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**(54) Fuel pump operated by means of a shape memory material**

(57) A fuel pump (1) for an internal combustion engine; the fuel pump (1) is equipped with at least one pumping chamber (2) with variable volume; with at least one inlet valve (3) communicating with the pumping chamber (2); with at least one outlet valve (4) communicating with the pumping chamber (2); with at least one flexible membrane (6) that delimits the pumping chamber (2); and with an actuating device (7) that acts on the flex-

ible membrane (6) to cyclically vary the volume of the pumping chamber (2); the actuating device (7) presents at least one shape memory material (8) that modifies its geometry upon application of an external influence of a physical nature and is mechanically coupled with the flexible membrane (6), and a piloting device (9) to cyclically apply an external influence of a physical nature to the shape memory material (8).

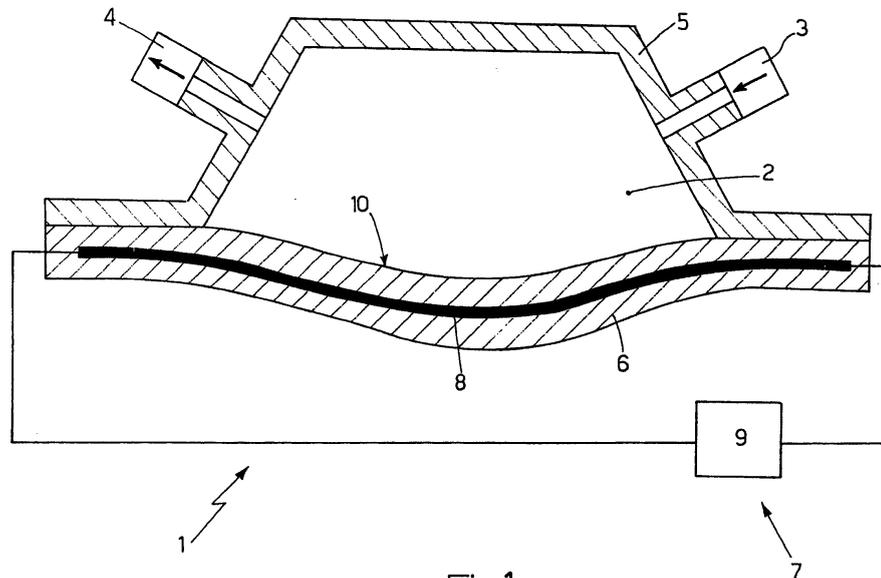


Fig.1

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**Description**TECHNICAL FIELD

**[0001]** The present invention relates to a fuel pump for an internal combustion engine.

BACKGROUND ART

**[0002]** In an internal combustion engine at least one fuel pump is present which has the function of feeding the fuel from a tank to an injection system. Moreover, a modern internal combustion engine with direct injection of the fuel comprises both a low pressure fuel pump positioned in correspondence with the petrol tank and a successive high pressure fuel pump positioned inside the engine compartment.

**[0003]** A low pressure fuel pump normally comprises an electric motor, which operates the pump itself; this construction solution simplifies the positioning and the fitting of the fuel pump inside the fuel tank, but is also bulky and heavy due to the presence of the electric motor.

**[0004]** Normally, a high pressure fuel pump comprises at least one cylinder equipped with a piston mechanically operated by the engine shaft in order to have a reciprocating motion inside said cylinder; a monodirectional inlet valve, which allows the fuel to flow into the cylinder, and a monodirectional outlet valve, which allows the fuel to flow out of the cylinder are positioned on the top of the cylinder.

**[0005]** These high pressure fuel pumps must be mechanically connected to the engine shaft, in order to receive from the engine itself the reciprocating motion required for the movement of the piston; this condition inevitably leads to rigid limits to the positioning of the fuel pump inside the engine compartment. Moreover, the piston generally effects one cycle (i.e. one intake stroke and one pumping stroke) every two rotations of the engine shaft; consequently, the pressure of the fuel downstream the fuel pump presents oscillations of considerable width, while for the correct operation of the injection system it is important for the pressure level of the fuel downstream the fuel pump to be as equal as possible to a desired value generally variable over time.

**[0006]** In order to reduce the pressure oscillations of the fuel downstream the fuel pump, it is possible to increase the number of cylinders of the fuel pump itself (using two, three or four cylinders); however this solution, although simple to construct, involves a substantial increase in costs and in the dimensions of the fuel pump. Alternatively, it is possible to increase the speed of the piston so that the piston performs a complete cycle with every rotation of the engine shaft; nonetheless, to make the piston of the fuel pump perform one cycle for every rotation of the engine shaft, instead of one cycle for every two rotations of the engine shaft, entails a double in the average speed of the piston itself with evident problems of mechanical resistance and reliability over time.

**[0007]** According to one embodiment, the high pressure fuel pump is sized to feed in all operating conditions a quantity of fuel in excess of the effective consumption, and downstream the fuel pump there is a pressure regulator that maintains the pressure level of the fuel equal to a desired value discharging the excess fuel towards a recirculation channel which returns the excess fuel to the tank. In this case, the fuel pump must be sized to feed a quantity of fuel equal to the maximum possible consumption; however, this condition of maximum possible consumption rarely occurs, and in all the remaining operating conditions the quantity of fuel fed to the fuel pump is much greater than the effective consumption and, therefore, a considerable part of this fuel must be discharged by the pressure regulator in the tank. It is evident that the work carried out by the fuel pump in pumping the fuel that is subsequently discharged by the pressure regulator is "useless" work, therefore the system presents very low energetic efficiency. Moreover, the fuel tends to overheat, since when the excess fuel is discharged by the pressure regulator in the recirculation channel, the fuel itself moves from very high pressure to substantially environmental pressure and the effect of this leap in pressure is a tendency to increase the temperature of the fuel. Finally, the pressure regulator and the recirculation channel connected to the pressure regulator are fairly bulky.

**[0008]** To solve the problems described above, a solution has been proposed of the type presented in the patent application EP-0481964-A1, which describes the use of a high pressure, variable flow fuel pump capable of feeding only the quantity of fuel required to maintain the pressure of the fuel downstream the fuel pump at an average equal to the desired value; in particular, the fuel pump is equipped with an electromagnetic actuator capable of varying the capacity of the fuel pump from moment to moment, instantly varying the moment of closure of the inlet valve of the fuel pump itself (the flow is decreased delaying the moment of closure of the intake valve and is increased anticipating the moment of closure of the inlet valve).

**[0009]** However, the variable flow high pressure fuel pumps of the type described above are particularly complex and expensive due to the presence of the electromagnetic actuator and the electronics for piloting and control thereof. Moreover, there is a continual alternation of fuel entering and leaving the cylinder through the inlet valve and this continual alternate stream of fuel entering and leaving clearly entails waste of part of the energy used by the pump.

DISCLOSURE OF INVENTION

**[0010]** It is the object of the present invention to make a fuel pump for an internal combustion engine, said fuel pump being free from the shortcomings described above and, in particular, being easy and inexpensive to produce.

**[0011]** According to the present invention a fuel pump is made for an internal combustion engine according to the appended claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** The present invention will now be described with reference to the attached drawings, which show a preferred non-limitative embodiment thereof, in which:

- figure 1 is a schematic side section of a fuel pump made in accordance with the present invention; and
- figure 2 is a schematic view with some details removed for clarity of a component of the fuel pump in figure 1.

#### PREFERRED EMBODIMENTS OF THE INVENTION

**[0013]** In figure 1, it is indicated as a whole by 1 a fuel pump for an internal combustion chamber. The fuel pump 1 comprises a pumping chamber 2 with variable volume, a monodirectional inlet valve 3, communicating with the pumping chamber 2 and a monodirectional outlet valve 4 communicating with the pumping chamber 2. The pumping chamber 2 is contained inside a rigid open container 5 and is delimited by a flexible membrane 6, which is connected to the rigid container 5 and is made of hyperelastic or rigid polymeric material; moreover the flexible membrane 6 is equipped with an actuating device 7 that acts on the flexible membrane 6 to cyclically vary the volume of the pumping chamber 2 and therefore actuating the fuel pumping.

**[0014]** The actuator device 7 comprises a shape memory material 8 that modifies its geometry upon application of an external influence of a physical nature and is mechanically coupled with the flexible membrane 6, and a piloting device 9 to cyclically apply an external influence of a physical nature to the shape memory material 8.

**[0015]** The shape memory material 8 is a Shape Memory Alloy (SMA) capable of changing its physical characteristics upon application of an external influence of a physical nature; in particular metal alloys are used (for example nickel-titanium or a copper-based alloy) capable of changing its dimensions upon application of heat. In other words, the variation of the geometry of the shape memory material 8 is obtained by heating (i.e. by raising the temperature) of the shape memory material 8 itself.

**[0016]** At room temperature, the shape memory material 8 is of a given length, while when the temperature of the shape memory material 8 exceeds a set temperature threshold (depending on the chemical-physical characteristics of the material), the shape memory material 8 shortens by a predetermined quantity (depending on the chemical-physical characteristics of the material) generating a reduction in the distance existing between the extremities of the shape memory material 8 itself. Preferably, the shape memory material 8 is "two-way", i.e. it shortens when heated and lengthens spontaneously

ly returning to its initial size when cooled.

**[0017]** The shape memory material 8 is filiform and extends along the entire length of the flexible membrane 6; in particular a plurality of wires is envisaged, which are made of the shape memory material 8 and are uniformly distributed along the flexible membrane 6. Upon application of an external influence of a physical nature the shape memory material 8 contracts, shortening and consequently deforming the flexible membrane 6 and therefore varying the volume of the pumping chamber 2.

**[0018]** According to a preferred embodiment, the piloting device 9 applies heat to modify the geometry of the shape memory material 8 and, in particular, the piloting device 9 circulates an electric current through the shape memory material 8 to heat the shape memory material 8 itself by Joule effect. According to a different embodiment (not shown), the heating of the shape memory material 8 occurs by means of a phenomenon of magnetic or electromagnetic nature, or the shape memory material 8 is heated by a hot fluid.

**[0019]** Preferably, the shape memory material 8 is buried in the flexible membrane 6; in particular the flexible membrane 6 is made of pressed plastic material and the shape memory material 8 is co-pressed inside the flexible membrane 6.

**[0020]** In use, the shape memory material 8 is cyclically crossed by an impulsive electric current, which by the Joule effect determines the heating of the shape memory material 8 itself; following the heating, the shape memory material 8 contracts, shortening and determining a deformation of the flexible membrane 6 which causes a variation in the volume of the pumping chamber 2. Once the deformation of the flexible membrane 6 occurs, the electric current passing through the shape memory material 8 is interrupted and the shape memory material 8 itself cools returning to its original length and determining a new deformation in the flexible membrane 6 equal and opposite to the previous deformation. The cyclical alternation of the deformations of the flexible membrane 6 determines a cyclical variation in the volume of the pumping chamber 2 and therefore actuates the fuel pumping.

**[0021]** Regulating the frequency and/or the intensity of the physical influence applied to the shape memory material 8 it is possible to regulate the average capacity of the fuel pump 1 in an extremely simple and precise manner; in particular by increasing the frequency and/or intensity of the physical influence applied to the shape memory material 8 the average capacity of the fuel pump 1 is increased and vice versa.

**[0022]** It is important to stress that the cooling of the shape memory material 8 is due to thermal conduction, since the shape memory material 8 transmits the heat to the surrounding flexible membrane 6, which is maintained at room temperature by the fuel that continually flows through the pumping chamber 2 and which wets an internal wall 10 of the flexible membrane 6 itself.

**[0023]** According to another embodiment (not shown), the fuel pump 1 comprises a plurality of pumping cham-

bers 2; moreover, one pumping chamber 2 could comprise two or more flexible membranes 6, each of which is coupled with a corresponding actuator device 7.

**[0024]** As previously mentioned, the shape memory material 8 is "two-way", i.e. it shortens when heated and lengthens spontaneously returning to its original dimensions when cooled. Alternatively, the shape memory material 8 could be "one-way", i.e. it shortens when heated, but does not lengthen spontaneously returning to its original dimensions when cooled; in this case the lengthening of the shape memory material 8 when cooled is determined by the force of the spring-back of the flexible membrane 6.

**[0025]** The fuel pump 1 described above presents numerous advantages, since it is simple and easy to construct and has at the same time a highly reduced size and a high level of energetic efficiency. The actuation of the fuel pump 1 described above is completely independent from the motion of the engine shaft and therefore the positioning and the fitting of the fuel pump 1 itself is extremely simple. The fuel pump 1 described above may be activated with a very higher frequency than the rotation of the engine shaft; therefore the pressure of the fuel downstream the fuel pump 1 presents extremely limited oscillations. Finally, by regulating the frequency and/or intensity of the physical influence applied to the shape memory material 8 it is possible to regulate the average capacity of the fuel pump 1 in an extremely simple and precise manner.

**[0026]** It is important to stress that the fuel pump 1 described above can be used both as a low pressure fuel pump and as a high pressure fuel pump.

## Claims

1. A fuel pump (1) for an internal combustion engine; the fuel pump (1) comprising:

at least one pumping chamber (2) with variable volume;  
 at least one inlet valve (3) communicating with the pumping chamber (2);  
 at least one outlet valve (4) communicating with the pumping chamber (2);  
 at least one flexible membrane (6) that delimits the pumping chamber (2); and  
 an actuating device (7) that acts on the flexible membrane (6) to cyclically vary the volume of the pumping chamber (2);  
 the fuel pump (1) is **characterised in that** the actuating device (7) comprises:

at least one shape memory material (8) that modifies its geometry upon application of an external influence of a physical nature and is mechanically coupled with the flexible membrane (6); and

a piloting device (9) to cyclically apply an external influence of a physical nature to the shape memory material (8).

2. A fuel pump (1) according to claim 1, wherein the shape memory material (8) is buried inside the flexible membrane (6).
3. A fuel pump (1) according to claim 2, wherein the flexible membrane (6) is made of pressed plastic material and the shape memory material (8) is compressed with the flexible membrane (6).
4. A fuel pump (1) according to claim 1, 2 or 3, wherein the shape memory material (8) is filiform and extends along the entire length of the flexible membrane (6).
5. A fuel pump (1) according to claim 4, wherein a plurality of wires are envisaged, which are composed of the shape memory material (8) and are uniformly distributed along the flexible membrane (6).
6. A fuel pump (1) according to any of claims from 1 to 5, wherein the piloting device (9) applies heat to modify the geometry of the shape memory material (8).
7. A fuel pump (1) according to claim 6, wherein the piloting device (9) circulates an electric current through the shape memory material (8) to heat the shape memory material (8) itself by Joule effect.
8. A fuel pump (1) according to any of the claims from 1 to 7, wherein the shape memory material (8) contracts and shortens upon application of an external influence of a physical nature.
9. A fuel pump (1) according to any of the claims from 1 to 8, wherein the flexible membrane (6) is made of hyperelastic material.
10. A fuel pump (1) according to any of the claims from 1 to 8, wherein the flexible membrane (6) is made of rigid polymeric material.
11. A fuel pump (1) according to any of the claims from 1 to 10, wherein an internal wall (10) of the flexible membrane (6) is wet by the fuel that flows through the pumping chamber (2).
12. A fuel pump (1) according to any of the claims from 1 to 11, wherein the shape memory material (8) is "two-way".
13. A fuel pump (1) according to any of the claims from 1 to 12, wherein the pumping chamber (2) is defined inside a rigid open container (5) to which the flexible membrane (6) is connected.

14. A fuel pump (1) according to any of the claims from 1 to 13, wherein the piloting device (9) varies the frequency and/or the intensity of the physical influence applied to the shape memory material (8) in order to regulate the average capacity of the fuel pump (1) itself. 5

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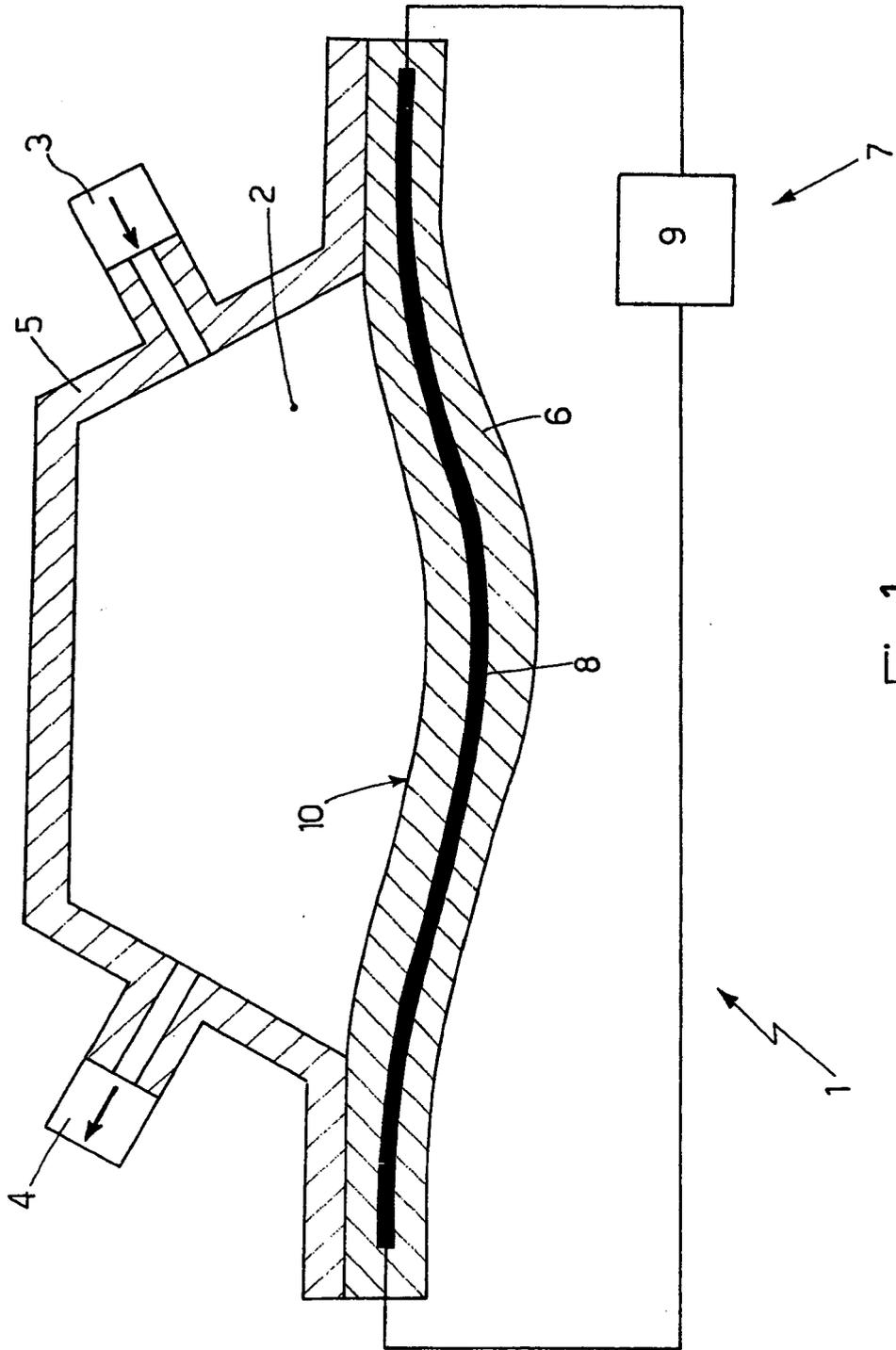


Fig.1

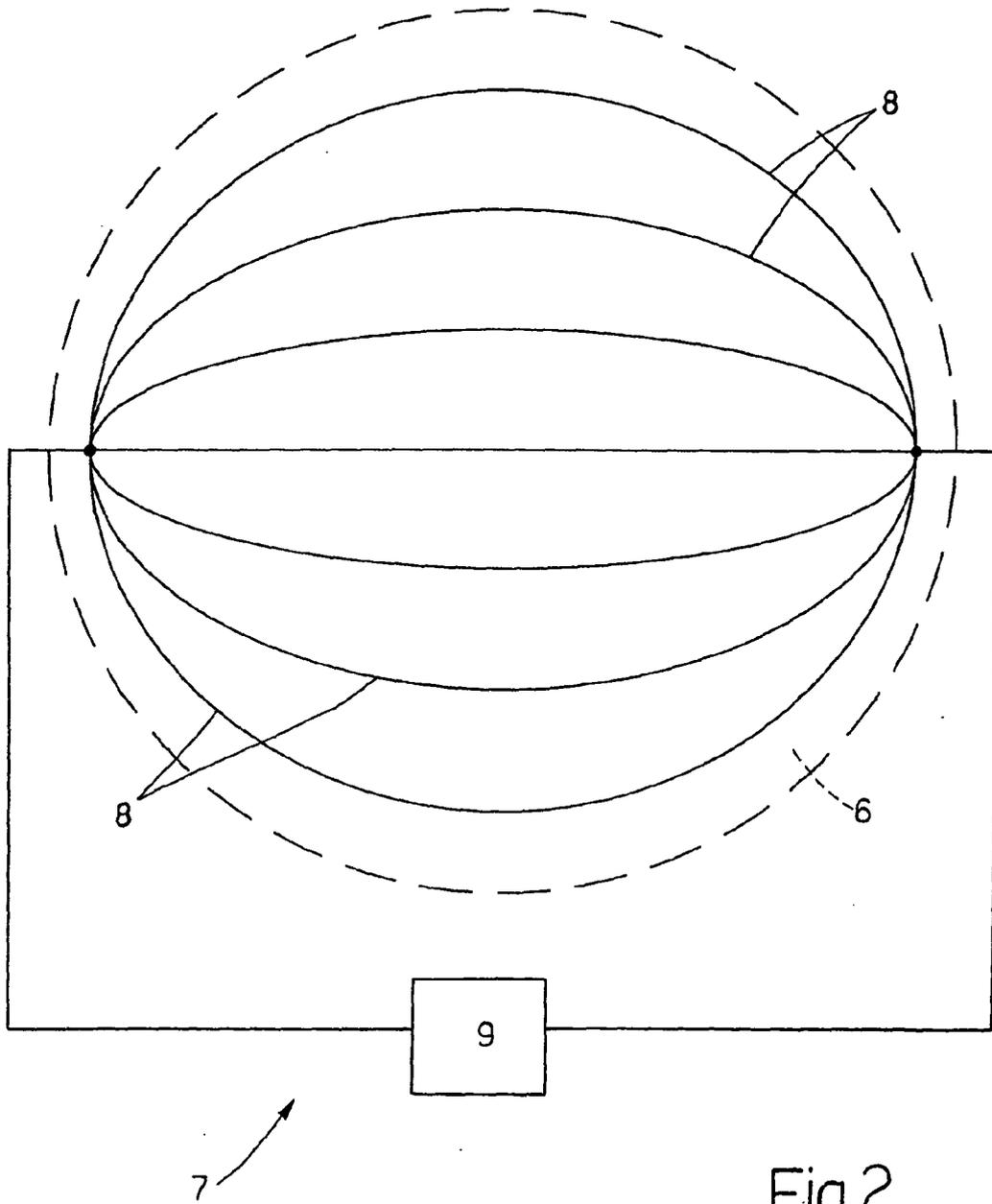


Fig.2



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EPO FORM 1503 03.02 (P04C01)

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