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• **Carpentier, Christophe**
57100 Thionville (FR)

(74) Representative: **Gregory, John David Charles**
Delphi Diesel Systems
Patent Department
Courteney Road
Gillingham
Kent ME8 0RU (GB)

(71) Applicant: **Delphi Technologies Holding S.à.r.l.**
4940 Bascharage (LU)

(72) Inventors:
• **Winandy, Jean-Pierre**
6700 Arlon (BE)

(54) **Actuator Arrangement for use in a Fuel Injector**

(57) The present invention relates an actuator arrangement for use in a fuel injector, comprising: a piezo-electric actuator having a body section, said body section having a first end piece and a second end piece; a sleeve which enshrouds at least part of the body section of the actuator; and at least one constrictive member, disposed externally with respect to the sleeve wherein the constrictive member applies a constrictive force to the sleeve to maintain a seal between the sleeve and the underlying body section of the actuator. The underlying body section comprises an alternation of smooth sections and rough sections; said rough sections comprising superficial markings.

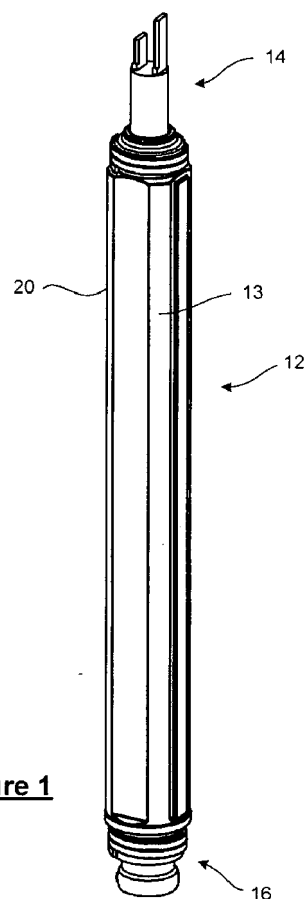


Figure 1

Description

Technical field

[0001] The present invention relates to an actuator arrangement for use in a fuel injector of the type intended for use in a fuel system of an internal combustion engine. The invention relates, more particularly, to an end-seal of an actuator arrangement of a fuel injector of the accumulator or common rail type, the fuel injector being of the type controlled using a piezoelectric actuator.

Background Art

[0002] It is known to use piezoelectric actuators in fuel injectors of internal combustion engines. Such piezoelectrically operable fuel injectors provide a high degree of control over the timing of injection events within the combustion cycle and the volume of fuel that is delivered during each injection event. This permits improved control over the combustion process, which is essential in order to keep pace with increasingly stringent worldwide environmental regulations. Such fuel injectors may be employed in compression ignition (diesel) engines or spark ignition (petrol) engines.

[0003] A typical piezoelectric actuator unit designed for use in an automotive fuel injector has a stack structure formed from an alternating sequence of piezoelectric elements or layers and planar internal electrodes. The piezoelectric layers, in turn, form an alternating sequence of oppositely polarised layers, and the internal electrodes form an alternating sequence of positive and negative internal electrodes. The positive internal electrodes are in electrical connection with a first external electrode, hereinafter referred to as the positive side electrode. Likewise, the internal electrodes of the negative group are in electrical connection with a second external electrode, hereinafter referred to as the negative side electrode.

[0004] If a voltage is applied between the two external electrodes, the resulting electric fields between each adjacent pair of positive and negative internal electrodes cause each piezoelectric layer, and therefore the piezoelectric stack, to undergo a strain along its length, i.e. along an axis normal to the plane of each internal electrode. Because of the polarisation of the piezoelectric layers, it follows that not only can the magnitude of the strain be controlled by adjusting the applied voltage, but also the direction of the strain can be reversed by switching the polarity of the applied voltage. Rapidly varying the magnitude and/or polarity of the applied voltage causes rapid changes in the strength and/or direction of the electric fields across the piezoelectric layers, and consequently rapid variations in the length of the piezoelectric actuator. Typically, the piezoelectric layers of the stack are formed from a ferroelectric material such as lead zirconate titanate (PZT).

[0005] Such an actuator is suitable for use in a fuel

injector, for example of the type known from the present Applicant's European Patent No. EP 0995901. The fuel injector is arranged so that a change in length of the actuator results in a movement of a valve needle. The needle can be thus raised from or lowered onto a valve seat by control of the actuator length so as to permit a quantity of fuel to pass through drillings provided in the valve seat.

[0006] In use, the actuator of such a fuel injector is surrounded by fuel at high pressure. The fuel pressure may be up to or above 2000 bar. In order to protect the piezoelectric actuator from damage and potential failure, the piezoelectric actuator must be isolated from this environment by at least a layer of barrier material, herein referred to as 'encapsulation member'. It is known to encapsulate the piezoelectric actuator with an inert fluoropolymer, for example as described in the Applicant's PCT published Patent Application No. WO02/061856A1 (EP 1356529 A), which acts to prevent permeation of liquid fuel, water and contaminant substances dissolved in the water or fuel, into the structure of the actuator. The encapsulation means must also be able to withstand fuel and water permeation over the entire operational temperature range of between around -40°C to around 175°C during the lifetime of the fuel injector which is about 10 years.

[0007] A piezoelectric actuator suitable for use in an automotive fuel injector, comprising a device body bearing encapsulation member to protectively encapsulate the device body wherein the encapsulation member includes several organic layers and at least one metal layer is known from the Applicant's published PCT Patent Application No. WO2007093921 A.

[0008] It has been observed, however, that there may still be ingress of fluid into the interface between the actuator and the coating or sleeve. For example, the aforementioned sleeves are preferably formed from elastic or heat-shrink materials such as tubes with open first and second ends such that the actuator can be inserted into the open tube. The tube is then allowed to contract elastically, or is made to contract by the application of heat (i.e. heat shrinkage), in order to encapsulate the actuator. It will be understood that although the sleeve now bears tightly against the actuator, the first and second ends of the tube present paths for the ingress of fluid into the interface between the coating and the encapsulated actuator.

[0009] One or more clips may be provided at the ends of the sleeve in order to improve end sealing, as described in the Applicant's co-pending application EP 05256852. The clips are placed externally with respect to the sleeve and exert a constrictive force sufficient to urge the sleeve against the underlying external surface of the actuator so as to create a seal at the interface between the sleeve and the actuator surface.

[0010] Nevertheless, under the challenging environmental conditions within a fuel injector there remains a risk that fluid may migrate underneath the ends of the sleeve despite the presence of the clips.

[0011] It is known to provide a filler material, as described, for example, in the Applicant's co-pending application WO 02/061856, between the coating and the encapsulated actuator in an attempt to limit the ingress of fluid between the coating and the actuator. However, this requires filling the entire space defined between the coating and the actuator with a curable substance, and may also require a degassing step, which adds to the complexity of the actuator arrangement and the method of assembly.

[0012] It has been found that in the known encapsulations, the seal of the organic polymer sleeve at both ends of the actuator provides a weak spot allowing over time the infiltrations of liquids such as diesel fuel, rapeseed methyl ester (RME) based fuels and water in the actuator and that further efforts are needed to ensure a better encapsulation at reasonable costs. It is indeed often a matter of time and temperature, as to when fuel or other liquids will permeate through the end seals of the encapsulation means leading to fatal component failure of the piezoelectric actuator and, thus, the fuel injector as a whole. Different solutions to this problem have already been proposed.

[0013] In the Applicant's co-pending application EP 1783842 A1, there is provided an actuator arrangement comprising a piezoelectric actuator having a body section, a shroud which enshrouds at least part of the body section of the actuator, and at least one constrictive member disposed externally with respect to the shroud. The constrictive member applies a constrictive force to the shroud to maintain a seal between the shroud and the underlying body section of the actuator.

[0014] In the Applicant's co-pending application W02007/128948, there is provided a method for enshrouding an actuator for use in a fuel injector, comprising the steps of providing an actuator, having a body section, a first end piece and a second end piece; providing a shroud having first and second ends; applying a sealant material to at least one portion of an exterior surface of the end pieces, and/or to at least one part of the shroud; and enshrouding the actuator with the shroud, such that the sealant material provides an intermediate layer between the end pieces and the shroud and forms a fluid-tight seal between them.

[0015] Against this background, it would be desirable to provide an improved encapsulating means, which provides a reduced permeability at the end pieces to fuel, water and other substances therein over time.

Summary of the Invention

[0016] This object is achieved by an actuator arrangement for use in a fuel injector, comprising: a piezoelectric actuator having a body section, said body section having a first end piece and a second end piece; a sleeve which enshrouds at least part of the body section of the actuator; and at least one constrictive member, disposed externally with respect to the sleeve wherein the constrictive

member applies a constrictive force to the sleeve to maintain a seal between the sleeve and the underlying body section of the actuator characterized in that the underlying body section comprises an alternation of smooth sections and rough sections, said rough sections comprising superficial markings or engravings. It is understood that these markings nevertheless have a certain depth.

[0017] It is understood that the term rough has to be seen in relative to the term smooth, the smooth surface being the non-treated surface whereas the rough surface being the treated surface.

[0018] The smooth and rough sections are preferably perpendicular to the longitudinal axis of the actuator arrangement respectively the piezoelectric stack. The smooth and rough sections are preferably annular sections, i.e. are situated around the entire perimeter of the underlying bodysection.

[0019] The markings comprise preferably straight lines, wavy lines, zigzag lines, dots or combinations thereof. The best results are obtained with a ratio between the rough sections and the smooth sections comprised between about 20-80 and about 80-20, preferably between about 40-60 and about 60-40 and most preferably at about 50-50.

[0020] The number of rough sections is preferably comprised between 3 and 10 and the number of smooth sections is preferably comprised between 3 and 10.

[0021] The width of the sections is preferably comprised between 0.1 and 0.5 mm and more preferably between 0.2 and 0.4 mm.

[0022] The depth of the superficial markings is comprised preferably between 10 μm and 40 μm from peak to valley.

[0023] The underlying bodysection, i.e. the end piece is made of plastic preferably of a fluoropolymeric material and most preferably of ethylene tetrafluoroethylene (ETFE).

[0024] The major advantage of the actuator arrangement according to the invention is to provide a piezoelectric actuator stack, which has an improved fuel seal over time at at least one of the end pieces.

[0025] It has been found during the research leading to the present invention that the constrictive force i.e. the clamping load of the constriction means at the end piece side, in particular the ball joint side, leads to an excessive flowing of the polymer of which this end piece is made, when exposed to hot temperature conditions between 110 and 130°C. The flowing of the polymer at high temperatures may lead to a partial or even sometimes complete loss of the clamping load, which may lead in turn to a lack of sealing under certain temperature end pressure conditions.

[0026] Surprisingly, it has been found that superficial markings by a so called marking laser or by electro discharge machining (EDM) at some locations of the end piece also called ball joint allow to significantly enhance the clamping load on the end piece after the production. It has also been found that the clamping load remains

high even under severe temperature and pressure conditions. It is thus possible obtain a better seal between the sleeve and the end piece, not only at low temperatures but also at high temperatures and over time.

[0027] Laser systems suitable for marking and engraving the rough sections are widely available and are commonly used to apply computer-generated images (bar codes, labeling equipment, serial numbers, logos, UID, etc.) to a wide variety of metallic and nonmetallic materials. A variety of manufacturers offer suitable apparatuses for the purpose.

[0028] Electric discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking or wire erosion, is a manufacturing process whereby material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the workpiece-electrode, or 'workpiece'. As an alternative to the above discussed laser systems, EDM may be used to create the rough sections. A variety of manufacturers offer suitable EDM equipment for the purpose.

[0029] The actuator arrangement may, according to a preferred embodiment, further comprise a metallic film positioned around the sleeve.

[0030] Such a metallic film may be realized in different ways known to those skilled in the art. Some suitable examples are described in more detail in W02007/093921. Aluminum and stainless steel are preferred for the metallic film.

[0031] The material of the sleeve may be chemically or physically modified in order to bond to the substrate or surface of the stack, to facilitate bonding to the stack or to the optional metallic film.

[0032] A large number of polymers are currently available to produce the sleeve:

- PTFE (fluoropolymer) tubes have the widest operating temperature range (-270 to 260 °C), low coefficient of friction, and high resistance to chemicals. 1.5:1, 2:1 and 4:1 shrink ratios are available on the market.
- Viton, another fluoropolymer with high chemical resistance and highly flexible. Viton is a brand of synthetic rubber and fluoropolymer elastomer commonly used in moulded or extruded goods. The name is a registered trademark of DuPont Performance Elastomers L.L.C.. Viton fluoroelastomers are categorized under the ASTM D1418 & ISO 1629 designation of FKM. This class of elastomers is a family comprising copolymers of hexafluoropropylene (HFP) and vinylidene fluoride (VDF or VF₂), terpolymers of tetrafluoroethylene (TFE), vinylidene fluoride (VDF) and hexafluoropropylene (HFP) as well as perfluoromethylvinylether (PMVE) containing specialties.

- Polyvinylidene fluoride (PVDF) tubes are intended for high temperature applications; -55 °C up to 150 °C (flexible PVDF) or up to 175 °C (semi-rigid Kynar). Common shrink ratio is 2:1, and shrink temperature ranges around 170°C.

- Fluorinated ethylene propylene (FEP) is a lower-cost alternative to PTFE. Its operating temperature range is up to 204 °C and the shrink temperature is as low as 190 °C. Available shrink ratios are 3:1 and 6:1.

- Silicone rubber offers excellent resistance to scrape abrasion and high flexibility. The shrink temperature is 200 °C

[0033] Particularly preferred in the context of the present invention are the following thermoplastic polymers for heat shrinkable sleeves: ethylene tetrafluoroethylene (ETFE), a polytetrafluoroethylene (PTFE) thermoplastic, a polyvinylidene fluoride (PVDF), a fluorinated ethylene-propylene (FEP), a perfluoroalkoxy (PFA) or a polytetrafluoroethylene-perfluoromethylvinylether (MFA) and polymers of tetrafluoroethylene, hexafluoropropylene and vinylidene fluoride (THV).

Brief Description of the Drawings

[0034] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0035] FIG. 1 is a perspective view of a known piezoelectric actuator arrangement including a preferred embodiment of the present invention;

[0036] FIG. 2 is an enlarged detail perspective view of a first end of the actuator arrangement of FIG. 1,

[0037] FIG. 3 is an enlarged sectional view of the first end of the actuator arrangement of FIG. 1,

[0038] FIG. 4 is an enlarged sectional detail view of part of the second end of the actuator of FIG. 1,

[0039] FIG. 5 is an enlarged view of part of the ball joint of the second end of the actuator of FIG. 1,

[0040] FIG. 6 is an enlarged view of the markings on the ball joint of Fig. 5,

[0041] FIG. 7 is an enlarged cross section detail view of the markings on the ball joint of Fig. 6,

[0042] FIG. 1 shows all actuator arrangement, which is elongate and generally cylindrical in shape. The arrangement includes a known piezoelectric actuator 20 having at least one piezoelectric element (not shown), and is suitable for use in a fuel injector of an internal combustion engine.

[0043] The actuator 20 includes a generally cylindrical body section 12, comprising: a central major portion 13 containing a piezoelectric stack; and first and second end pieces 14 and 16 respectively. End piece 14, at the first end of body section 12, includes an electrical connector with first and second terminals, which in use receives a voltage from a voltage supply (not shown). End piece 16,

at the second end of body section 12, includes a load transmitting member which in use co-operates with a control piston or valve needle (not shown) of the fuel injector.

[0044] As shown in FIG. 2, inwardly of the electrical connector at the first end of body section 12, end piece 14 is narrower than the major portion 13 such that in longitudinal cross-section the first end of body section 12 has a stepped profile comprising neck 125 and shoulder 126. Although not shown in FIG. 2, it will be appreciated that inwardly of the load transmitting member at the second end of body section 12, end piece 16 is narrower than the major portion 13, apart from the similarly narrow neck 125 at the first end, such that in longitudinal cross-section the second end of body section 12 has a stepped profile comprising neck 127 and shoulder 128.

[0045] Details of the piezoelectric stack and internal components of actuator 20 and a description of how the actuator operates are disclosed fully in the Applicant's granted patent EP 0995901, so will not be discussed here.

[0046] Referring to FIGS. 2 to 4, there are provided coiled clips 30, 40 at the first and second ends respectively of body section 12. The successive coils of clips 30, 40 abut one another, such that each clip 30, 40 defines a ring in the form of a short expandable tube.

[0047] As shown in detail in FIG. 2, clip 30 encircles body section 12 at neck 125, outwardly of shoulder 126. Additionally, it will be appreciated that clip 40 encircles body section 12 at neck 127, outwardly of shoulder 128. The location of clips 30 and 40 can be seen in more detail in the sectional views of FIGS. 3 and 4.

[0048] Evident from FIGS. 3 and 4 is the presence of a flexible sleeve 50, which enshrouds and is conformed to the contours of body section 12. Sleeve 50 extends along the length of body section 12 from end piece 14 to end piece 16.

[0049] Referring to FIG. 3, clip 30 is positioned externally with respect to sleeve 50 around neck 125 of body section 12, such that the interior surface of clip 30 bears against the exterior of sleeve 50. Clip 30 is formed from a conventional spring wire material that can be expanded and contracted resiliently to vary its internal diameter. When positioned around neck 125, clip 30 exerts a constrictive force upon sleeve 50 sufficient to urge the interior of sleeve 50 against the exterior of body section 12. The constrictive force is sufficiently strong that a fluid-tight seal is maintained at the interface between sleeve 50 and body section 12 beneath clip 30.

[0050] From FIG. 4 it can be seen that clip 40 is positioned externally with respect to sleeve 50 around neck 127, and forms a seal in the same way as described for clip 30.

[0051] Clips 30 and 40 encircle necks 125, 127 respectively by at least two full turns of their coils around the circumference of those regions. The coiled shape provides a large, substantially continuous area of contact pressure against sleeve 50 beneath clips 30, 40, while minimising the external diameter of actuator arrange-

ment 10.

[0052] Alternatively to the clips described above, an annular clip may be used to encircle body section 12 at neck 125, outwardly of shoulder 126, 127. It is to be appreciated that a similar annular clip could be provided at the second end of body section 12 to encircle body section 12 at neck 127, outwardly of shoulder 128. Such annular clips encircle necks 125, 127 by one full turn around the circumference of those regions.

[0053] The annular clips are positioned externally with respect to sleeve 50 around necks 125, 127 respectively of body section 12 such that the interior female surface of each clip 60 bears against the exterior of sleeve 50. When positioned around necks 125, 127, clips exert a constrictive force upon sleeve 50 sufficient to urge the interior of sleeve 50 against the exterior of body section 12. These coiled clips and annular clips are described in detail in Applicant's granted European patent EP 1783842 and are therefore not described in detail herein.

[0054] Referring now to FIG. 5, a preferred embodiment of the end piece 16 is shown in more detail. Five horizontal, i.e. perpendicular to the axis of the actuator, circumferential, annular rough sections 130 alternating with four circumferential smooth sections 132 can be seen on the neck 127 of the second end piece 16. Each of the rough sections 130 comprises a series of zigzag lines 134 shown in more detail on FIG. 6. These lines have been made by a laser marker. The cross section of a zigzag line is shown in more detail on FIG. 7. The lines are in fact shallow grooves 136 flanked on each side by a lip 138, 140.

[0055] The end piece 16 in this particular case has a total height of about 10 mm and a diameter of between 7.0 and 9.5 mm. The zone on the neck 127 of the end piece i.e. the underlying body section which comprises an alternation of smooth sections and rough sections, said rough sections comprising superficial markings is about 3.1 mm wide and in the present example comprises 8 rough sections and 7 smooth i.e. non marked zones in alternation with the rough sections. The superficial markings in the form of zigzag lines have been made by a laser marking apparatus "Trumpf TruMark 6230" and have a depth "peak to valley" i.e. from the top of the lip to the bottom of the groove of 15 μm and a width of 40 μm , measured between the top of the lips. Each rough section has a width of 210 μm and comprises 4 zigzag lines, the distance between adjacent peaks is 100 μm , the length of the straight sections is 60 μm , the zigzag has an amplitude of 30 μm . The shortest distance between two adjacent lines is 30 μm .

[0056] The constrictive force or the clamping load is sufficiently strong that a fluid-tight seal is maintained at the interfaces between sleeve 50 and body section 12 beneath the annular clips.

[0057] Surprisingly, the constrictive force exerted onto the sleeve was 50% higher than in an identical actuator without the alternation of smooth sections and rough sections, comprising superficial markings.

Legend:**[0058]**

12	body section
13	central major portion
14	first end piece
16	second end piece
20	piezoelectric actuator
30	clips
40	clips
50	sleeve
125	neck of first end piece
126	shoulder of first end piece
127	neck of second end piece
128	shoulder of second end piece
130	rough section
132	smooth section
134	zigzag line
136	groove
138	lip
140	lip

Claims

1. An actuator arrangement for use in a fuel injector, comprising: a piezoelectric actuator having a body section, said body section having a first end piece and a second end piece; a sleeve which enshrouds at least part of the body section of the actuator; and at least one constrictive member, disposed externally with respect to the sleeve wherein the constrictive member applies a constrictive force to the sleeve to maintain a seal between the sleeve and the underlying body section of the actuator **characterized in that** the underlying body section comprises an alternation of smooth sections and rough sections, said rough sections comprising superficial markings.

2. The actuator arrangement according to claim 1,

wherein the smooth sections and the rough sections are perpendicular to a longitudinal axis of the actuator arrangement.

3. The actuator arrangement according to claims 1 or 2, wherein the smooth sections and the rough sections are annular sections.

4. The actuator arrangement according any of the claims 1 to 3, wherein the underlying body section is at least one end piece.

5. The actuator arrangement according any of the claims 1 to 4, wherein the markings comprise straight lines, wavy lines, zigzag lines, dots or combinations thereof.

6. The actuator arrangement according any of the claims 1 to 5, wherein the ratio between the rough sections and the smooth sections is comprised between 20-80 and 80-20.

7. The actuator arrangement according to any of the claims 1 to 6, wherein the number of rough sections is comprised between 3 and 10.

8. The actuator arrangement according to any of the claims 1 to 7, wherein the number of smooth sections is comprised between 3 and 10.

9. The actuator arrangement according to any of the claims 1 to 8, wherein the width of the sections is comprised between 0.1 and 0.5 mm.

10. The actuator arrangement according to any of the claims 1 to 9, wherein the superficial markings have a depth measured from peak to valley comprised between 10 μm and 40 μm .

11. The actuator arrangement according to any of the claims 1 to 10, wherein the end piece is made of plastic preferably of a fluoropolymeric material and most preferably of ethylene tetrafluoroethylene (ETFE).

12. The actuator arrangement according to any of the claims 1 to 11, wherein the actuator arrangement further comprises a metallic film positioned around the sleeve.

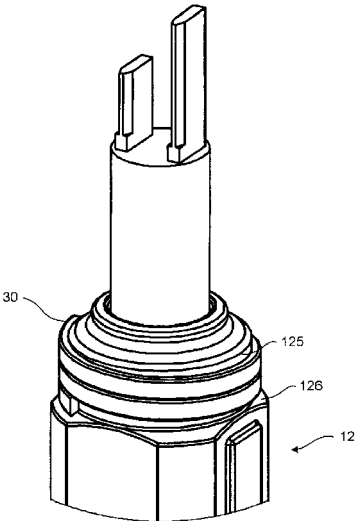
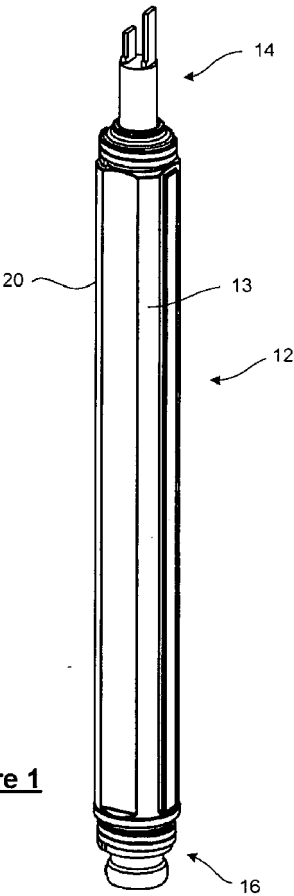


Figure 3

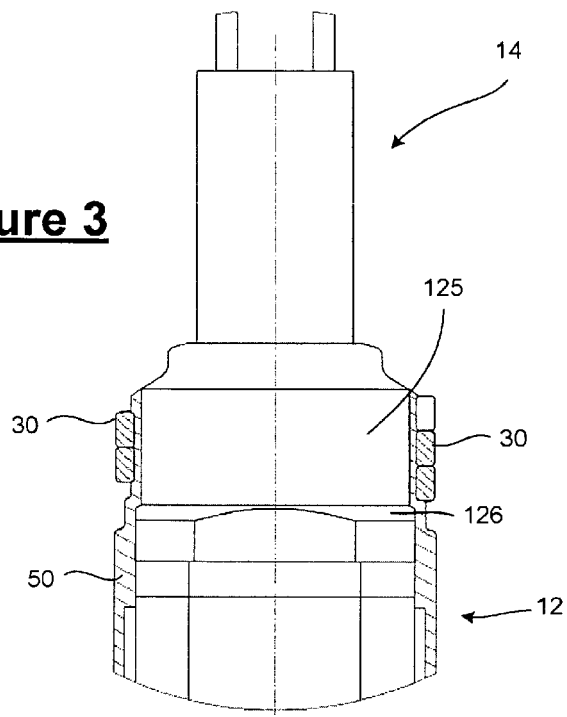
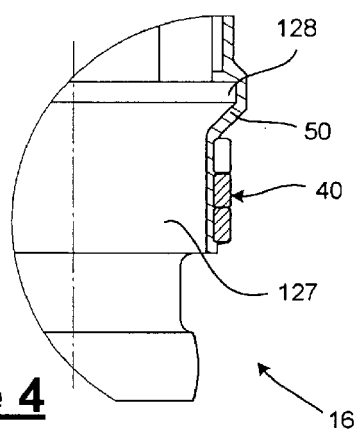
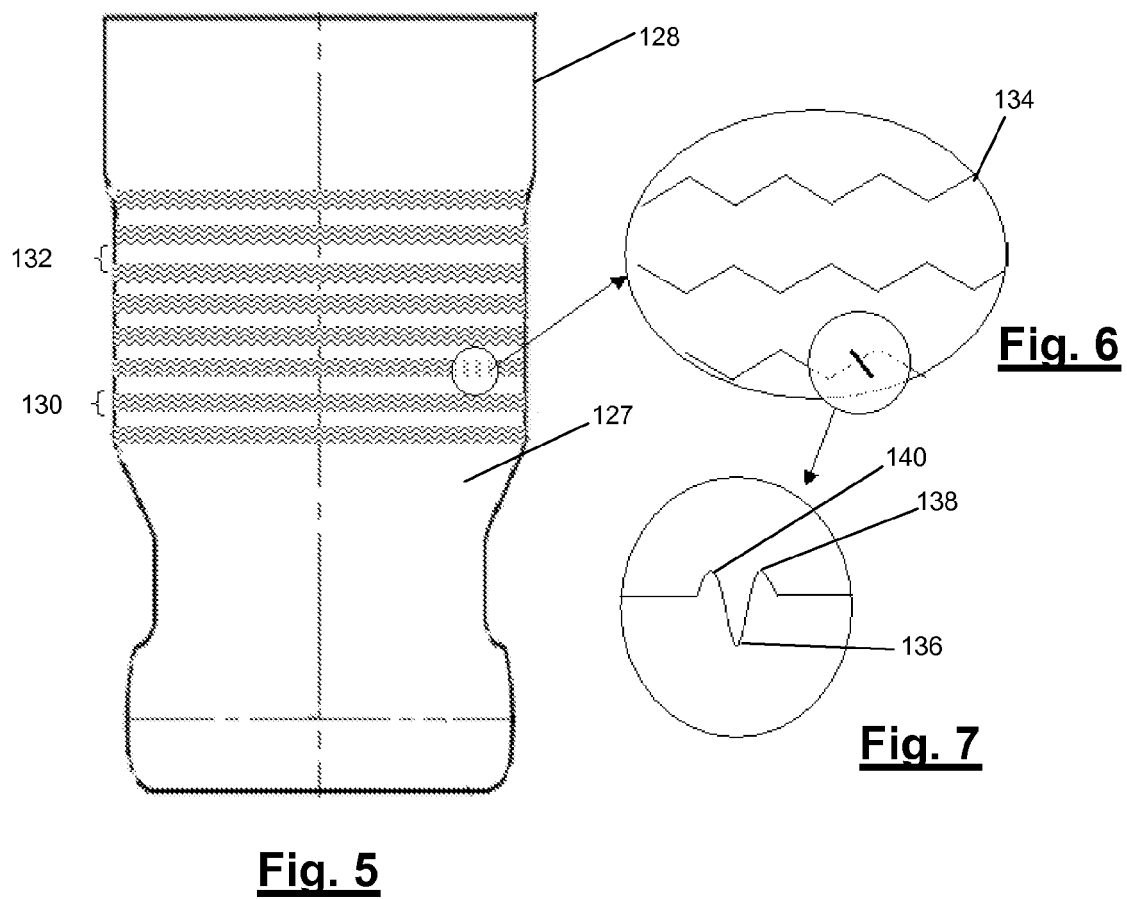


Figure 4







EUROPEAN SEARCH REPORT

Application Number
EP 10 15 7760

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 6 August 2010	Examiner Etschmann, Georg
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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EPO FORM 1503 03.82 (P04C01)

**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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