force, and the control valve. Moreover, the fluid pressure within the first fluid chamber and the second fluid chamber are preferably equal when the extension amount of the electrostrictive actuator is zero.

**[0014]** According to a further embodiment of the invention, in the fuel injection valve, high pressure fuel from a high pressure fuel passage of the fuel injection valve is preferably supplied to the first fluid chamber and the second fluid chamber, once the pressure of the high pressure fuel has been reduced.

**[0015]** According to a further embodiment of the invention, in the fuel injection valve, the high pressure fuel from the high pressure fuel passage of the fuel injection valve is preferably supplied to the first fluid chamber and the second fluid chamber.

**[0016]** According to a further embodiment of the invention, in the fuel injection valve, a pressure receiving area in the control valve within the first fluid chamber which receives pressure directly or indirectly is set to equal a pressure receiving area in the control valve within the second fluid chamber which receives pressure directly or indirectly.

**[0017]** According to a further embodiment of the invention, in the fuel injection valve, the first fluid chamber and the second fluid chamber which mutually face each other are preferably provided. Furthermore, the actuator is preferably the electrostrictive actuator, and the second fluid chamber is preferably disposed between the electrostrictive actuator for converting the extension amount of the electrostrictive actuator into the pushing force which acts as the operation force and the control valve. In addition, a fluid pressure within the first fluid chamber is preferably maintained at an almost constant pressure which exerts substantially no impact on movement of the control valve and which is set to be equal to or less than a fluid pressure within the second fluid chamber.

**[0018]** According to a further embodiment of the invention, it is preferable that low pressure fluid is supplied to the first fluid chamber from a low pressure fluid passage of the fuel injection valve.

**[0019]** According to a further embodiment of the invention, in the fuel injection valve, the pressure receiving area in the control valve within the second fluid chamber which receives pressure directly or indirectly is set to be larger than the pressure receiving area in the control valve within the first fluid chamber which receives pressure directly or indirectly.

**[0020]** The fuel injection valve according to the invention is provided with the control valve which is displaced in order to control a pressure within the pressure chamber acting upon the jet hole valve, the actuator which generates the operation force for displacing the control valve, and the elastic support means which elastically supports the control valve in resistance to the operation force. The actuator can change the operation force by controlling the control amount, and the elastic support means is displaced along with the control valve in accordance with increase of the operation force. When the control valve is displaced to a chosen intermediate position it abuts with the abutting member. This abutting member is pushed by the set pushing force, generated by the elastic member which is separate from the elastic support means, which acts in the opposite direction to the operation force prior to the displacement of the abutting member.

**[0021]** As a result, in order to further displace the control valve from the intermediate displacement it is necessary to offset the pushing force acting upon the abutting member due to the elastic member, thus also displacing the abutting member. In other words, until this pushing force is offset, even if the operation force is changed, the control valve, along with the abutting member, is not displaced from the intermediate displacement. This means that it is possible to accurately set the control valve to a chosen intermediate displacement, by setting the operation force of the actuator such that it is within a range between an operation force that abuts the control valve with the abutting member and an operation force that offsets the aforementioned pushing force. Even if the actual operation force of the actuator varies slightly with respect to the control amount, it is easy to set the operation force within the aforementioned range. By doing so, it is possible to reliably control the control valve to a chosen intermediate displacement by controlling the control amount of the actuator.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0022]** The above and other objects, features, advantages, technical and industrial significances of this invention will be better understood by reading the following detailed description of preferred embodiments of the invention, when considered in connection with the accompanying drawings in which:

FIG. 1 is a cross sectional view of a fuel injection valve according to a first embodiment of the invention;

FIG. 2 is a figure which explains an operation of a control valve and a jet hole valve of the fuel injection valve according to the first embodiment of the invention, with (A) showing the control valve when it has a zero displacement, (B) showing the control valve when it has an intermediate displacement, and (C) showing the control valve when it has a maximum displacement;

FIG. 3 is a graph showing a relationship between a pushing force acting as an operation force of the fuel injection valve and the displacement of the control valve, according to the first embodiment of the invention;

FIG. 4 is a cross sectional view showing a fuel injection valve according to a second embodiment of the invention;

FIG. 5 is a cross sectional view showing a fuel injection valve according to a third embodiment of the invention;

FIG. 6 is a time chart showing one fuel injection method of the fuel injection valve according to each embodiment of the invention;

FIG. 7 is a time chart showing another fuel injection method of the fuel injection valve according to each embodiment of the invention;

FIG. 8 is a time chart showing another fuel injection method of the fuel injection valve according to each embodiment of the invention;

FIG. 9 is a time chart showing yet another fuel injection method of the fuel injection valve according to each embodiment of the invention; and

FIG. 10 is a time chart showing yet another fuel injection method of the fuel injection valve according to each embodiment of the invention.

## DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

**[0023]** In the following description and the accompanying drawings, the invention will be described in more detail in terms of exemplary embodiments.

(Embodiment One)

**[0024]** FIG. 1 shows a cross sectional view showing a fuel injection valve according to a first embodiment. This fuel injection valve directly injects fuel into the cylinders of, for example, a diesel engine or an in-cylinder injection type spark ignition internal combustion engine, by injecting high pressure fuel which is pressurized in an accumulator shared by each cylinder. Of course, this fuel injection valve is not limited to use with such cylinders, but could be used for executing fuel injection into, for example, an intake port. Reference numeral 1 indicates the body of the fuel injection valve. This body is divided into five portions along a central axis such that a plurality of fuel channels, and the like, within the body can be machined.

**[0025]** A first body portion 1a is located closest to a tip of the fuel injection valve 1. A jet hole 2 is formed at the tip of the first body portion 1a. In addition, a portion of a high pressure fuel passage 3 leading to the jet hole 2 is also formed in the first body portion 1a. Furthermore, a pressure chamber 5 which abuts with the base portion of the jet hole 4 for opening and closing the jet hole 2 is also formed. The jet hole valve 4 is such that it can close the high pressure fuel passage 3 at the side of the jet hole 2 upstream of the end portion. A valve closing spring 6 which energizes the jet hole valve 4 in a closing direction is disposed within the pressure chamber 5. As a result, when a fuel pressure within the pressure chamber 5 becomes equal to a fuel pressure within the high pressure fuel passage 3, the jet hole valve 4 is closed by energizing force of the valve closing spring 6. Accordingly, communication of the jet hole 2 and the high pressure fuel passage 3 is blocked and thus fuel injection is stopped.

**[0026]** Next, in a second body portion 1b located toward the tip of the fuel injection valve 1, another portion of the high pressure fuel passage 3 and a first fluid chamber 7 are formed. Following this, in a third body portion 1c located toward the tip of the fuel injection valve 1, a further portion of the high pressure fuel passage 3, and a sliding hole 9 of a control valve 8 which is formed coaxially and which communicates with the first fluid chamber 7, are formed. Next, in a fourth body portion 1d located toward the tip of the fuel injection valve 1, another portion of the high pressure fuel passage 3, a control chamber 10 formed coaxially which communicates with the sliding hole 9, and a portion of a low pressure fuel passage 11 communicating with the control chamber 10, are formed. In addition, a sliding hole 13 of a small diameter piston 12 formed coaxially and communicating with the control chamber 10 is also formed.

**[0027]** A fifth body portion 1e is located at the end of the fuel injection valve 1 nearest to the base end. A further portion of the high pressure fuel passage 3, a portion of the low pressure fuel passage 11, and a sliding hole 15 of a large diameter piston 14 formed so as to communicate with the sliding hole 13 of the small diameter piston 12 are formed in the fifth body portion 1e. A portion of the sliding hole 15 of the large diameter piston 14 and a portion of the sliding hole 13 of the small diameter piston 12 form a second fluid chamber 16 which is filled by fuel and interposed between the large diameter piston 14 and the small diameter piston 12. An electrostrictive actuator 17 is disposed so as to abut with the base side of the large diameter piston 14. A disc spring 18 which energizes the large diameter piston 14 toward the electrostrictive actuator 17 side is disposed in the second fluid chamber 16.

**[0028]** The high pressure fuel passage 3 within the fifth body portion 1e has a port leading to the outside of the fuel injection valve which is connected, for example, to an accumulator, not shown, shared by the fuel injection valves of all the cylinders. High pressure fuel within the accumulator is pressurized by a high pressure pump and supplied to the fuel injection valve 1. On the other hand, the low pressure fuel passage 11 also has a port leading to the outside of the fuel injection valve which is connected, for example, to an atmospheric pressure portion of a fuel tank, or the like. A fuel pressure within the low pressure fuel passage 11 is equal to atmospheric pressure. These five body portions 1a, 1b, 1c, 1d and 1e are mutually connected by a case 19 so as to be oil tight.

**[0029]** The center of the control valve 8 disposed within the control chamber 10 is configured from a tip side valve 8a and a base portion side valve 8b whose diameters become gradually smaller toward the tip side and base portion side of the fuel injection valve 1, respectively. A valve cylinder 20 which forms a seat portion of this base portion side valve 8b is disposed in the control chamber 10. Furthermore, an adjustment ring 21 which abuts with this valve cylinder 20 is also provided. As shown in FIG. 1, as a result of the base portion side valve 8b of the control valve 8 abutting with the valve cylinder 20, the communication of the control chamber 10 and the low pressure fuel passage 11 is blocked. The control valve 8 is such that it slides within a through hole of the valve cylinder 20 using an expansion sliding portion. Notches are formed in the axial direction of this expansion sliding portion. When the base portion side valve 8b of the control valve 8 separates from the valve cylinder 20, the inside of the control chamber 10 and the low pressure fuel passage 11 are communicated via these notches.

**[0030]** On the other hand, the tip side valve 8a of the control valve 8 abuts with a seat portion of the sliding hole 9 of the control valve 8 formed in the third body portion 1c, such that communication of the sliding hole 9 and the control chamber 10 can be blocked. The control valve 8 has the expansion sliding portion for sliding within the valve cylinder 20, and also another expansion sliding portion. Thus, the control valve 8 slides coaxially within the valve cylinder 20 and the sliding hole 9. The control valve 8 has a tip portion 8c which protrudes toward the inside of the first fluid chamber 7 formed in the second body portion 1b, and a shoulder portion 8d. The control valve 8 is energized toward the electrostrictive actuator 17 side by pushing force from a first spring 22 (also referred to as elastic support means 22) via the tip portion 8c.

**[0031]** Furthermore, in the first fluid chamber 7, an abutting member 23 is disposed which surrounds the shoulder portion 8d and has a through hole which the tip portion 8c of the control valve 8 passes through. This abutting member 23 has a first abutting surface 23a which surrounds the through hole and which is abutted by the shoulder portion 8d of the control valve 8 due to displacement of the control valve 8. In addition, the abutting member 23 has a second abutting surface 23b which abuts with an inner wall of the first fluid chamber 7 on the electrostrictive actuator 17 side by pushing force of a second spring 24.

**[0032]** The second fluid chamber 16 and the high pressure fuel passage 3 are communicated by a communicating passage 25. A check valve 26 which only permits fuel flow toward the second fluid chamber 16 is disposed in this communicating passage 25. In addition, a pin member 27 is inserted in the communicating passage 25. When high pressure fuel within the high pressure fuel passage 3 passes around the pin member 27, the pressure of the fuel decreases. In addition, the pressure falls still further due to an orifice 28 disposed in the communicating passage 25. The fuel is then supplied to the second fluid chamber 16. Furthermore, fuel which has had its pressure reduced in this way is also supplied to the first fluid chamber 7 by a branched passage 29.

**[0033]** A groove 27a which extends in a circumferential direction is formed around the circumference of the pin member 27. As a result, even if minute foreign matter, and the like, is mixed within the pressurized fuel supplied to the high pressure fuel passage 3 from the accumulator, this foreign matter is collected in the groove 27a when the pressurized fuel passes around the pin member 27 in the communicating passage 25. As a result, foreign matter does not flow into the first fluid chamber 7 and the second fluid chamber 16, and the operations of the abutting member 23 in the first fluid chamber 7, and the small diameter piston 12 and large diameter piston 14 in the second fluid chamber 16, are not hindered by foreign matter.

**[0034]** The communicating passage 25 which decreases the pressure of the pressurized fuel from the high pressure fuel passage 3 and supplies it to the first fluid chamber 7 and the second fluid chamber 16, is connected to the low pressure fuel passage 11 via an orifice 30. Depending on a fuel amount flowing to the low pressure fuel passage 11 via the orifice 30, the pressure of fuel supplied to the first fluid chamber 7 and the second fluid chamber 16 is maintained at a set pressure which is equal to or above atmospheric pressure. The low pressure fuel passage 11 supplies low pressure fuel for lubrication to the circumference of a sliding O-ring 31 of the large diameter piston 14.

**[0035]** FIG. 2 shows cross sections of the area around the control valve 8, in order to explain a displacement control of the control valve 8 in the fuel injection valve.

FIG. 2 (A) shows, like FIG. 1, the fuel injection valve when the control valve 8 has a zero displacement. At this time, voltage is not applied to the electrostrictive actuator 17 and thus its extension amount is zero. As a result, the fuel pressure within the second fluid chamber 16 is the fuel pressure of the fuel supplied from the communicating passage 25 and is equal to the fuel pressure within the first fluid chamber 7. Furthermore, a pressure receiving area in the control valve 8 within the second fluid chamber 16 which indirectly receives pressure via the small diameter piston 12, namely, the area of the small diameter piston 12 on the second fluid chamber 16 side, and the pressure receiving area in the control valve 8 within the first fluid chamber 7 which directly receives pressure, namely, the cross sectional area of the expansion sliding portion of the control valve 8 with respect to the sliding hole 9 of the third body portion 1c, are equal. Accordingly, at this time, the mutually opposing pushing forces received by the control valve 8 from the fuel within the first fluid chamber 7 and the fuel within the second fluid chamber 16 become equal.

**[0036]** When the control valve 8 is displaced to the electrostrictive actuator 17 side by pushing force of the first spring 22 disposed within the first fluid chamber 7, the base portion side valve 8b abuts with the valve cylinder 20 and thus communication of the control chamber 10 and the low pressure fuel passage 11 is blocked. At this time as well, the first spring 22 is displaced and compressed such that a first set pushing force is applied to the control valve 8 by the first spring 22. The high pressure fuel passage 3 is communicated with both the control chamber 10 via an orifice 32 and the pressure chamber 5 via an orifice 33.

**[0037]** In this way, the communication of the control chamber 10 and the low pressure fuel passage 11 is blocked, and the fuel pressure within the control chamber 10 and the pressure chamber 5 becomes the high fuel pressure within the high pressure fuel passage 3, as indicated by the check shading. Normally, the high fuel pressure within the high pressure fuel passage 3 is applied to the tip side of the jet hole valve 4. However, when the fuel pressure within the pressure chamber 5 becomes this high fuel pressure, the pushing forces applied to the tip side and the base portion side of the jet hole valve 4 become mutually equal. The jet hole valve 4 is closed by the valve closing spring 6 disposed within the pressure chamber 5, and there is no injection of fuel from the high pressure fuel passage 3 via the jet hole 2.

**[0038]** The pressure chamber 5 is communicated with the control chamber 10 via an orifice 34, and the sliding hole 9 via an orifice 35. When the control valve 8 has a zero displacement, the sliding hole 9 and the control chamber 10 are communicated. At this time, the fuel pressure within the sliding hole 9 also becomes the high fuel pressure within the high pressure fuel passage 3, as indicated by the check shading.

**[0039]** When voltage is applied to the electrostrictive actuator 17 it is extended. Thus, the fuel pressure within the second fluid chamber 16 increases, and the control valve 8 is displaced while resisting the pushing force from the first spring 22. If the applied voltage is raised, the control valve 8 is further displaced, and the shoulder portion 8d of the control valve 8 abuts with the first abutting surface 23a of the abutting member 23, as shown in FIG. 2 (B).

**[0040]** At this time, the second spring 24 is displaced and compressed such that a second set pushing force is applied to the abutting member 23 by the second spring 24. In order to further displace the control valve 8, it becomes necessary to displace the abutting member 23 in resistance to the pushing force from the second spring 24. As a result, the applied voltage is raised further which increases the fuel pressure within the second fluid chamber 16 even more. However, even if the pushing force applied to the control valve 8 via the second fluid chamber 16 is increased, until this pushing force offsets the second set pushing force of the abutting member 23, the abutting member 23 is not displaced, and, accordingly, the control valve 8 is also not displaced.

**[0041]** At this time, the control valve 8 is maintained at the intermediate displacement, at which the base portion side valve 8b of the control valve 8 is separated from the valve cylinder 20. Thus the control chamber 10 and the low pressure fuel passage 11 are communicated and the tip side valve 8a of the control valve 8 does not block the sliding hole 9. In this way, the fuel pressure within the control chamber 10 is reduced to the atmospheric pressure within the low pressure fuel passage 11. At this time, some of the high pressure fuel outflows to the control chamber 10 via the orifice 34, and as well as this, some of the high pressure fuel outflows to the control chamber 10 from the sliding hole 9 via the orifice 35. On the other hand, some of the high pressure fuel from the high pressure fuel passage 3 outflows to the pressure chamber 5 via the orifice 33. When a total fuel outflow amount is greater than a total fuel inflow amount, the fuel pressure within the pressure chamber 5 is within the dotted area indicated in the figure, decreases at a speed in accordance with the difference between the total fuel outflow amount and the total fuel inflow amount, namely, the relative fuel outflow amount.

**[0042]** In this manner, the fuel pressure within the pressure chamber 5 is reduced to a predetermined pressure, and the jet hole valve 4 begins to open when a total valve closing direction pushing force (including the pushing force generated by the valve closing spring 6) of the jet hole valve 4 becomes a fraction smaller than a total valve opening direction pushing force. As a result, the high pressure fuel within the high pressure fuel passage 3 is injected via the jet hole 2. Since the volumetric capacity of the pressure chamber 5 decreases along with the opening of the jet hole valve 4, in order to open the jet hole valve 4 still further it is necessary for relative outflow of fuel to be executed such that the fuel pressure within the pressure chamber 5 is, at the least, maintained at the predetermined pressure. (Strictly speaking, since the pressure receiving area which receives high pressure at the tip side of the jet hole valve 4 at the time of valve opening is enlarged, it is possible to maintain the valve in an open position even if the fuel pressure within the pressure chamber 5 is higher than the predetermined pressure, by increasing the opening direction pushing force.) In this way, a valve opening speed of the jet hole valve 4 increases as the relative fuel outflow increases.

**[0043]** When the voltage applied to the electrostrictive actuator 17 is increased still further, the pressure within the second fluid chamber 16 increases more. Accordingly, the second set pushing force generated by the second spring 24 of the abutting member 23 is offset, and the control valve 8 begins to be displaced along with the abutting member 23. The control valve 8 reaches the maximum displacement when the control valve 8 is displaced still further and the tip side valve 8a abuts with the sliding hole 9, as shown by FIG. 2 (C).

**[0044]** At this time, the control chamber 10 is communicated with the low pressure fuel passage 11 by the control valve 8. However, the communication of the sliding hole 9 and the control chamber 10 by the tip side valve 8a is blocked, or in other words, as compared to the intermediate displacement of the control valve 8 shown in FIG. 2 (B), the outflow of some of the high pressure fuel within the pressure chamber 5 to the control chamber 10 from the sliding hole 9 via the orifice 35 does not occur.

**[0045]** Furthermore, at this time, the total fuel outflow amount is greater than the total fuel inflow amount and the fuel pressure within the pressure chamber 5 decreases within the indicated dotted area. As described previously, when the fuel pressure within the pressure chamber 5 decreases to the predetermined pressure, the jet hole valve 4 begins to open. However, as compared to the intermediate displacement of the control valve 8, the valve opening speed of the jet hole valve 4 is slow since the relative fuel outflow amount from the pressure chamber 5 is smaller. In addition, the time taken for the fuel pressure within the pressure chamber 5 to reduce to the predetermined pressure is longer.

**[0046]** FIG. 3 is a graph showing a relationship between a pushing force from the electrostrictive actuator 17 acting via the second fluid chamber 16 and the displacement of the control valve 8, in the fuel injection valve. A summary of the previous explanation will be given using this graph. When no voltage is applied to the electrostrictive actuator 17 the control valve 8 is maintained at the zero displacement at which the base portion side valve 8b abuts with the valve cylinder 20, due to the first set pushing force generated by the first spring 22. At this time, the jet hole valve 4 is closed.

**[0047]** When the voltage applied to the electrostrictive actuator 17 is gradually increased, the pushing force acting via the second fluid chamber 16 gradually increases. When the first set pushing force generated by the first spring 22 is offset, the control valve 8 is displaced along with the first spring 22 elastically supporting the control valve 8 in resistance to the pushing force via the second fluid chamber 16. Accordingly, the displacement gradually increases.

**[0048]** When the pushing force is increased to P1, the control valve 8 abuts with the abutting member 23, and the control valve 8 is at the intermediate displacement. Following this, as the pushing force is raised up until P2, the second set pushing force generated by the second spring 24 prior to the displacement of the abutting member 23 is not offset, and thus the control valve 8, along with the abutting member 23, is not displaced. Accordingly, the control valve 8 is maintained at the intermediate displacement.

**[0049]** When the pushing force becomes P2 and the second set pushing force generated by the second spring 24 is offset, the control valve 8 begins to be displaced along with the abutting member 23. At this time, the first spring 22, and at the same, the second spring 24 energizing the abutting member 23, must be displaced, and thus the increase in the displacement accompanying the increase in the pushing force is slow, as compared to that prior to the intermediate displacement being reached.

**[0050]** When the pushing force becomes P3, the tip side valve 8a of the control valve 8 abuts with the sliding hole 9 and thus the control valve 8 reaches the maximum displacement. Even if the pushing force is raised still more, no further displacement occurs. In this manner, in this fuel injection valve, the control valve 8 reliably has a zero displacement when no voltage is applied to the electrostrictive actuator 17. Moreover, when voltage is applied to the electrostrictive actuator 17 via the second fluid chamber 16 such that the pushing force becomes equal to or more than P3, the control valve 8 reliably has the maximum displacement. Furthermore, when voltage is applied to the electrostrictive actuator 17 via the second fluid chamber 16 such that pushing force is within the range from P1 to P2, the control valve 8 reliably has a chosen intermediate position. As a result, when the voltage applied to the electrostrictive actuator 17 is such that the pushing force generated by the electrostrictive actuator 17 has, on average, a value between P1 and P2 (preferably, when (P1 + P2) / 2), even if the actual pushing force varies slightly due to various factors, it is possible for the control valve 8 to reliably maintain the chosen intermediate displacement as long as the pushing force does not drop below P1 or rise above P2.

**[0051]** In this fuel injection valve, the second fluid chamber 16 is formed between the large diameter piston 14 on the electrostrictive actuator 17 side and the small diameter piston 12 on the control valve 8 side. As a result, it is possible to substantially increase the pressure within the second fluid chamber 16 using a very small extension amount of the electrostrictive actuator 17. The fuel injection valve utilizes the electrostrictive actuator

17 for the operation of the control valve 8. However, other actuators may be used which can change the operation force for the control valve using control of a control amount such as voltage, so as to combine the electrostrictive actuator and the fluid chamber. For example, a solenoid actuator can be used for operation of the control valve. This solenoid actuator can directly generate an operation force for the control valve such as a magnetic attraction force or a magnetic repulsion force, by controlling a control amount, that is, voltage. As a result, it is also possible to omit usage of a second fluid chamber.

**[0052]** It should be noted that when the control valve 8 is displaced from the maximum displacement to the zero displacement, in particular, the volumetric capacity of the second fluid chamber 16 increases rapidly and thus pressure suddenly decreases, due to the disc spring 18. At this time, fuel having pressure higher than atmospheric pressure inflows to the second fluid chamber 16 via the check valve 26. As a result, a negative pressure exists within the second fluid chamber 16, and a vacuum does not form within the second fluid chamber 16 due to precipitation of gas contained within the fuel. If such a vacuum were to be formed, even if the electrostrictive actuator 17 extended, the pressure within the second fluid chamber 16 would not rise sufficiently, and it would be impossible to accurately execute displacement control of the control valve 8.

(Second Embodiment)

**[0053]** A fuel injection valve according to a second embodiment of the invention is shown in FIG. 4. In order to explain the differences between this fuel injection valve and that of the previously described first embodiment, additional reference numerals have been attached to relevant members. However, since all other members are the same as those in the fuel injection valve shown in FIG. 1, explanation of these members will be omitted here. According to the fuel injection valve of the second embodiment, the first fluid chamber 7 is filled with atmospheric pressure fuel due to communication with the low pressure fuel passage 11.

**[0054]** According to the fuel injection valve of the first embodiment shown in FIG. 1, the volumetric capacity of the first fluid chamber 7 decreases along with displacement of the control valve 8. Strictly speaking, when the pressure within the first fluid chamber 7, including the branched passage 29 set with a set pressure higher than atmospheric pressure, becomes slightly higher, this causes the pushing force via the second fluid chamber 16 to rise enough to displace the control valve 8. However, if the first fluid chamber 7 communicates with the low pressure fuel passage 11 as in this fuel injection valve, even if the volumetric capacity of the first fluid chamber 7 decreases along with displacement of the control valve 8 in the above described manner, the pressure within the first fluid chamber 7 does not rise. Of course, according to this fuel injection valve, as with the fuel injection valve shown in FIG. 1, control of the electrostrictive actuator 17 such that the control valve 8 has the chosen intermediate displacement can be easily executed.

**[0055]** According to the fuel injection valve of the second embodiment, high pressure fuel from the high pressure fuel passage 3 whose pressure has been reduced by the pin member 27 and the orifice 28 is supplied to the second fluid chamber 16, as was the case with the fuel injection valve shown in FIG. 1. Accordingly, the fuel pressure within the second fluid chamber 16 is normally higher than atmospheric pressure. In addition, a small diameter piston 12' for transmitting a pushing force to the control valve 8 has a larger diameter than the equivalent piston of the fuel injection valve shown in FIG. 1. In line with this, in order to apply a displacement direction pushing force to the control valve 8 using the pressure difference between the first fluid chamber 7 and the second fluid chamber 16, even when the control valve 8 has the zero displacement, it is necessary to set a first set pushing force of a first spring 22' disposed within the first fluid chamber 7 larger than the pushing force of the equivalent spring of the first embodiment shown in FIG. 1.

(Third Embodiment)

**[0056]** A fuel injection valve according to a third embodiment of the invention is shown in FIG. 5. In order to explain the differences between this fuel injection valve and that of the previously described first embodiment, additional reference numerals have been attached to relevant members. However, since all other members are the same as those in the fuel injection valve shown in FIG. 1, explanation of these members will be omitted here. According to the fuel injection valve of the third embodiment, the second fluid chamber 16 communicates with the high pressure fuel passage 3 via the check valve 26. Therefore, according to this fuel injection valve, as a result of communication of both the first fluid chamber 7 and the second fluid chamber 16 with the high pressure fuel passage 3, the first fluid chamber 7 and the second fluid chamber 16 are filled with high pressure fuel. If the first fluid chamber 7 communicates with the high pressure fuel passage 3 in this way, as with the fuel injection valve of the second embodiment, even if the volumetric capacity of the first fluid chamber 7 decreases along with displacement of the control valve 8, the pressure within the first fluid chamber 7 does not rise. Of course, according to this fuel injection valve, as with the fuel injection valve shown in FIG. 1, control of the electrostrictive actuator 17 such that the control valve 8 has the chosen intermediate displacement can be easily executed.

**[0057]** Furthermore, since high pressure fuel is supplied to the second fluid chamber 16, it is obvious that when the control valve 8 has the zero displacement no vacuum is generated within the second fluid chamber 16. Furthermore, the fuel pressures within the first fluid chamber 7 and the second fluid chamber 16 are equal. As a result, in particular, it is not necessary to set the first set force of the first spring within the first fluid chamber 7 higher than the equivalent force in the fuel injection valve shown in FIG. 1.

**[0058]** According to the previously described three fuel injection valves, fuel is supplied to the first fluid chamber 7 and the second fluid chamber 16. However, a hydraulic fluid other than fuel may be used.

**[0059]** In this manner, the fuel injection valves according to the invention can easily achieve fuel injection with changeable injection rates. Accordingly, for example, the fuel injection methods explained below are possible.

**[0060]** FIG. 6 shows a time chart for one fuel injection method. The vertical axis shows the fuel injection rate. With this fuel injection method, when timings of a pilot fuel injection and a main fuel injection are relatively close, the control valve 8 is maintained at the intermediate position and a lift speed of the jet hole valve 4 is set to be fast for the pilot fuel injection. Meanwhile, for the main fuel injection, the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set to be comparatively slow.

**[0061]** As a result, when the pilot fuel injection begins, the fuel pressure in the vicinity of the jet hole within the fuel injection valve rises rapidly, and thus it is possible to inject the small amount of fuel of the pilot injection at high speed. This pilot injection fuel which is injected at high speed has great penetration force. Therefore, even though the injection amount is small, the injected fuel reaches the vicinity of the periphery area of the combustion chamber and then combusts. Accordingly, the fuel injected at the time of the main fuel injection begins combustion from the section of the fuel which reaches the combustion gas generated by the pilot fuel injection and formed at the periphery area of the combustion chamber. Following this, the main injection fuel combusts toward the center of the combustion chamber from the periphery area. As a result, a combustion temperature of the main injection fuel is comparatively low and the generation of NOx is inhibited.

**[0062]** Furthermore, since the lift speed of the jet hole valve 4 is comparatively slow for the main fuel injection, the fuel injection rate during the start of the main fuel injection is comparatively low. Accordingly, even if the fuel injection timing is advanced, no detrimental effect on the combustion state occurs, and thus it is possible to complete the fuel injection with a comparatively fast timing. Moreover, it is also possible to constrain the increase in smoke generated due to fuel injected during the expansion stroke which has a reduced combustion temperature.

**[0063]** FIG. 7 shows a time chart for another fuel injection method, similar to that shown in FIG. 6. In this fuel injection method, the control valve 8 is maintained at the intermediate displacement and the lift speed of the jet hole valve 4 is slow for the pilot fuel injection. Meanwhile, for the main fuel injection, during a first half of the injection period the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set to be comparatively slow. During a second half of the injection period the control valve 8 is set to the intermediate displacement and the lift speed of the jet hole valve 4 is set to be fast. As a result, as compared with the fuel injection method shown in FIG. 6, the fuel injection rate during the second half of the main fuel injection rises and it is possible to speed up completion of the fuel injection. Accordingly, it is possible to constrain smoke increase even more reliably.

**[0064]** FIG. 8 shows a time chart for a further fuel injection method, similar to that shown in FIG. 6. In this fuel injection method, the pilot fuel injection is executed at a comparatively early period of the compression stroke, the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set to be slow during the pilot fuel injection. Meanwhile, during the main fuel injection as well, the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set to be slow. However, a potential problem could occur, since in the comparatively early period of the compression stroke, the pressure and the temperature of the combustion chamber do not rise sufficiently, and the piston is also at a position away from top dead center. As a result, it is possible that the injection fuel could reach the internal cylinder walls while remaining in a liquid state and easily attach to the walls. This attached fuel could then cause dilution of the lubricating oil.

**[0065]** However, in this fuel injection method, during the pilot fuel injection executed at the comparatively early period of the compression stroke, the lift speed of the jet hole valve 4 is comparatively slow. As a result, the rise in the fuel pressure within the fuel injection valve in the vicinity of the jet hole is gentle, and the small-fuel amount pilot fuel injection is executed at low speed. Accordingly, the pilot injection fuel forms a spray with low penetration force and the problem of adherence to the internal cylinder walls does not occur.

**[0066]** FIG. 9 shows a time chart for a further fuel injection method, similar to that shown in FIG. 6. In this fuel injection method, a post fuel injection in which fuel is injected again is executed after the main fuel injection. The post fuel injection is executed in order to inhibit the generation of exhaust smoke resulting from incomplete combustion of fuel when the amount of the main fuel injection is large. In this case, the post fuel injection is executed during the expansion stroke when the temperature and pressure within the combustion chamber is reduced. Moreover, the piston is at a position away from top dead center. As a result, similar to the early period pilot fuel injection of the fuel injection method described in FIG. 8, the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set to be comparatively slow. Accordingly, the penetration force of the post injection fuel is reduced and adherence to the internal cylinder walls is inhibited.

**[0067]** FIG. 10 shows a time chart for yet another fuel injection method, similar to that shown in FIG. 6. In this fuel injection method, during the main fuel injection, the control valve 8 is set to the intermediate displacement and when lift of the jet hole valve 4 is started the control valve 8 is set to the maximum displacement. During the main fuel injection it is preferable that the fuel injection rate is set comparatively low so as to inhibit, in particular, the generation of substantial noise due to one-time ignition combustion of large amounts of fuel during the initial period of fuel injection. In order to do so, in the fuel injection method explained above, the control valve 8 is set to the maximum displacement and the lift speed of the jet hole valve 4 is set comparatively slow during the main fuel injection.

**[0068]** However, as a result of doing this the reduction speed of the fuel pressure within the pressure chamber 5 is slowed. Due to this, it requires a comparatively long time period for the high fuel pressure within the pressure chamber 5 to reduce to a pressure at which lift of the jet hole valve 4 in resistance to the valve closing spring 6 starts. In other words, the time delay between issuing the fuel injection command and the start of the actual fuel injection increases. In order to reduce this time delay, in this fuel injection method, at the same time as issuing the fuel injection command, the control valve 8 is set to the intermediate displacement thus speeding up the reduction speed of the fuel pressure within the pressure chamber 5. At the time when the fuel pressure within the pressure chamber 5 is reduced to the pressure at which lift of the jet hole valve 4 starts, the control valve 8 is set to the maximum displacement. Following this, the relative fuel outflow amount from the pressure chamber 5 is set to be small, the lift speed of the jet hole valve 4 is slowed and the injection rate during the actual fuel injection is lowered.

**[0069]** In this fuel injection method, whether the lift of the jet hole valve 4 has started may be observed using the fuel pressure within the pressure chamber 5, observed directly from the lift of the jet hole valve 4, or determined based on a set time according to the fuel pressure within the high pressure fuel passage 3. Furthermore, although the jet hole valve 4 is set to the maximum displacement prior to the actual start of lift of the jet hole valve 4, it is possible to reduce the time delay, depending on the setting of the jet hole valve 4 to the intermediate displacement.

**[0070]** The fuel injection valve according to the invention is provided with the control valve 8 which is displaced in order to control the pressure within the pressure chamber 5 applied to the jet hole valve 4, the electrostrictive actuator 17 which generates an operation force for displacing the control valve (8), and the elastic support means 22 which elastically supports the control valve in resistance to the operation force. Furthermore, the actuator 17 can change the operation force by controlling the control amount, and the elastic support means 22 is displaced along with the control valve 8 in accordance with increase of the operation force. In addition, when the control valve 8 is displaced to the chosen intermediate position it abuts with the abutting member 23. This abutting member 23 is pushed by the set pushing force, generated by the second spring 24 which is separate from the elastic support means 22, which acts in the opposite direction to the operation force prior to the displacement of the abutting member. By structuring the fuel injection valve in this way, it is possible to accurately control the control valve 8 such that it has the chosen intermediate displacement.

**[0071]** While the invention has been described with reference to exemplary embodiments thereof, it is to be understood that the invention is not limited to the exemplary embodiments or constructions. To the contrary, the invention is intended to cover various modifications and equivalent arrangements. In addition, while the various elements of the exemplary embodiments are shown in various combinations and configurations, which are exemplary, other combinations and configurations, including more, less or only a single element, are also within the spirit and scope of the invention.

## Claims

1. A fuel injection valve (1) provided with a control valve (8) which is displaced to control a pressure within a pressure chamber (5) acting upon a jet hole valve (4), an actuator (17) which generates an operation force for displacing the control valve (8), and elastic support means (22, 22') elastically supporting the control valve (8) in resistance to the operation force, **characterised in that**

   the actuator (17) is capable of changing the operation force by controlling a control amount,

   the elastic support means (22, 22') is displaced along with the control valve (8) in accordance with increase of the operation force,

   the control valve (8) abuts with an abutting member (23) when the control valve (8) is displaced to a chosen intermediate displacement, and

   the abutting member (23) is pushed by a set pushing force generated by a elastic member (24) separate from the elastic support means (22, 22'), this pushing force acting in the opposite direction to the operation force acting prior to the displacement of the abutting member (23).

2. A fuel injection valve according to claim 1, **characterised in that**

   the actuator (17) is an electrostrictive actuator (17),

   a fluid chamber (16) for converting an extension amount of the electrostrictive actuator (17) into a pushing force which acts as the operation force is provided between the control valve (8) and the electrostrictive actuator (17),

the fluid chamber (16) and a high pressure fuel passage (3) of the fuel injection valve (1) are communicated by a communication passage (25), and

a check valve (26) only permitting flow of fuel toward the fluid chamber (16) is disposed in the communication passage (25).

**3.** A fuel injection valve according to claim 2, **characterised in that**

a pin member (27) is inserted in the communication passage (25),

high pressure fuel within the high pressure fuel passage (3), which has reduced pressure due to passing around the pin member (27), is supplied to the fluid chamber (16), and

a groove (27a) is formed so as to extend around a circumference of the pin member (27) in a circumferential direction.

**4.** A fuel injection valve according to claim 1, **characterised by** including:

a first fluid chamber (7) and a second fluid chamber (16) which mutually face each other; and **characterised in that**
the actuator (17) is an electrostrictive actuator (17),
the second fluid chamber (16) is disposed between the electrostrictive actuator (17), for converting an extension amount of the electrostrictive actuator (17) into a pushing force which acts as the operation force, and the control valve (8), and
fluid pressures within the first fluid chamber (7) and the second fluid chamber (16) are equal when the extension amount of the electrostrictive actuator (17) is zero.

**5.** A fuel injection valve according to claim 4, **characterised in that**

the high pressure fuel from a high pressure fuel passage (3) of the fuel injection valve (1) is supplied to the first fluid chamber (7) and the second fluid chamber (16) once after the pressure of the high pressure fuel has been reduced.

**6.** A fuel injection valve according to claim 4, **characterised in that**

the high pressure fuel from a high pressure fuel passage (3) of the fuel injection valve (1) is supplied to the first fluid chamber (7) and the second fluid chamber (16).

**7.** A fuel injection valve according to any one of claims 4 to 6, **characterized by** including:

a pressure receiving area in the control valve (8) which receives pressure in one of a direct and indirect manner within the first fluid chamber (7) is equal to a pressure receiving area in the control valve (8) which receives pressure in one of a direct and indirect manner within the second fluid chamber (16).

**8.** A fuel injection valve according to claim 1, **characterised by** including:

a first fluid chamber (7) and a second fluid chamber (16) which mutually face each other; and **characterised in that**
the actuator (17) is an electrostrictive actuator (17),
the second fluid chamber (16) is disposed between the electrostrictive actuator (17) for converting an extension amount of the electrostrictive actuator (17) into a pushing force which acts as the operation force and the control valve (8), and
a fluid pressure within the first fluid chamber (7) is maintained at an almost constant pressure which exerts substantially no impact on movement of the control valve (8) and which is set to be equal to or less than a fluid pressure within the second fluid chamber (16).

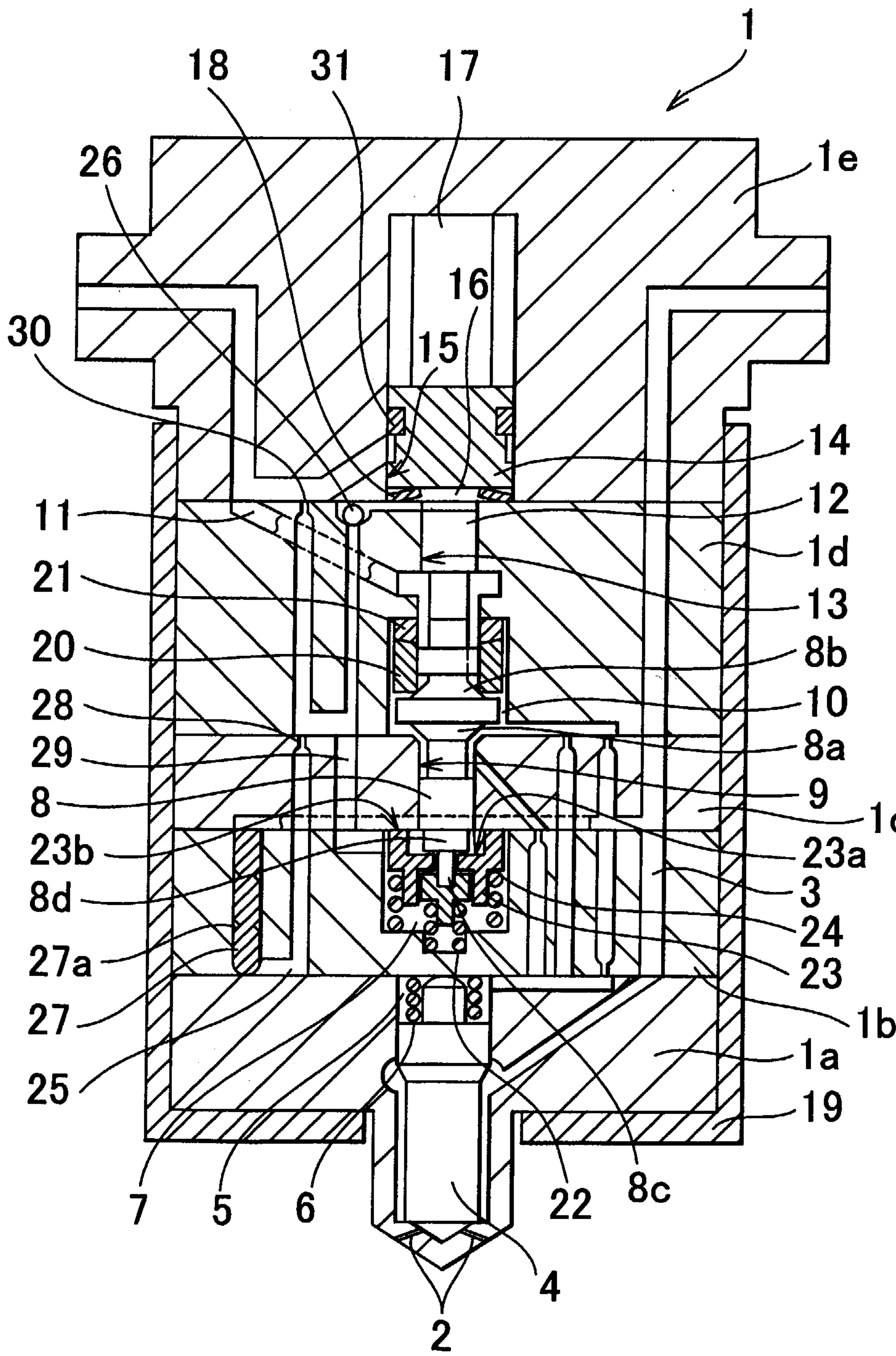
**9.** A fuel injection valve according to claim 8, **characterized in that**

low pressure fluid is supplied to the first fluid chamber (7) from a low pressure fluid passage (11) of the fuel injection valve (1).

**10.** A fuel injection valve according to any one of claims 8 or 9, **characterized by** including:

a pressure receiving area in the control valve (8) which receives pressure in one of a direct and indirect manner within the second fluid chamber (16) is set to be larger than a pressure receiving area in the control valve (8) which receives pressure in one of a direct and indirect manner within the first fluid chamber (7).

FIG. 1


1
26
18
31
17
1e
16
30
15
14
11
12
1d
21
13
20
8b
28
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8a
8
9
1c
23b
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6
22
8c
4
2

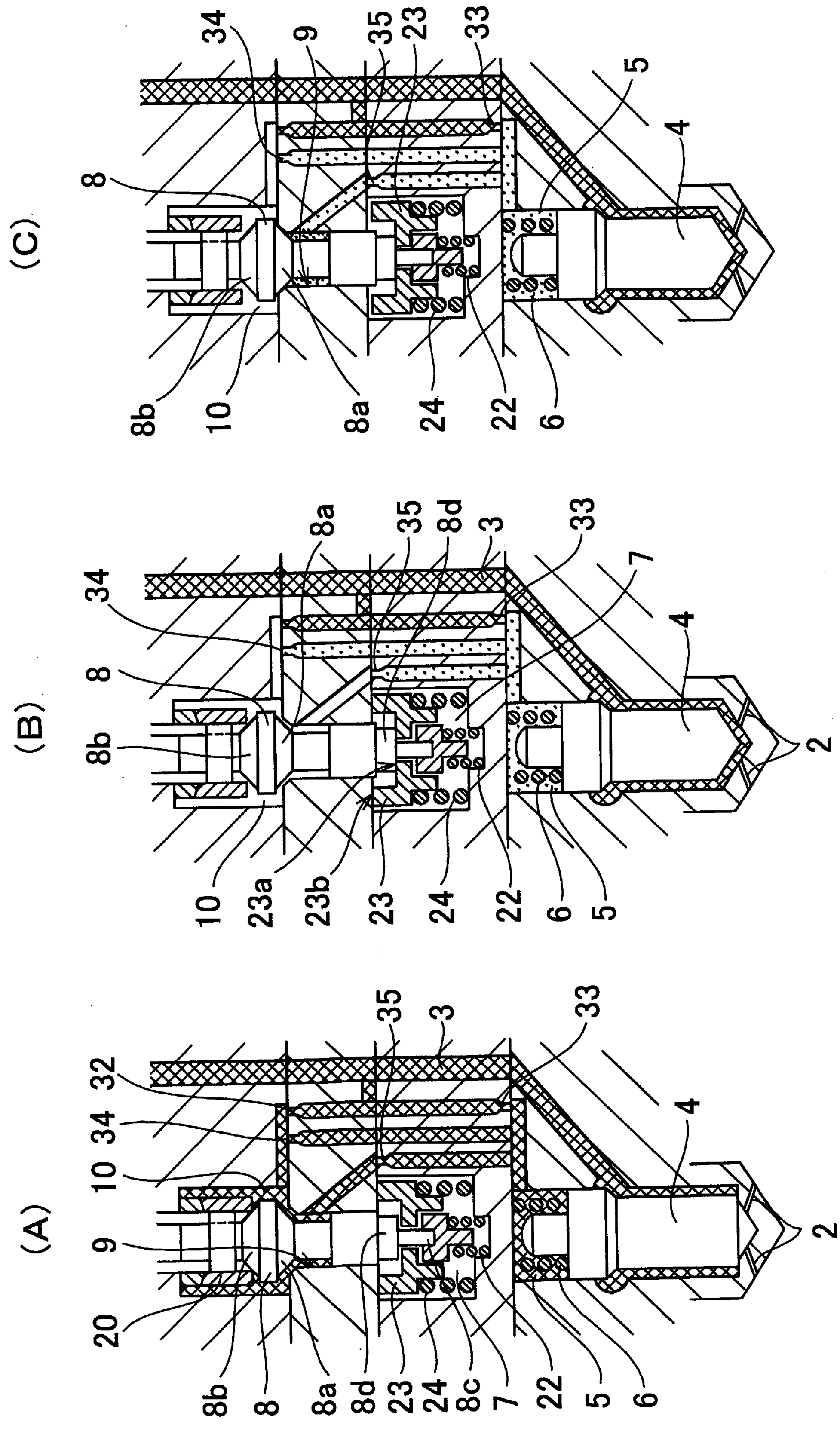



FIG. 2

# FIG. 3

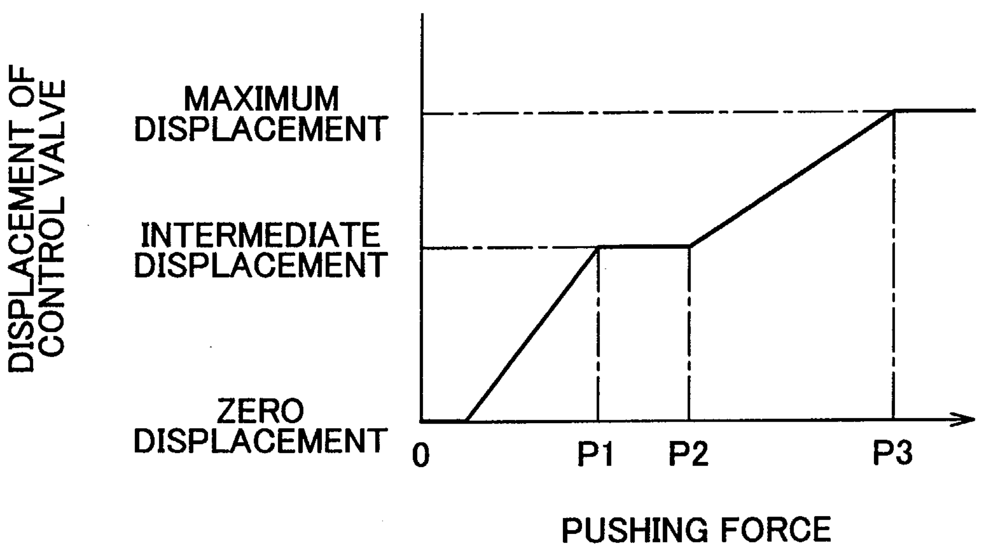

DISPLACEMENT OF CONTROL VALVE
MAXIMUM DISPLACEMENT
INTERMEDIATE DISPLACEMENT
ZERO DISPLACEMENT
0
P1
P2
P3
PUSHING FORCE

FIG. 4

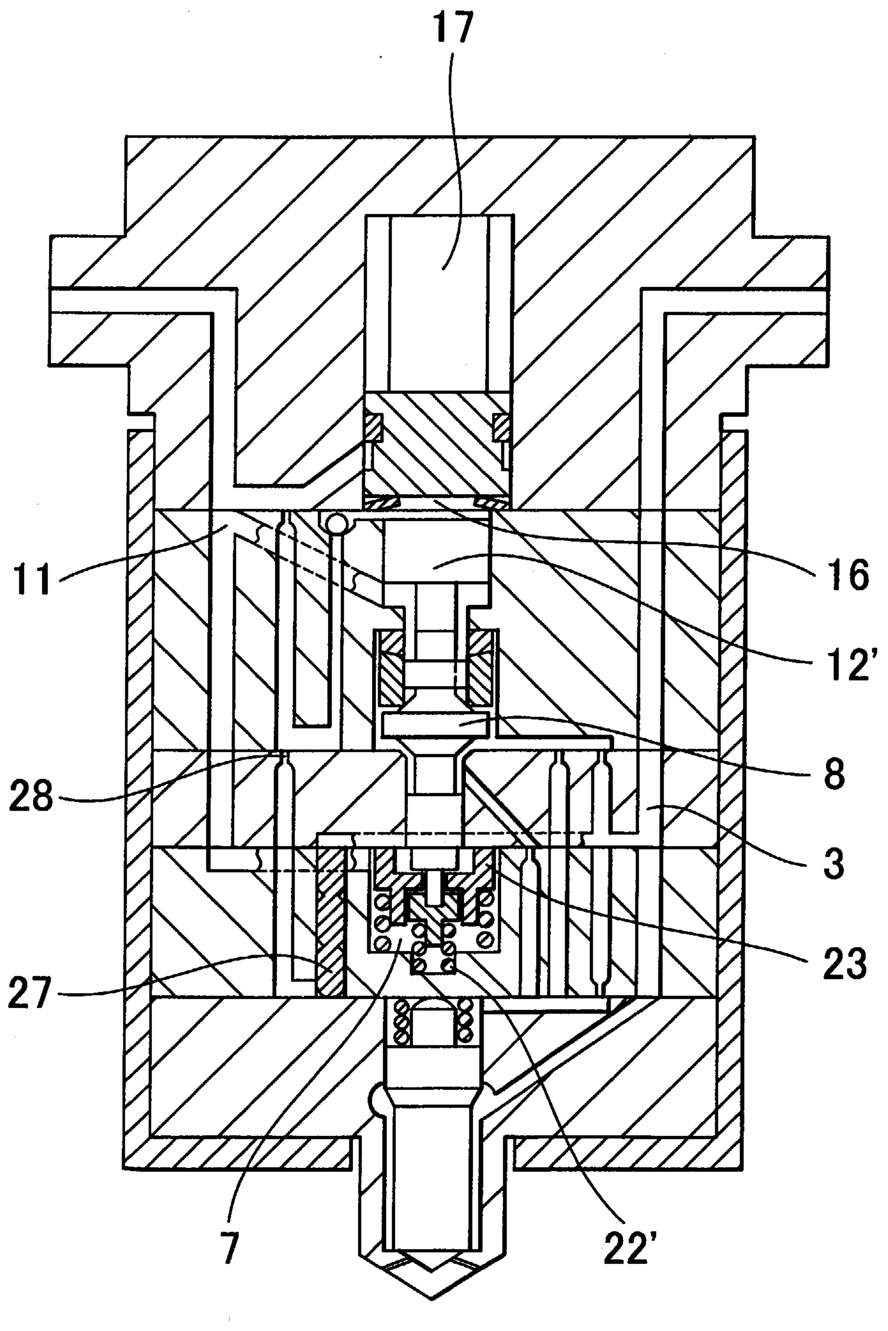
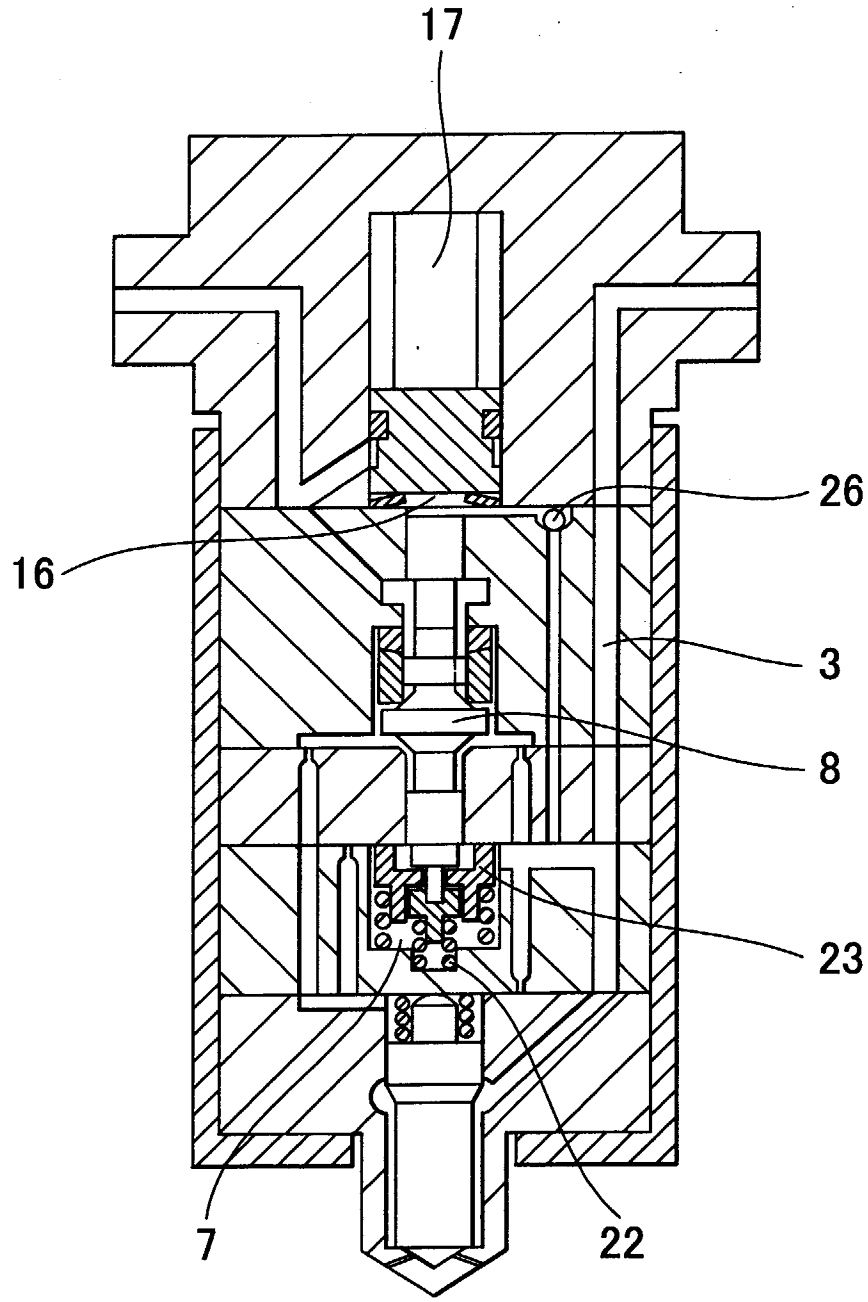
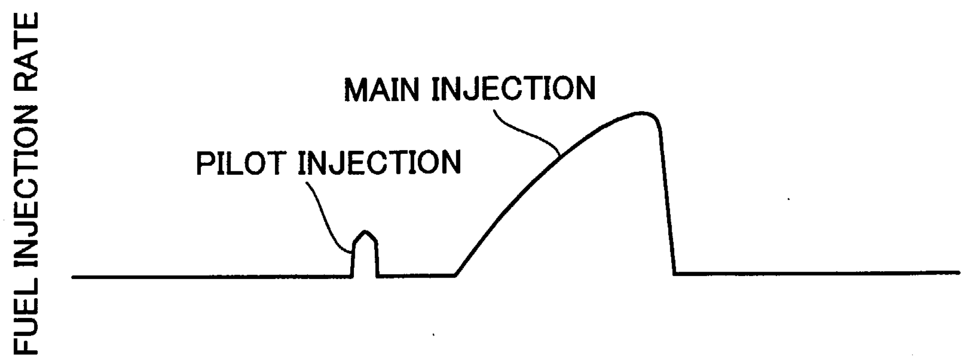


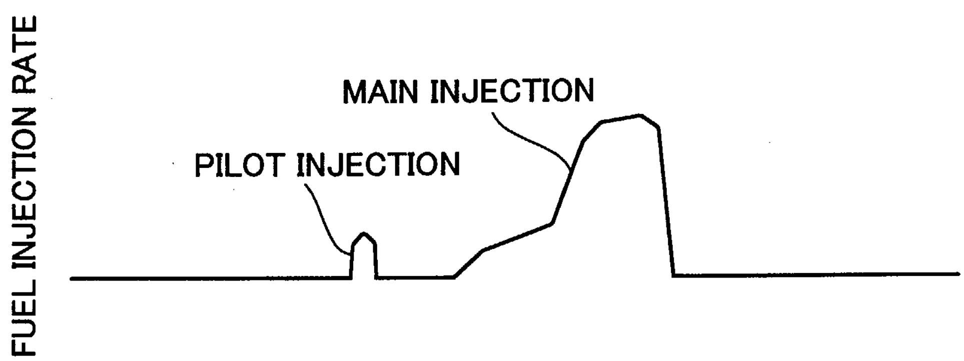
FIG. 5



# FIG. 6




# FIG. 7




# FIG. 8

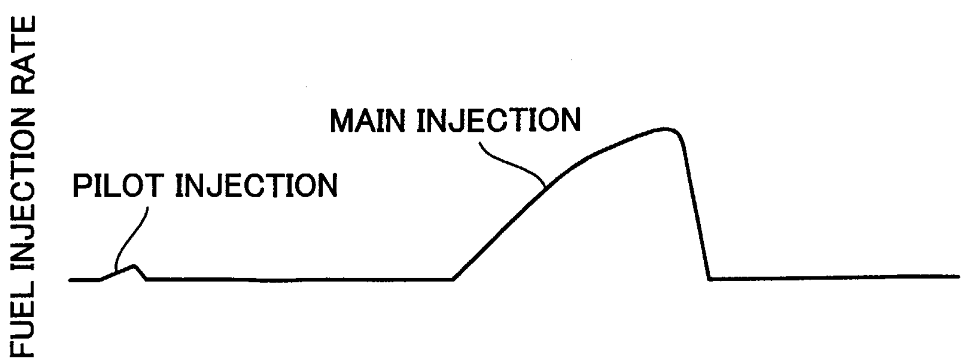


FIG. 9

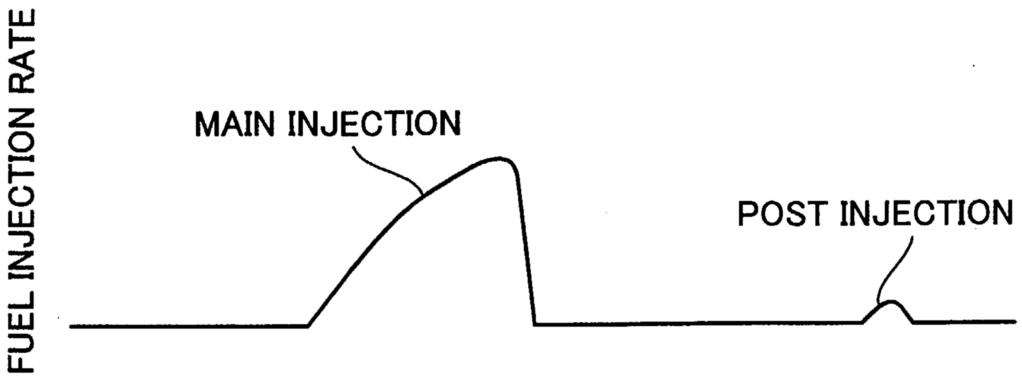
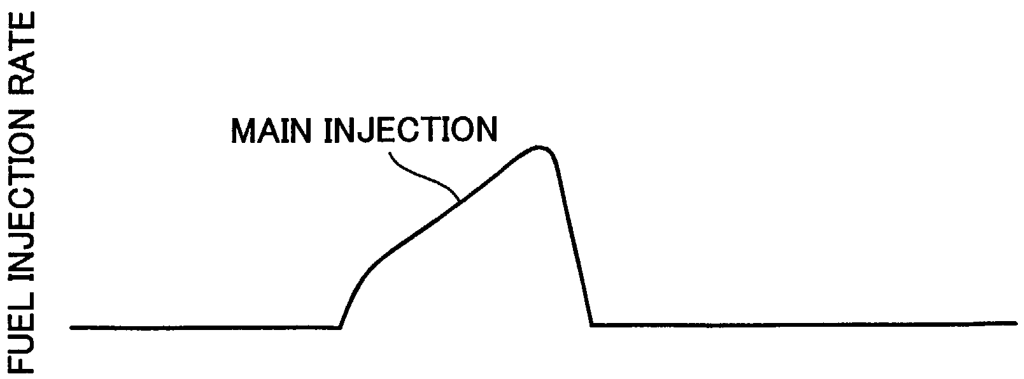

FUEL INJECTION RATE
MAIN INJECTION
POST INJECTION

FIG. 10


FUEL INJECTION RATE
MAIN INJECTION