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(54) **Fuel injector**

(57) A fuel injector for an internal combustion engine comprises a valve needle (12) which is movable within a bore (30) relative to a valve needle seating (34) defined by the bore to control fuel delivery through at least one outlet (38) of the injector, the bore (30) being supplied with fuel at high pressure for injection when the valve needle is moved away from the valve needle seating (34); an actuator (14) coupled to the valve needle (12) so as to effect movement thereof; and a sac volume (40) for fuel at a lower end of the valve needle (12) and downstream of the valve needle seating (34). A balance chamber (60) for fuel is provided at an upper end of the valve needle (12) which communicates with the sac volume (40) via a connecting flow path (62). The balance chamber (60), the connecting flow path (62) and the sac volume (40) define a volume for fuel which is isolated from fuel within the bore (30) when the valve needle (12) is engaged with the valve needle seating (34).

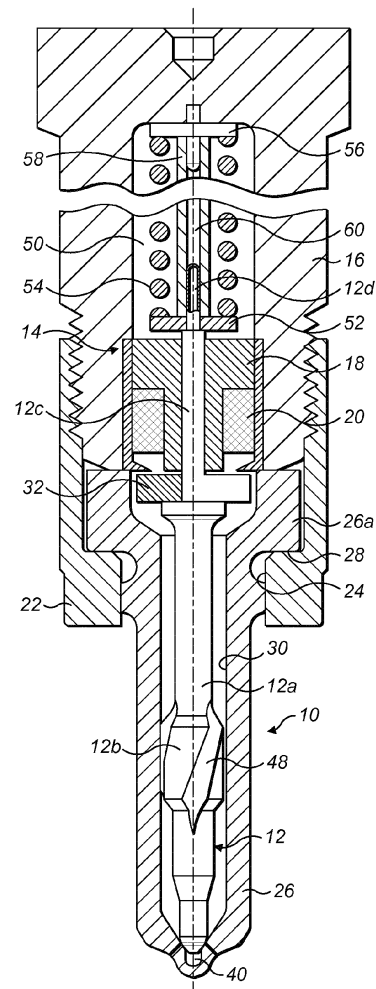


FIG. 1

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Description

Technical field

[0001] The invention relates to a fuel injector of the type suitable for delivering fuel to a combustion space of an internal combustion engine and, in particular, to the combustion space of a compression ignition internal combustion engine.

Background to the invention

[0002] In a known fuel injector, a valve needle is movable relative to a valve needle seating to control whether or not fuel is delivered through a plurality of injector outlets into an associated engine cylinder. The movement of a valve seat at a lower end of the valve needle towards and away from the valve needle seating controls injection.

[0003] In a direct-acting injector, valve needle movement is controlled by means of an actuator which is coupled directly to the valve needle so that movement of the actuator results in a direct control of movement of the valve needle. Typically, in a direct acting injector a piezoelectric actuator is used to move the valve needle. The piezoelectric actuator provides a high force to initiate movement of the valve needle away from the valve needle seating to start injection, but only a relatively small degree of movement.

[0004] In a servo-hydraulic system (an indirect-acting injector) a control valve is operable to control fuel pressure within a control chamber at the upper end of the valve needle. A surface of the valve needle is exposed to fuel pressure within the control chamber. As fuel pressure is varied in the control chamber the downward force on the valve needle is varied and so the valve needle is moved towards and away from the valve needle seating accordingly. Typically, servo-hydraulic injectors make use of a solenoid actuator for the control valve. A solenoid actuator provides a relatively low force which is sufficient to move the control valve, but is capable of movement over a relatively large distance.

[0005] There is a desire to provide a direct-acting injector in which a solenoid actuator is used to control movement of the valve needle directly, utilising the benefits of both a solenoid actuator and those of a direct-acting system.

Statements of invention

[0006] It is with a view to addressing this need that, in accordance with the present invention, there is provided a fuel injector comprising a valve needle which is movable within a bore relative to a valve needle seating defined by the bore to control fuel delivery through at least one outlet of the injector, the bore being supplied with fuel at high pressure for injection which occurs when the valve needle is moved away from the seating. The fuel injector

further comprises an actuator which is coupled to the valve needle so as to effect movement thereof, and a sac volume for fuel at a lower end of the valve needle and downstream of the valve needle seating. A balance chamber is provided for fuel at an upper end of the valve needle which communicates with the sac volume via a connecting flow path. The balance chamber, the connecting flow path and the sac volume define a volume for fuel which is isolated from fuel at high pressure within the bore.

[0007] In one embodiment, a valve spring is arranged to bias the valve needle towards the valve needle seating.

[0008] The benefit of the invention is that fuel pressure at the upper and lower ends of the valve needle is substantially the same at all times because of the closed volume of the balance chamber, the connecting flow path and the sac volume. The valve needle is therefore substantially pressure-balanced, so that the force required to lift the valve from the valve needle seating to commence injection is relatively low and need only overcome the biasing force of the valve spring. The invention therefore provides a particular advantage when employed in an injector having an electromagnetic actuator. Even though an electromagnetic actuator can only provide a relatively low force to initiate movement of the valve needle, the pressure-balancing of the valve needle means that this type of actuator is still effective. It is one benefit of using an electromagnetic actuator is that it is of relatively low cost compared with other actuator types, for example piezoelectric actuators.

[0009] The valve needle preferably includes an upper seat and a lower seat, wherein the upper and lower seats engage with the valve needle seating when the valve needle is seated.

[0010] Preferably the valve needle comprises a balance surface which is exposed to fuel within the balance chamber, wherein the lower seat and the balance surface have substantially the same diameter so that the valve needle is substantially pressure balanced when the valve needle is seated against the valve needle seating.

[0011] A further advantage is that leakage from the bore in the nozzle body is avoided because any fuel that leaks from the bore in the nozzle body down the valve length is retained within the enclosed volume of the balance chamber, the connecting flow path and the sac volume when the upper and lower seats are engaged with the valve needle seating.

[0012] In a further preferred embodiment, the valve needle carries or is integrally formed with an armature which is movable under the influence of a force due to the electromagnetic actuator.

[0013] It is preferable if the actuator is coupled directly to the valve needle, as opposed to, for example, an indirect servo-valve mechanism.

[0014] In one embodiment, the balance chamber is defined, at least in part, by a resilient member.

[0015] Preferably, the resilient member is a tube and the internal bore of the tube defines the balance chamber.

[0016] The fuel injector may further comprise a spring chamber for housing a closing spring which serves to urge the valve needle towards the valve needle seating.

[0017] The resilient member is preferably located within the spring chamber and, optionally, is received within the closing spring. This provides a particularly space-efficient arrangement.

[0018] The valve needle may carry a flange at its upper end to define a seat for an end of at least one of the resilient member and the closing spring.

[0019] In one embodiment, the resilient member comprises a plastic material.

[0020] The resilient member may be elastically anisotropic. For example, the resilient member may be a composite structure comprising first and second windings, wound coaxially in opposite directions, and a binding resin, and wherein the balance chamber is defined within the windings.

[0021] In another embodiment the resilient member comprises a bellows device, wherein the balance chamber is defined within the bellows device.

[0022] For convenience, the connecting flow path is preferably provided within the valve needle.

Brief description of the drawings

[0023] The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a cross sectional view of a fuel injector in accordance with an embodiment of the invention;

Figure 2 is an enlarged view of a lower end of the fuel injector in Figure 1;

Figure 3 is an enlarged view of a lower end of the valve needle of the fuel injector of Figure 1 to illustrate upper and lower seats of the valve needle;

Figure 4 is a cross sectional view of the valve needle of the injector in Figure 1 to illustrate a projected area of a portion of the valve needle, in a horizontal plane, which is exposed to fuel pressure within the sac volume of the injector; and

Figure 5 shows a resilient tube element of an alternative embodiment of the invention to that shown in Figures 1 to 4.

Detailed description of preferred embodiments

[0024] Referring to Figure 1, a fuel injector for use in an internal combustion engine and in accordance with a first embodiment of the invention includes an injection nozzle 10 having a valve needle 12 and an actuator 14 that is operable to control movement of the valve needle 12 so as to control fuel injection into a combustion space

(not shown) of the engine. The actuator 14 takes the form of an electromagnetic actuator that is housed within an injector housing 16. The actuator comprises an actuator core 18 and a solenoid winding 20 through which a current is supplied, in use, to energise the winding 20. The injector housing 16, at its lower end in the orientation shown, is received in screw threaded connection within an internal bore 24 of a cap nut 22. The actuator 14 is coupled directly to the valve needle 12. In other words, actuation of the actuator 14 directly controls movement of the valve needle 12 rather than controlling an intermediate servo-valve or other hydraulic system.

[0025] The injection nozzle 10 includes a nozzle body 26 having an enlarged upper end 26a which is also received within the cap nut 22 so as to engage with a step 28 in the internal bore 24. The nozzle body 26 is provided with a blind bore 30 within which a lower portion 12a of a valve needle 12 is received. The upper end 26a of the nozzle body 26 is provided with a recess for receiving an armature 32 that is carried by the valve needle part way along its length. The armature 32 is movable under the influence of the electromagnetic field generated by the solenoid actuator 14, and in this way movement of the valve needle 12 is controlled.

[0026] As best illustrated in Figures 2 and 3, a valve needle seating 34 is defined towards the blind end of the bore 30 with which a seating portion of the valve needle 12 is engageable to control fuel injection through a plurality of nozzle outlets 38 (shown only in Figure 2) provided in the nozzle body 26. The seating portion of the valve needle includes upper and lower valve seats, 41 and 42 respectively, both of which are engageable with the valve needle seating 34. A upper frusto-conical region 43 lies upstream of the upper seat 41 and a lower frusto-conical region 44 lies downstream of the lower seat 42. Between the seats 41, 42 the valve needle includes a shaped portion 36 which defines a fuel volume together with the adjacent region of the bore 30.

[0027] A sac volume 40 for fuel is defined at the blind end of the bore, downstream of the lower valve seat 42. The pressure of fuel acting downstream of the lower seat 42 contributes an upwardly-directed force to the valve needle 12 due to fuel pressure within the sac volume 40, as will be described in further detail below. The fuel volume between the shaped portion 36 of the valve needle and the bore 30 communicates with the entry ends of the outlets 38.

[0028] Fuel at high pressure is delivered to the bore 30 in the nozzle body 26 through a supply passage (not shown) from a high pressure fuel pump (also not shown) in a conventional manner. The lower portion 12a of the valve needle 12 includes a guide portion 12b of the needle, of the same diameter as the bore 30 in the nozzle body 26, which serves to guide movement of the valve needle 12 within the bore as it moves. The guide portion 12b is provided with grooves or flutes 48 which allow fuel at high pressure, that is delivered to the bore upstream of the guide portion 46, to flow past the guide portion 12b

and towards the sac volume 40. When the valve needle is lifted from the valve seats 41, 42, fuel is able to flow from the bore 30, past the upper seat 41 to the outlets 38 and from the sac volume 40 past the lower seat 42 to the outlets 38. When the valve needle is seated, fuel is unable to flow from the bore 30 past the upper seat 41 through the outlets 38 and is unable to flow from the sac volume 40 past the lower seat 42 to the outlets 38.

[0029] An upper portion 12c of the valve needle 12 extends through the actuator body and projects into a chamber 50 defined within the injector housing 16. The upper portion 12c of the valve needle 12 carries an annular member 52 which defines a seat for one end of a valve closing spring 54 housed within the chamber 50. The other end of the spring 54 abuts a plate 56 located at the upper end of the chamber 50.

[0030] Internally within the spring 54, a resilient tube 58 is located within which the uppermost tip 12d of the valve needle is received. The resilient tube 58 defines a balance chamber 60, so-called for reasons which will be explained further below. The valve needle 12 is provided with a connecting flow path 62 along its entire length which provides a communication channel between the balance chamber 60 at the upper end of the valve needle and the sac volume 40 at the other end of the valve needle. The connecting flow path 62 is best illustrated in Figures 2 and 3. The balance chamber 60 forms an enclosed space so that there is no fuel flow permitted between the balance chamber 60 and the surrounding spring chamber 58. In this way, the balance chamber 60, the connecting flow path 62 through the valve needle 12 and the sac volume 40 define a fully enclosed volume for fuel that is isolated from fuel within the bore 30 of the nozzle body 26 when the valve needle 12 is seated with the upper and lower valve seats 41, 42 against the valve needle seating.

[0031] In use, in the non-injecting position, the valve needle 12 is engaged with the valve needle seating 34 so that fuel that is supplied to the bore 30 is unable to flow past the upper seat 41 into the outlets 38 and fuel within the sac volume 40 is unable to flow past the lower seat 42 into the outlets. It is an important feature of the valve needle 12 that the diameter of the lower seat 42 that is exposed to fuel pressure within the sac volume 40 is the same as the diameter of the valve needle at its upper end 12d that is exposed to fuel pressure within the sealed balance chamber 60. Because the balance chamber 60 and the sac volume 40 are in communication with one another, this means that the upwardly-directed force acting on the valve needle 12 beneath the lower seat 42 is balanced with the downwardly-directed force acting on the exposed uppermost end 12d of the valve needle within the balance chamber 60. The valve needle 12 is therefore said to be "substantially" pressure balanced when seated against the valve needle seating 34. "Substantially" pressure balanced is intended to mean that the valve needle is pressure balanced with the exception of the vertical component of the force that arises

due to fuel pressure acting on the shaped portion 36 of the valve needle. Figure 4 shows a section view of the shaped portion 36 of the valve needle in a horizontal plane, and in which the projected vertical area 64 of the surface 36 is identified. This area 64 experiences an upwardly directed force due to fuel pressure acting beneath the lower seat 42, but there is no equivalent downwardly-directed surface area with which it is balanced. Because the projected area 64 results in a deviation from force balance across one end of the valve needle to the other, it is beneficial if the projected area 64 of the shaped portion 36 is made as small as possible.

[0032] Because the valve needle 12 is substantially pressure balanced (with the exception of the projected area 64 of the shaped portion 36), the force that is required to move the valve needle 12 away from the valve needle seating 34 is relatively low, being only that force that is required to overcome the force due to the spring 54. Applying a relatively low force by the actuator 14 therefore serves to move the valve needle 12 away from the valve needle seating 34 with relative ease so that fuel within the bore 30 is able to flow past the upper and lower valve seats 41, 42 and out through the nozzle outlets 38 into the combustion space. The actuator 14 is activated by passing a current through the solenoid so that an electromagnetic force attracts the armature 32 on the valve needle upwards, and therefore serves to move the valve needle 12 upwards, breaking engagement between the upper and lower valve seats 41, 42, respectively, and the valve needle seating 24.

[0033] Because the sac volume 40 is connected to the balance chamber 60 via the connecting flow path 62 in the valve needle, any change in fuel pressure at the lowermost end of the needle during needle lift will also be experienced at the uppermost end of the valve needle, so that the hydraulic forces are substantially balanced throughout needle lift (with the exception of the force acting over the projected area 64 of the shaped portion 36).

[0034] In order to seat the valve needle 12 against the valve needle seating 34, the actuator 14 is de-energised so as to remove the electromagnetic force from the armature 32, allowing the upper and lower valve seats 41, 42 to re-engage with the valve needle seating 34 under the force of the spring 54. Once the valve seats 41, 42 are seated against the valve needle seating 34, any residual fuel within the enclosed volume of the sac volume 40, the connecting flow passage 62 and the balance chamber 60 will act equally at the upper and lower exposed surfaces of the valve needle 12 to substantially balance the valve needle, ready for the next injection event.

[0035] As the valve needle 12 moves away from the valve needle seating 34, the resilient tube 58 within the spring chamber 50, together with the spring 54, will undergo compression. The volume of the balance chamber 60 therefore varies throughout an injection cycle depending on whether the valve needle 12 is opening and the resilient member 58 is being compressed, or whether the

valve needle 12 is closing and moving towards the valve needle seating 34 and the resilient member 58 is expanding.

[0036] The resilient tube 58 is elastically anisotropic so that its resilience in one direction, along the axis of the valve needle 12, is greater than its resilience along a perpendicular direction, perpendicular to the valve needle axis. The axial stiffness of the resilient tube 58 must be designed carefully and must not hinder lifting motion of the valve needle 12. The Young's modulus of the material from which the resilient tube 58 is formed must be relatively low with respect to, for example, common steel. On the other hand, the resilient tube 58 must be circumferentially strong and with a relatively high Young's modulus in order to avoid unwanted changes in the diameter of the tube throughout the opening and closing cycle of the valve needle 12. A transverse isotropic material provides a good compromise between the aforementioned requirements. For example, a glass fibre reinforced plastic with a fibre orientation perpendicular to the injector axis provides a composite material that is strong against pressure and weak against the magnetic actuator.

[0037] In another embodiment (not shown), the resilient member which defines the balance chamber may take the form of a bellows device. The bellows device is another example of an elastically anisotropic device having greater elasticity along the valve needle axis than in the perpendicular direction.

[0038] As an alternative to using a plastic-based resilient member to define the balance chamber 60, in an alternative embodiment (as shown in Figure 5) the resilient member is a composite element formed of two fibre windings 66, 68 and a suitable resin 70 to bind the two windings together. The windings 66, 68 are wound coaxially, in opposite directions, to define the balance chamber 60 within their internal volumes. A minimum of two windings of opposite handedness is required so as to avoid unwanted torsion deformations. This provides an advantage over a one-piece element in that the helical nature of the windings 66, 68 provides reinforced strength during compression of the tube through the injection cycle.

[0039] Several further variations and modifications not explicitly described above are also possible without departing from the scope of the invention as described in the appended claims. For example, in another embodiment (not shown) the spring may be removed and the resilient tube may provide the function of both defining the balance chamber volume and also providing a biasing force for the valve needle to urge it against the valve needle seating.

[0040] Although the invention provides a particular advantage in that it allows a direct-acting actuator to be used to actuate movement of the valve needle, it is also possible to implement the invention in an injector having an indirect-acting actuator, for example where the actuator controls a valve for controlling fuel pressure in a valve needle control chamber.

Claims

1. A fuel injector for an internal combustion engine, the fuel injector comprising:

a valve needle (12) which is movable within a bore (30) relative to a valve needle seating (34) defined by the bore to control fuel delivery through at least one outlet (38) of the injector, the bore (30) being supplied with fuel at high pressure for injection when the valve needle is moved away from the valve needle seating (34); an actuator (14) coupled to the valve needle (12) so as to effect movement thereof;

a sac volume (40) for fuel at a lower end of the valve needle (12) and downstream of the valve needle seating (34); and

a balance chamber (60) for fuel at an upper end of the valve needle (12) which communicates with the sac volume (40) via a connecting flow path (62);

wherein the balance chamber (60), the connecting flow path (62) and the sac volume (40) define a volume for fuel which is isolated from fuel within the bore (30) when the valve needle (12) is engaged with the valve needle seating (34).

2. The fuel injector as claimed in claim 1, wherein the actuator (14) is coupled directly to the valve needle (12).

3. The fuel injector as claimed in claim 1 or claim 2, wherein the valve needle includes an upper seat (41) and a lower seat (42), wherein the upper and lower seats (41, 42) engage with the valve needle seating (34) when the valve needle is seated.

4. The fuel injector as claimed in claim 3, wherein the valve needle (12) comprises a balance surface which is exposed to fuel within the balance chamber (60), wherein the lower seat (42) and the balance surface have substantially the same diameter so that the valve needle (12) is substantially pressure balanced when the valve needle (12) is seated against the valve needle seating (34).

5. The fuel injector as claimed in any of claims 1 to 4, wherein the balance chamber (60) is defined, at least in part, by a resilient member (58).

6. The fuel injector as claimed in claim 5, wherein the resilient member is a tube (58) and the internal bore of the tube defines the balance chamber (60).

7. The fuel injector as claimed in claim 5 or claim 6, further comprising a spring chamber (50) for housing a closing spring (54) which serves to urge the valve needle towards the valve needle seating (34).

8. The fuel injector as claimed in claim 7, wherein the resilient member (58) is located within the spring chamber (50).
9. The fuel injector as claimed in claim 8, wherein the resilient member (58) is received within the closing spring (54). 5
10. The fuel injector as claimed in any of claims 7 to 9, wherein the valve needle (12) carries a flange (52) at its upper end to define a seat for an end of at least one of the resilient member (58) and the closing spring (54). 10
11. The fuel injector as claimed in any of claims 5 to 10, wherein the resilient member comprises a plastic material. 15
12. The fuel injector as claimed in claim 11, wherein the resilient member (58) is elastically anisotropic. 20
13. The fuel injector as claimed in claim 12, wherein the resilient member (58) is a composite structure comprising first and second windings (66, 68), wound coaxially in opposite directions, and a resin, and wherein the balance chamber is defined within the windings (66, 68). 25
14. The fuel injector as claimed in claim 12, wherein the resilient member comprises a bellows device, wherein the balance chamber is defined within the bellows device. 30
15. The fuel injector as claimed in any of claims 1 to 14, wherein the connecting flow path (62) is provided within the valve needle (12). 35

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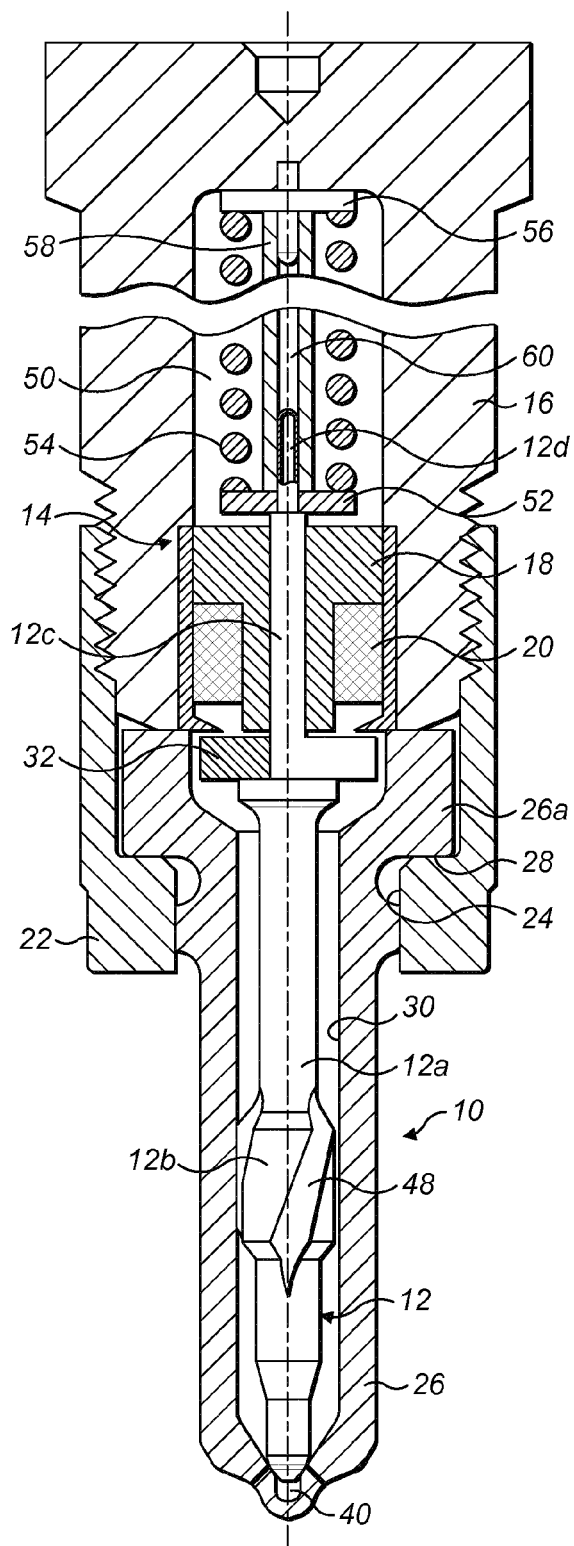


FIG. 1

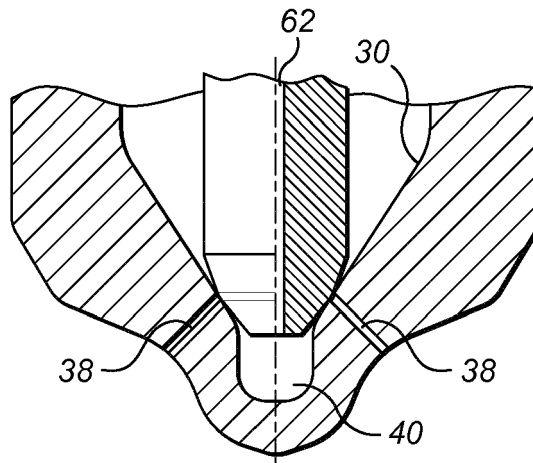


FIG. 2

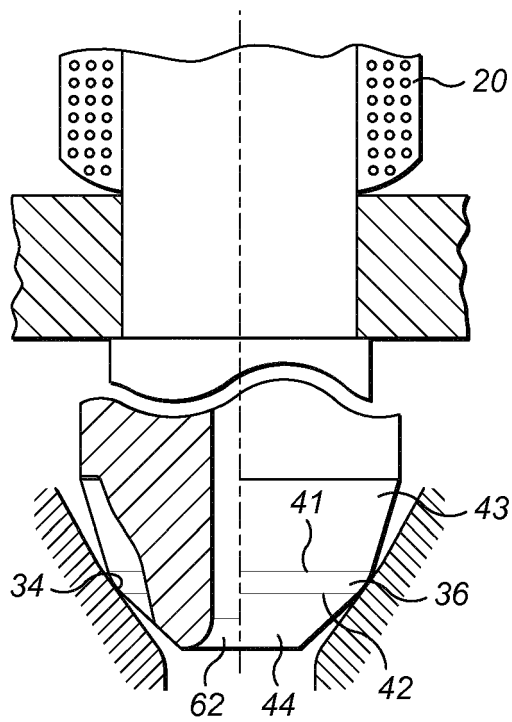


FIG. 3

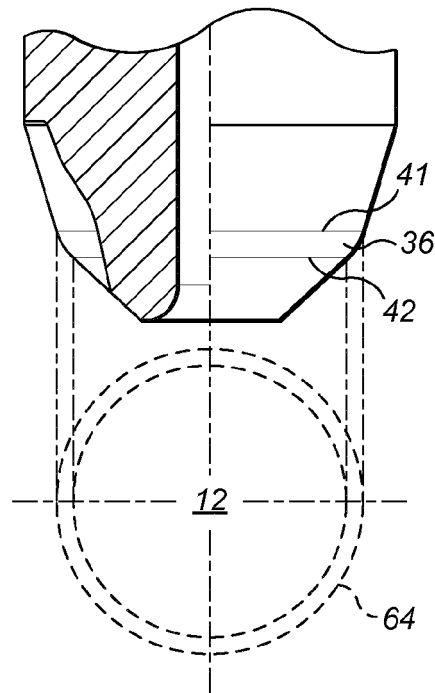


FIG. 4

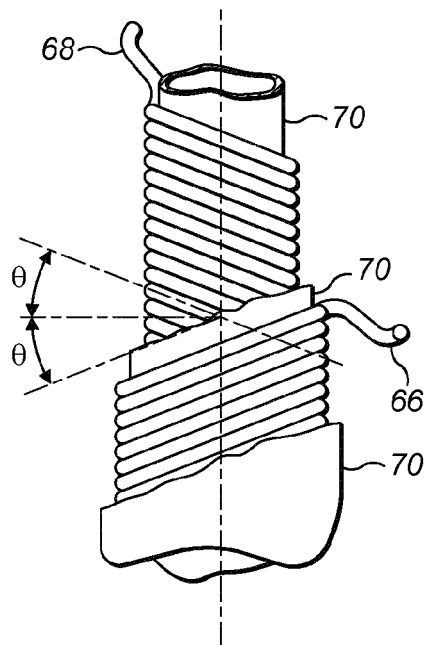


FIG. 5



EUROPEAN SEARCH REPORT

Application Number
EP 12 16 6388

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Place of search Munich		Date of completion of the search 17 October 2012	Examiner Landriscina, V
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82