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(54) **Intermediate drive assembly**

(57) An intermediate drive assembly (1) is provided for a fuel pump (10) having a pump housing (12) provided with at least one bore (20a, 20b, 20c) for receiving the intermediate drive assembly (1) and a pumping plunger (30) which are driven, in use, in a reciprocal manner within the bore (20a, 20b, 20c) by a drive arrangement (2) so as to pressurise fuel within a pump chamber (32). The intermediate drive assembly (1) is arranged so as to cooperate between the drive arrangement (2) and the pumping plunger and comprises a tappet (34) having a base portion (38) and a side wall portion (36), and a coupling mechanism, in use for coupling the pumping plunger (30) to the base portion (38). The coupling mechanism comprises a spring seat (40) adapted to engage an end of the pumping plunger (30), and interlocking means, in use for substantially preventing relative rotation between the base portion (38) and the spring seat (40). The base portion (38) has a drive surface (5) for cooperating with the drive arrangement (2), a thrust surface (7) for cooperating with and imparting drive to the pumping plunger (30), and a recess (9), the recess (9) receiving an insert (11) formed of a material having a hardness greater than the base portion (38). The insert (11) is a clearance fit in the recess (9).

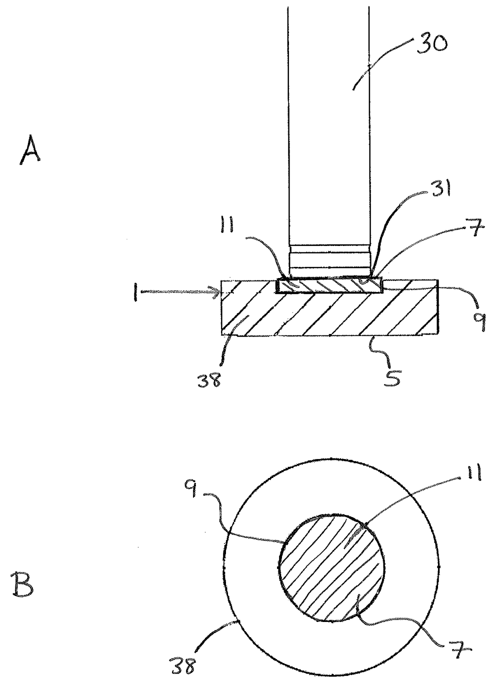

Figure 4

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Description

FIELD OF THE INVENTION

[0001] This invention relates to an intermediate drive assembly for a fuel pump. In particular, the invention relates to a mechanism for reducing mechanical wear in a fuel pump, and specifically reducing mechanical wear between the pumping plunger and the thrust surface of the intermediate drive assembly against which an end of the plunger is seated.

BACKGROUND OF THE INVENTION

[0002] In a known common rail fuel pump, for example as described in EP 1184568, three pumping plungers are arranged at equi-angularly spaced locations around an engine driven cam. The cam carries a cam ring (or cam rider), which travels over the surface of the cam as it is driven by the engine. Each plunger is mounted within a respective plunger bore provided in a pump housing and, as the cam is driven, each of the plungers is caused to reciprocate within its bore. As the plungers reciprocate, each causes pressurisation of fuel within an associated pump chamber. The delivery of fuel from the pump chambers to a common high pressure supply passage is controlled by means of respective delivery valves associated with each of the pumps. The high pressure supply passage supplies fuel to a common rail, or other accumulator volume, for delivery to the downstream injectors of the injection system.

[0003] In this arrangement it is typical for an intermediate drive member in the form of a tappet to be provided to transmit drive from the cam / cam rider arrangement to each of the plungers. Each tappet is located within a tappet bore provided in the main pump housing and arranged so that, as the cam is driven, each tappet is caused to reciprocate within its respective bore, resulting in reciprocating motion to the plungers. As the tappet is driven radially outward from the shaft by the cam rider, its respective plunger is driven to reduce the volume of the pump chamber. This part of the pumping cycle is referred to as the forward stroke of the plunger, during which fuel within the associated pump chamber is pressurised to a relatively high level. During a return stroke of the plunger, the plunger is urged in a radially inward direction under the influence of a plunger return spring. A secondary function of the tappet is to reduce lateral forces applied to the plunger by transmitting transverse loads to the tappet bore so that generally the plunger is driven by the tappet along its longitudinal axis. A known tappet is generally cup-shaped and has a cylindrical side wall portion to cooperate with the wall of the bore, and a base end portion opposing the cam rider, which together define an internal chamber. Vents may be provided in the side wall portion to allow a lubricating fluid to flow from a region around the cam mechanism to a region within the tappet so that hydraulic forces do not inhibit free movement of the tappet within a tappet bore.

[0004] A spring seat or plate is mounted to or otherwise engaged with the lower end of the plunger and is received in the internal chamber of the tappet. A plunger return spring abuts the radially outer face of the spring seat and is compressed during a pumping stroke of the plunger, in order that a return biasing force is applied to the plunger, via the spring seat, to help drive the plunger return stroke.

[0005] To ensure that there is a degree of articulation between the tappet and the base of the pumping plunger, one or both of the plunger and tappet interfaces may have a spherical radius, which results in a Hertzian contact condition between the two components. Since the full pumping load is transmitted through this small Hertzian contact area, large contact stresses are generated, which can cause extensive and excessive wear at the plunger / tappet interface. This wear not only creates problems and shortens the life span of the plunger and tappet arrangement, in addition, any debris that is generated can spread to and promote increased wear in other parts of the fuel pump. Accordingly, it would be beneficial to reduce the amount of wear between the tappet and pumping plunger, so as to increase the operational lifespan of the apparatus, but without compromising the quality of the connection arrangement.

[0006] In this respect, it is already known to provide lubrication between the interface of the tappet and plunger by providing a relatively thin fluid film between the two surfaces to generate a transient fluid pressure. As the tappet is driven through the pumping cycle, the thin fluid film serves to reduce friction between the sliding surfaces, and as fluid it dispelled between the surfaces transient fluid pressure supports return loading of the tappet. In addition, currently, plungers and tappets are typically made from a good quality bearing steel which is hard, fatigue resistant and dimensionally stable, which is intended to increase wear resistance and lifespan. Nevertheless, the inventors have now recognised, from long endurance testing, that these known measures do not completely overcome the problems of frictional and stress-related wear between the tappet and plunger, such that a significant amount of wear can still be observed in some circumstances. Furthermore, premature aging of fuel pumps can be expected to become a still more significant problem in future fuel pumps, which are likely to be required to deliver fuel at very high pressure (e.g. perhaps well in excess of 2000 bar), and so give rise to extremely high pumping loads acting on the tappet. Hence, it would be desirable to have a tappet / pumping plunger arrangement for a fuel pump in which the forces acting at the contact interface of the tappet and pumping plunger and/or the wear between the opposing surfaces is reduced or eliminated, for example, so as to increase fuel pump lifespan.

[0007] Accordingly, the present invention seeks to address at least one of the aforementioned problems in the art.

SUMMARY OF THE INVENTION

[0008] In broad terms, the invention provides a system for reducing mechanical wear in a fuel pump. In particular, the sliding motion and frictional forces between a pumping plunger and an intermediate drive assembly, which drives the plunger reciprocally in its bore, leads to mechanical wear and degradation of the material at the interface and the release of particles into the fuel pump. This is especially problematic at high pumping pressures, during sustained / endurance uses, and where starting and stopping of the pump is frequent. The invention therefore provides mechanisms that reduce and/or counter the frictional forces and mechanical wear between the pumping plunger and intermediate drive assembly. In one approach one or more contact surfaces that form the interface between the pumping plunger and the intermediate drive assembly is reinforced, for example, using a suitable hard material to reduce the amount of mechanical wear. In another approach an engagement or interlocking mechanism is used to prevent relative rotation of the pumping plunger and intermediate drive assembly, thereby to reduce the sliding distance of the pumping plunger across a surface of the intermediate drive assembly. The two approaches may be combined to reduce and/or prevent mechanical wear. The invention thus provides benefits in terms of reducing fuel pump component wear and increasing the expected useful lifetime of the components and assemblies.

[0009] In one aspect the invention provides an intermediate drive assembly for a fuel pump. The fuel pump may include a pump housing provided with at least one bore for receiving the intermediate drive assembly and a pumping plunger which together are driven, in use, in a reciprocal manner within the bore by a drive arrangement to pressurise fuel within a pump chamber. The intermediate drive assembly is arranged so as to cooperate between the drive arrangement and a pumping plunger of the fuel pump. The intermediate drive assembly comprises a base portion (or base plate) having a drive surface for cooperating with a drive arrangement, and a thrust surface for cooperating with and imparting drive to a pumping plunger. In accordance with the invention, the intermediate drive assembly is provided with means to reduce mechanical wear between the thrust surface and the pumping plunger in use.

[0010] In one embodiment, the base portion is provided with a recess (for example, a blind bore), in which an insert of a material having a hardness greater than the material of the base portion is received. The recess and, hence, the insert are preferably located centrally relative to the base portion. In this embodiment the insert defines the region of the intermediate drive assembly that in use contacts or engages the base (or bottom end / surface) of the pumping plunger, i.e. the 'thrust surface'. The insert may of course have a larger upper surface area than the area that actually engages with the pumping plunger during use. The insert may be a shim or disc (i.e. short cylinder) of material, typically having a larger diameter than its depth. Suitable materials for the insert (depending on the choice of material for the base portion) include a material selected from, cemented carbide, heat-treated steel or ceramic. Suitable ceramic materials may be based on zirconia, alumina, silicon or carbide ceramic, such as boron carbide, tungsten carbide, silicon nitride or silicon carbide ceramic. Preferably the recess has a flat lower surface (or base) and the base of the insert is similarly flat so that the insert receives maximum support from the base portion.

[0011] Advantageously, the insert is a clearance fit in the recess. Such an arrangement is particularly beneficial where the base portion and insert are fabricated of different materials, because they can be subject to changes in temperature - particular temperature increases during use - as this may result in different thermal expansion, which could lead to increased stress and wear on the components. By way of example, a clearance fit may be a small clearance of up to 0.5 mm on the diameter, such as approximately 0.15 to 0.35 mm between the diameter of the insert and the diameter of the recess.

[0012] The thrust surface and the drive surface of the base portion may be substantially parallel. Where an insert is located in a recess in the base portion, it can be advantageous that the thrust surface of the insert is substantially flush with the upper surface of the base portion, i.e. the surface of the base portion surrounding the recess. According to a beneficial embodiment, however, the thrust surface of the insert, and optionally the upper surface of the base portion surrounding the recess is part-spherical for articulation between the intermediate drive assembly and the pumping plunger. For example, the thrust surface may be concave or convex. In a particularly suitable embodiment the thrust surface is convex. The radius of curvature of the part-spherical surface may be, for example, approximately 1 m. The base of the pumping plunger that contacts the thrust surface may also be part-spherical to complement the thrust surface. Thus, if for example the thrust surface is convex, the base of the pumping plunger may be concave; typically with a similar (or slightly smaller) radius of curvature.

[0013] Conveniently the intermediate drive assembly of the invention comprises a tappet, such as a bucket tappet. When, the intermediate drive assembly comprises a tappet, it typically further comprises a side wall portion of generally cylindrical shape, which is upstanding from the perimeter of the base portion. Accordingly, the side wall extends perpendicularly to the plane of the base portion. In use, the outer surface of the side wall acts as a guide for the intermediate drive assembly within the bore of the pump housing, so that the action of the drive apparatus on the intermediate drive assembly is converted into reciprocal translational motion along the axis of the bore and pumping plunger. The side wall portion and base portion together form a bucket shape (i.e. with a channel-shaped cross-section), which has an internal chamber within which the pumping plunger is at least partially receiving in use.

[0014] In one embodiment of this aspect, the intermediate drive assembly also includes a pumping plunger and/or a coupling arrangement to couple the pumping plunger to the base portion, such that motion of the base portion (and hence of the intermediate drive assembly) is directly linked to motion of the pumping plunger. Suitably, the coupling arrangement comprises a spring seat (or plate), which links the base portion (and side wall) to the pumping plunger. Conveniently, the spring seat is provided with an aperture for receiving a lower end of the pumping plunger. The name spring seat is given, because in use it is typical for a spring to be located between the spring seat and the pump housing to bias the intermediate drive assembly downwards, to maintain contact between the plunger and the base portion of the intermediate drive assembly, and also to help generate the return stroke of the pumping plunger. Thus, in this embodiment a pumping stroke of the pumping plunger (to pressurise fuel within the pump chamber) is driven by the drive arrangement against the action of the spring. Advantageously, interlocking means are also provided for substantially preventing relative rotation between the base portion (or tappet) and the plumping plunger and/or spring seat. Further details of the interlocking means are described below in relation to another aspect of the invention.

[0015] In an alternative, it is envisaged that the insert may be replaced by having a thrust surface that is at least partially comprised of a material that is harder than the base portion. For example, this harder material may be located at least in the surface region of the base portion that is contacted with the pumping plunger so that material wear is reduced. One advantage of this arrangement is that it is not necessary to fabricate the entire base portion (or body thereof) in the harder material, which could be beneficial for cost and/or mechanical reasons. For example, mechanical properties of the harder material may not be suited to the function of the base portion. The harder material may be a coating, layer or surface treatment applied to the upper surface of the base portion (i.e. the surface that facing the pumping plunger in use). One suitable material is diamond-like carbon (DLC).

[0016] In another aspect of the invention or in embodiment of the preceding aspect there is provided an intermediate drive assembly for a fuel pump as previously described, which comprises a tappet having a base portion and a side wall portion of generally cylindrical shape upstanding from the perimeter of the base portion and defining an internal chamber with the base portion; and a coupling mechanism to couple the pumping plunger to the base portion. The coupling mechanism comprises a spring seat that is adapted to be received within the internal chamber of the intermediate drive assembly and to engage with an end of the pumping plunger. In accordance with these aspects and embodiments of the invention, interlocking means are also provided for substantially preventing relative rotation between the base portion and the plumping plunger and/or spring seat in use. In this way, the sliding distance of the pumping plunger across the thrust surface of the base portion is reduced or eliminated. In other words, when the tappet, spring seat and pumping plunger are assembled for use, relative rotation and/or sliding between the thrust surface of the base portion and end / base of the pumping plunger is substantially prevented. This, in turn, reduces heat generation and particularly mechanical wear at the interface between the thrust surface and bottom of the pumping plunger. Generally, the spring seat is rigidly coupled (e.g. by interference) to the pumping plunger, in use, such that the pumping plunger and spring seat move in unison. In this way, the interlocking means can conveniently be adapted to engage between the tappet (e.g. the base portion) and the spring seat.

[0017] The interlocking mechanism in any aspect or embodiment may be formed in any appropriate manner. For example, it may comprise a pin and hole arrangement, a keyed arrangement, or a splined shaft between the tappet and spring seat. Preferably, the base portion is provided with a male member (such as a pin) protruding from the upper or thrust surface, and the spring seat is provided with a female member (such as a hole) adapted to receive the male member (e.g. pin) of the base portion. Generally it is desirable to have a small clearance between the hole and the pin (or other male and female member pair) to allow for any small manufacturing misalignments within acceptable tolerance limits. Advantageously, the pin and hole coupling is spaced from the central axis through the base portion, spring seat and plunger, which arrangement provides the advantage of reducing both rotational and translational movement of the base portion relative to the plunger. Also in this way the interlocking means is preferably located away from the surface area of the base portion in contact with the pumping plunger.

[0018] More generally, the interlocking means may comprise at least one male member associated with one or more of the spring seat, the base portion and the side wall portion for engagement with a corresponding at least one female member associated with one or more of the spring seat, the base portion and the side wall portion. In such embodiments the at least one male member and the at least one female member are arranged, in use, to interlock between the spring seat and the tappet (e.g. via the base portion and/or side wall portion) so that the spring seat (and plunger) and base portion (and tappet) are coupled. It will be appreciated that to provide the benefits of the invention, the interlocking must take effect between the pumping plunger on the one hand and the tappet on the other hand, so that movement of the two components relative to each other is reduced or substantially prevented. While in most applications one male member with a corresponding female member may be suitable, in some embodiments 2, 3 or more male member / female member pairs may be provided. It can also be envisaged that there may be one male member but more than one female member capable of receiving the male member. In one particularly suitable embodiment, the interlocking means may comprise a male member associated with one of the spring seat or base portion, and a female member associated with the other of the spring seat or base portion.

[0019] It will be appreciated that the pin (or other male member) may be formed separately from or integrally with the base portion. It may be convenient to form the male member separately and thereafter attach it to the base portion (or side wall as appropriate). For example, the base portion may be provided with a recess or blind bore in the thrust or upper surface to receive an end of the pin. In this embodiment, the pin is beneficially provided with grooves, ridges, splines or a screw thread to firmly secure it in the recess or blind bore of the base portion. The pin may be a friction or press fit with the hole, recess or bore into which it is located. Welding, gluing or any other suitable securing means may optionally also be used.

[0020] The pin (or other male member) may be formed of any suitable material, for example, heat-treated steel.

[0021] Desirably, the spring seat is adapted to engage the pumping plunger so as to prevent rotation of the plunger relative to the spring seat. Conveniently the spring seat engages the plunger towards or at the end thereof. By way of example, in one embodiment, the spring seat is provided with an aperture (such as a bore) that receives an end of the pumping plunger. Suitably, the aperture is a press fit or friction fit with the pumping plunger. Similarly, the spring seat may conveniently be cylindrical or disc-shaped and sized so as to be a clearance fit, within the internal chamber defined by the base portion and the side wall portion of the intermediate drive assembly or tappet.

[0022] In any aspect of the invention, the intermediate drive assembly may further include a pumping plunger - for example, the intermediate drive assembly, spring seat and/or pumping plunger may be provided in the form of a kit of parts for assembly as desired.

[0023] Furthermore, the base portion and/or side wall portion of the tappet may be provided with a plurality of vents (or holes) in use, for allowing the passage of fluid into the chamber of the tappet.

[0024] The invention further provides a pump assembly comprising an intermediate drive assembly of the invention. Thus, in one embodiment the pump assembly comprises a pump housing having an axially extending opening for receiving a drive arrangement. At least one bore extends generally radially from the axially extending opening and receives a pumping plunger and an intermediate drive assembly. An intermediate drive assembly is received for reciprocating sliding movement in the bore, and is arranged so as to cooperate between the drive arrangement and the pumping plunger, which is driven in use by the drive arrangement to pressurise fluid in a pumping chamber in a known manner. The drive arrangement comprises a cam rider, which is received in the axially extending opening of the pump housing, and has an inner surface arranged for cooperation with a cam drive shaft, and an outer surface arranged for cooperation with the intermediate drive assembly, so that rotation of the drive shaft causes the cam rider to drive the reciprocating sliding movement of the intermediate drive assembly in the bore. In this aspect, the intermediate drive assembly may be as defined in relation to any of the above aspects or embodiments of the invention.

[0025] It will be appreciated by the skilled person how any embodiment or feature of one aspect of the invention may optionally be combined with any embodiment or feature of any other aspect of the invention and *vice versa.* Thus, in a particularly beneficial embodiment of the invention the intermediate drive assembly comprises a tappet having an insert to provide the thrust surface for engaging the pumping plunger, and also an interlocking means to substantially prevent relative rotation between the punping plunger and a tappet. Together these features provide an improved intermediate drive assembly or pump assembly that greatly reduces wear on the components (especially between a pumping plunger and a tappet or base portion), in use, and can extend the lifespan of the apparatus and reduce maintenance requirements.

[0026] These and other aspects, objects and benefits of this invention will become clear and apparent on studying the details of this invention and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The invention will further be described, by way of example, with reference to the accompanying drawings:

Figure 1 is a sectional view of a fuel pump assembly;

Figure 2 is a perspective view showing in more detail a component of the intermediate drive assembly of Figure 1;

Figure 3 is a sectional view of an intermediate drive assembly shown in position within a fuel pump such as that shown in Figure 1;

Figure 4A is a sectional view of an embodiment of the intermediate drive assembly of the first aspect of the invention, and Figure 4B is a plan view of the intermediate drive assembly of Figure 4A;

Figure 5A is a sectional view of a spring seat and pumping plunger in accordance with a second aspect of the invention, and Figure 5B is a sectional view of a tappet in accordance with this second aspect of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0028] It should be appreciated that the term 'intermediate drive assembly' is used to encompass one or more separate components of the fuel pump apparatus that contribute to converting the motion of the drive apparatus, such as a cam shaft, to the pressurisation of fuel in a pumping chamber. Thus, in some embodiments the intermediate drive assembly of the invention includes features that may typically be contributed by a device such as a tappet. In other embodiments the intermediate drive assembly encompasses additional features, such as those attributed to a spring seat or equivalent (as described elsewhere herein), which may be used to couple the pumping plunger to the tappet component. In further embodiments the intermediate drive assembly is also considered to encompass the pumping plunger. The intermediate drive assembly may therefore include a kit of parts that can be assembled to form the assembly, or may be preassembled ready for use.

[0029] It should also be appreciated that the term 'spring seat' is used to denote a component that is coupled to the pumping plunger and may help to maintain an engagement between the pumping lounger and the tappet or other base portion of the intermediate drive assembly. Typically, a surface of the spring seat facing away from the thrust surface is adapted to engage a spring (or equivalent component) that puts a load onto the spring seat which functions to maintain a contact between the pumping plunger and the thrust surface of the base portion / tappet, especially during a radially-inwards / return stroke of the pumping plunger. However, the aspects and embodiments of the invention are not limited to the requirement for or presence of a spring, or the direct association between the spring seat as termed and a spring. For example, it is envisaged that, in some embodiments, additional components may be provided to assist in maintaining the force of contact between the pumping plunger and the thrust surface, such as intermediate members acting between a spring and the spring seat.

[0030] As used herein, the term 'hardness' is used to describe the resistance of a material or surface to mechanical damage or localised deformation, which may be caused by scratching, abrasion, puncture, general wear and tear etc. Damage may include scratching, fragmentation and so on, which result in the surface becoming uneven / rough and may lead to the release of particles of the material. Generally, the harder a material the better it will resist damage and/or wear due to sliding / contact with another surface. Thus, when a relatively harder material forms the thrust surface of the intermediate drive assembly, the greater is its resistance to degradation (wear) at the interface of the intermediate drive assembly and the plunger. The person of skill in the art is well aware of a number of alternative methods or systems that can be used to measure the hardness of a material, or to determine the relative hardness of different materials or surfaces in order to determine whether one material or surface is harder than another. Known methods for measuring hardness include, the Brinell, the Knoop, the Rockwell C (and B), and the Vickers hardness tests. For example, a particularly useful method for determining the hardness of small components is to measure the Vickers hardness number (HV) using the Vickers hardness test, which is based on an optical measurement system (e.g. ASTM E-384). Vickers hardness is a resistance value obtained by pressing a diamond indenter onto a test specimen at various loads. A method that may be used to determine the hardness of a material such as a fine ceramic is defined in JIS R 1610 (ISO 14075: 2000). It will be appreciated that relative hardness between more than one surface or object can be readily calculated by performing the same hardness assay on each material. Relative hardness may also be measured on a scale such as the Mohs Scale.

[0031] The surface region of the base portion (or insert) of the invention that, in use, is involved in contacting the base of the pumping plunger is conveniently termed herein as the 'thrust surface'. The thrust surface is conveniently located around the central axis of the base portion or intermediate drive assembly as in assembled form the central axis of the intermediate drive assembly would generally align with the central axis of the pumping plunger. Thus, the base portion of the intermediate drive assembly typically comprises a surface region on the same side as the thrust surface, but which is outside of the (central) region that is contacted by the plunger during normal use. This surface region is typically not contacted by the pumping plunger in normal use and is not exposed to the same intensity of wear as the thrust surface.

[0032] In accordance with one aspect of the invention, the thrust surface of the intermediate drive assembly is formed of a harder material than the body of the intermediate drive assembly in order to reduce wear at the interface between the intermediate drive assembly and the pumping plunger. Some exemplary materials that may be used to form the thrust surface of an intermediate drive assembly in accordance with any aspect of the invention, and their Vickers hardness values include: silicon carbide ceramic (SiC), 2800 HV (0.3 kg); alumina (Al_2O_3), 1600 HV (0.3 kg); cemented carbide, 1600 HV (0.3 kg); silicon nitride (Si_3N_4), 1550 HV (0.3 kg); and zirconia (ZrO_2), 1400 HV (0.3 kg). By way of comparison, the Vickers hardness of alloy or bearing steel, which may be used in part of the intermediate drive assembly is 800 HV (20 kg).

[0033] The present invention may be advantageously employed within any suitable fuel pump assembly in which an intermediate drive assembly is used to translate the motion of a drive assembly to the reciprocal movement of a pumping plunger. Such a pump assembly is described with reference to the known fuel pump of Figures 1 to 3.

[0034] Referring to Figure 1, the pump assembly 10 includes a main pump housing 12 provided with an axially extending opening 14. A cam drive shaft (not shown) having an axis of rotation 16 drives an eccentrically mounted cam 18 mounted in opening 14. The main pump housing 12 is provided with first, second and third radially extending openings or through bores 20a, 20b, 20c, each of which communicates, at a radially inner end thereof, with the axially extending opening 14 through the housing 12. A radially outer end of each opening 20a, 20b, 20c receives respective pump heads 22a, 22b and 22c. Each pump head 22a, 22b, 22c is substantially identical and therefore only pump head 22a is described in detail below with reference to Figures 1 to 3.

[0035] Pump head 22a includes a head portion 24 and a radially inwardly extending extension 26 which projects into a radially outer end of the opening 20a in the main pump housing 12. The extension 26 is provided with a plunger bore 28 within which a pumping plunger 30 is received. A blind end of the plunger bore 28 is located within the head portion 24 of the first pump head 22a. The blind end of the plunger bore 28 defines, together with a radially outer end face of the plunger 30, a pump chamber 32 to which fuel at relatively low pressure is delivered during a return stroke of the plunger 30, and within which pressurisation of fuel to a relatively high level suitable for injection takes place as the plunger 30 is driven to perform a pumping stroke upon rotation of the drive shaft. The extension 26 of the pump head portion 24 provides an increased sealing length for the plunger bore 28, which tends to reduce high pressure fuel leakage from the chamber 32.

[0036] A radially inner end of the radially extending opening 20a receives an intermediate drive assembly 1 for the plunger 30 in the form of a tappet 34. The known tappet is shown in more detail in Figure 2. The tappet 34 has a U-shaped or channelled cross section with a generally cylindrical wall portion 36 and a base portion 38. Such a tappet has the form of a bucket and may be referred to as a 'bucket tappet'. However, other forms of tappet may also be used in accordance with the invention. The tappet 34 locates within a radially inner end of the opening 20a so that an internal surface of the opening 20a is in sliding contact with the cylindrical wall portion 36 and serves to guide longitudinal movement and constrain lateral movement of the tappet 34, in use.

[0037] The bucket tappet 34 is coupled to the plunger 28 by suitable means so that relative longitudinal movement between the plunger 30 and tappet 34 is constrained. A spring seat 40 in the form of a plate is received in the internal chamber 52 of the tappet 34 and defines a central aperture for receiving a lower end of the plunger 30 in a press fit. The spring seat 40 locates one end of a plunger return spring 42 and the other end of the plunger return spring 42 abuts the radially inner surface of the head portion 24 of the first pump head 20a, so that the spring 42 serves to apply a return biasing force to the spring seat 40 and plunger 30 (and hence also to the tappet 34), to drive a plunger return stroke.

[0038] As can be seen in Figure 3, the spring seat 40 is slightly spaced from the base portion 38 so as to define a small gap 41 therebetween, which may be in the region of 1 to 2 mm. Since the spring seat 40 is not in direct contact with the base portion 38 of the tappet 34, this ensures that the plunger 30 and the tappet 34 stay together as a pair and that the plunger 30 always follows a full stroke.

[0039] The drive shaft cooperates with the cam 18 which, in turn, is cooperable with a generally tubular cam rider member 44 which extends co-axially with the cam 18. On its outer surface the cam rider 44 is provided with first, second and third flattened surfaces 46a, 46b, 46c, referred to as 'flats'. Each one of the flats 46a, 46b, 46c cooperates with the drive surface 5 at the base (bottom or radially inner face) of the tappet 34 of the intermediate drive assembly 1 for a respective one of the plungers 30. The flats 46a, 46b, 46c and the openings 20a, 20b, 20c are equi-radially spaced such that each drive surface 5 contacts a respective flat 46a, 46b, 46c simultaneously. In other words, the tappet 34 for the plunger 30 of the first pump head 22a cooperates with the first flat 46a on the cam rider 44 at the same time that the second pump head 22b cooperates with the second flat 46b on the cam rider 44, and so on. As the tappet 34 is coupled to the plunger 30, rotation of the shaft causes the cam rider 44 to ride over the surface of the cam 18, thereby imparting drive to both the intermediate drive assembly 1 and the plunger 30. As the tappet 34 is driven, a degree of lateral sliding movement is permitted between the lower surface of the tappet base (i.e. the drive surface 5) and the first flat 46a of the rider 44. Therefore, a slipper face 48 (as shown in Figure 2) may be provided for promoting such sliding movement. A lubricating fluid, such as fuel, is provided in opening 14 and bore 20a to limit wear due to friction.

[0040] As the cam 18 is driven, the intermediate drive assembly 1 comprising the tappet 34 and spring seat 40 are caused to reciprocate within the opening 20a and, as a consequence, the plunger 30 is caused to reciprocate within the plunger bore 28. The intermediate drive assembly 1 and the pumping plunger 30 are therefore driven together causing the plunger 30 to perform a pumping cycle including a pumping stroke, during which the intermediate drive assembly 1 and the plunger 30 are driven radially outward from the shaft (i.e. for the first pump head 22a, vertically upwards in Figure 1), to reduce the volume of the pump chamber 32. During this pumping stroke the pumping plunger 30 is driven inwardly within its plunger bore 28 (i.e. radially outwards from the cam 18), and fuel within the pump chamber 32 is pressurised to a relatively high level in a manner which would be familiar to those skilled in this technology field.

[0041] During a subsequent plunger return stroke, the intermediate drive assembly 1 and the plunger 30 are urged in a radially inward direction (i.e. for the first pump head 22a, vertically downwards in Figure 1), to increase the volume of the pump chamber 32. During the return stroke of the plunger 30 and its intermediate drive assembly 1, the plunger 30 is urged outwardly from the plunger bore 28 and fuel at relatively low pressure fills the associated pump chamber 32.

[0042] The provision of the plunger return spring 42 serves to urge the plunger 30 to perform its return stroke and, via the spring seat 40, additionally ensures contact is maintained between the drive surface 5 of the tappet 34 and the flat 46a of the rider 44 at all times throughout the pumping cycle. The intermediate drive assembly 1 and the plunger 30 perform cyclical sinusoidal motion and may typically be driven at a maximum frequency of about 120 Hz - although it should be appreciated that this frequency is exemplary only. The intermediate drive assembly 1 typically has a range of travel, between bottom-dead-centre and top-dead-centre, of around 10 mm.

[0043] As illustrated in Figure 2, vents or sidewall openings 50 are formed in the cylindrical wall portion 36 of the tappet 34 to provide a means for allowing fuel to flow between the chamber 52 within the intermediate drive assembly 1 and the opening 14 in the pump housing 12. Vents 50 reduce the pressure differential between chamber 52 and opening 14 and therefore prevent excessive hydraulic force on the intermediate drive assembly 1 during reciprocating motion. As the intermediate drive assembly 1 and plunger 30 are driven through the pumping stroke, fuel is dispelled from chamber 52 through the vents 50. As the intermediate drive assembly 1 and plunger 30 perform the return stroke, fuel is drawn into chamber 52 through the vents 50.

[0044] Referring to Figure 4, in accordance with the invention, the base portion 38 of intermediate drive assembly 1 is provided with a recess 9 to receive an insert 11 made from a material of greater hardness than the material of the base portion 38. In one example the insert is formed of cemented carbide. The top surface (or plunger-facing surface) of the insert 11 defines the thrust surface 7 of the intermediate drive assembly 1. The thrust surface 7 is the portion of the intermediate drive assembly that directly contacts the lower (or radially inner) end face of the pumping plunger 30. As previously described, in other embodiments (not depicted) the thrust surface 7 may be formed by coating the plunger-facing surface of the base portion 38 or the plunger-facing surface of the insert 11 with a suitably hard material. As depicted, the upper surface of the insert 11, which defines the thrust surface 7, may conveniently be substantially flush with the upper surface of the base portion 38 surrounding the insert 11. However, this is not essential where the end of the plunger does not directly contact any surface of the base portion 38 outside of the insert 11. While the thrust surface 7 is depicted in Figure 4A with a flat surface, in some alternative embodiments it may be beneficial for the thrust surface to have a part-spherical surface, such as a convex or concave surface, in which case the base (or end) of the plunger 31 may be concave or convex to complement the curvature of the thrust surface 7.

[0045] As shown in Figure 4B, the recess 9 is conveniently circular (e.g. as may be formed by a blind bore) and located in the centre of the base portion 38, in order to receive an insert 11 in the form of a disc or short cylinder of material. As described elsewhere, it can be advantageous to provide a clearance fit between the circumference of the insert 11 and the radially inner surface / edge of the recess 9 to allow for potentially different rates and extents of thermal expansion of the different materials of the insert 11 and base portion 38, which might otherwise create undesirable stresses on the components of the intermediate drive assembly.

[0046] To assemble the intermediate drive assembly of this embodiment, the insert 11 is simply placed into the recess 9 of the base portion 38. In some cases the insert may be rigidly fixed or glued into place, although in some embodiments it can be preferable not to rigidly secure the insert 11 to the base portion 38. In use, the insert 11 is kept in place within the recess 9 by the force of contact with the pumping plunger 30, via the spring / spring seat arrangement, which means that a rigid fixing is not generally required. For convenience, however. the insert 11 may be loosely secured within the recess 9, which may aid in assembly and/or transportation of the intermediate drive assembly. For example, it can be beneficial to loosely secure the insert 11 into place using (a blob of) grease or a weak glue.

[0047] In another embodiment, an insert 11 formed of zirconia is used in a base portion 38 formed of hardened steel. The insert 11 may be approximately 10 mm in diameter and approximately 2 mm in depth. In testing this insert against a control base portion formed of hardened steel with no recess or insert, mechanical damage / wear was reduced by approximately 90%. As previously indicated, however, any suitable material can be used for the insert, provided it is harder than the material of the base portion 38 in order to reduce the mechanical wear that would otherwise occur.

[0048] The size of the insert 11 is not critical, provided it encompasses the region in which the pumping plunger 30 makes contact with the intermediate drive assembly 1, i.e. the 'thrust surface'. Beneficially, the insert is larger in diameter than the minimum required area (i.e. the minimum area of the thrust surface) so as to minimise edge loading, which could lead to damage (e.g. fracturing) of the insert 11. The depth of the insert 11 is selected so that it is sufficiently thick to be strong enough to withstand the load / pressure of the pumping plunger: by way of example, there could be as much as 9 kN of force through each tappet abutment face when the high pressure rail of an engine is at 2000 bar. Therefore, the insert 11 should be sized so as not to break at such pressures and under these possible loads. For this reason, it is preferable that the base of the recess 9 is substantially flat so as to provide maximum support to the insert 11 and provide the most even loading and transmission of the load through the insert 11 to the base portion 38. Depending on the material selected and the desired properties of the insert 11, the insert 11 may have a diameter of between approximately 6 and 12 mm, such as between approximately 8 and 10 mm (e.g. 8, 9 or 10 mm); and a thickness of between approximately 1 and 3 mm, such as between approximately 1.5 and 2.5 mm (e.g. approximately 2 mm). In one embodiment the insert is a disc having a diameter of about 10 mm and a thickness of about 2 mm.

[0049] Figure 5 illustrates another aspect of the invention comprising an interlocking means in the form of at least one male and at least one female member cooperable with each other and which may be employed to reduce wear at the interface between the plunger 30 and the base portion 38 of an intermediate drive assembly 1 or tappet 34. It is readily apparent that this aspect of the invention can be employed either alone or in combination with any of the embodiments of the first aspect, such as described in relation to Figure 4.

[0050] Figure 5A is a sectional view through the centre of the pumping plunger 30. As illustrated, the spring seat 40 is provided with a hole or aperture 33 for receiving the pumping plunger 30 with a press fit (as previously descrived), and a first (or female) component of an interlocking means in the form of a hole (bore or aperture) 35, in which to receive a second (or male) component of an interlocking means in the form of a pin 29 associated with the base portion 38 of the tappet 34. It can be seen that while the aperture 33 for receiving the pumping plunger 30 is centralised within the spring seat 40, the hole 35 is off-centre. In this way, the interlocking means substantially prevents relative rotation of the spring seat 40 and base portion 38 when the intermediate drive assembly 1 is assembled in use. Although the hole 35 of the interlocking means is shown as a through bore, it will be appreciated that the hole 35 may be provided in the form of a blind bore or recess in the bottom surface of the spring seat 40. Although not apparent in Figure 5A, in this embodiment the hole 35 is circular, but in alternative embodiments the female member or hole may be shaped to receive a non-circular male member.

[0051] Figure 5B shows a tappet 34 of a intermediate drive assembly 1, which can be assembled for use with the spring seat 40 and pumping plunger 30 of Figure 5A. A male member in the form of pin 29 is fixed into and protrudes from the surface of the base portion 38. The pin 29 is located so as to fit within the hole 35 of spring seat 40 when the spring seat is correctly received within the chamber 52 defined by circular side wall portion 36 and base portion 38 of tappet 34. In the illustrated embodiment, the pin 29 is formed separately from the base portion 38 and is securely fixed into a bore in the base portion 38 adjacent to the region of the thrust surface 7 that contacts the base 31 of plunger 30. Ridges and/or grooves are provided in the surface of the lower half of the pin 29 to help secure the pin 29 into the base portion 38.

[0052] It will be appreciated that in alternative embodiments, the pin 29 or other male member may be provided on the spring seat 40 with a corresponding female member (e.g. a hole or bore) provided in the base portion 38. Also, depending on requirements, the position of the interlocking means may vary in different embodiments.

[0053] The pin 29 may be any appropriate size, for example, the pin may have an overall length of between approximately 5 and 10 mm (such as between approximately 6 and 8 mm), and a diameter of between approximately 1.5 and 3 mm (such as between approximately 1.8 and 2.5 mm). Where splines, grooves or ridges are provided in the pin, they may likewise have any suitable length, such as between approximately 1.5 and 3 mm (such as approximately 2 mm). The hole 35 is preferably sized to be a clearance fit with the pin 29 to allow some tolerance for machining mismatches. For example, the clearance may be from approximately 0.1 to 0.25 mm across the diameter of the hole. Typically, the pin will be located such that approximately half of its length protrudes from the surface into which it is fixed.

[0054] In other embodiments it will be appreciated that the pin could be formed integrally with the base member 38 or with the spring seat 40 to avoid the need to mechanically fix it into a recess. The pin 29 (or male member) can, of course, have any shape provided that the corresponding female member is suitably shaped to receive it.

[0055] In one example of this second aspect of the invention, in tests, mechanical wear between the pumping plunger and the base portion of the tappet was found to be reduced by approximately 50%. Therefore, by combining the above described aspects of the invention a significant reduction in wear between the pumping plunger and the base portion of the tappet can be achieved, for example, greater than 90%.

[0056] Although particular embodiments of the invention have been disclosed herein in detail, this has been done by way of example and for the purposes of illustration only. The aforementioned embodiments are not intended to be limiting, and it should be appreciated that various modifications may be made to the embodiments described above without departing from the scope of the invention as defined by the appended claims.

[0057] For example, although the invention has been described with reference to a pump 10 having three pumping chambers 20a, 20b, 20c, it should be appreciated that this need not be the case and the invention is applicable to pumps having one, or more than one, pumping chamber with an associated pumping plunger.

[0058] While the insert and recess of the first embodiment are exemplified as being circular, other shaped inserts and recesses may be used.

[0059] It should also be appreciated that while the embodiment of Figure 5 is illustrated with a single male / female pair for interlocking the spring seat and base portion of the intermediate drive assembly, more than one, such as 2 or 3 male / female pairs may be used.

[0060] As already described, in a preferred aspect of the invention, the intermediate drive assembly comprises features of both the first and second aspects of the invention. Thus, the intermediate drive assembly includes a base member having a recess and an insert defining the thrust surface formed from a harder material than the base member; and additionally comprises an interlocking means to further reduce wear between the intermediate drive assembly and pumping plunger in use.

Claims

1. An intermediate drive assembly (1) for a fuel pump (10), the fuel pump (10) including a pump housing (12) provided with at least one bore (20a, 20b, 20c) for receiving the intermediate drive assembly (1) and a pumping plunger (30) which are driven, in use, in a reciprocal manner within the bore (20a, 20b, 20c) by a drive arrangement (2) so as to pressurise fuel within a pump chamber (32), the intermediate drive assembly (1) being arranged so as to cooperate between the drive arrangement (2) and the pumping plunger (30);
the intermediate drive assembly (1) comprising:

    a tappet (34) having a base portion (38) and a side wall portion (36) of generally cylindrical shape upstanding from the perimeter of the base portion (38), in use, for co-operating with the bore (20a, 20b, 20c) of the pump housing (12) to guide said reciprocal movement of the intermediate drive assembly (1) and the pumping plunger (30), the side wall portion (36) and base portion (38) defining an internal chamber (52); the base portion (38) having a drive surface (5) for cooperating with the drive arrangement (2) and a thrust surface (7) for cooperating with and imparting drive to the pumping plunger (30), and a recess (9), the recess (9) receiving an insert (11) formed of a material having a hardness greater than the base portion (38), wherein the insert (11) defines the thrust surface (7) for engagement with the base (31) of the pumping plunger (30); and
    a coupling mechanism, in use for coupling the pumping plunger (30) to the base portion (38), wherein the coupling mechanism comprises:

        a spring seat (40) adapted to be received within the internal chamber (52) and to engage an end of the pumping plunger (30); and
        interlocking means, in use for substantially preventing relative

    rotation between the base portion (38) and the spring seat (40);
    and wherein the insert (11) is a clearance fit in the recess (9) of the base portion (38).

2. The intermediate drive assembly (1) of Claim 1, wherein the clearance is approximately 0.15 to 0.35 mm.

3. The intermediate drive assembly (1) of Claim 1 or Claim 2, wherein the thrust surface (7) is part-spherical.

4. The intermediate drive assembly (1) of any preceding claim, wherein the insert (11) is formed of a material selected from diamond-like carbon, cemented carbide, heat-treated steel or ceramic.

5. The intermediate drive assembly (1) of Claim 4, wherein the ceramic material is a zirconia, alumina, silicon or carbide ceramic.

6. The intermediate drive assembly (1) of Claim 4 or Claim 5, wherein the ceramic material is a boron carbide, tungsten carbide, silicon nitride or silicon carbide ceramic.

7. The intermediate drive assembly (1) of any preceding claim, which further includes a pumping plunger (30), and wherein the coupling arrangement comprises a spring seat (40) provided with an aperture (33) for receiving a lower end of the pumping plunger (30), in use.

8. The intermediate drive assembly (1) of Claim 7, wherein the spring seat (40) is provided with an aperture (33) for receiving an end of the pumping plunger (30), the aperture (33) being a press fit or friction fit with the end of the pumping plunger (30).

9. The intermediate drive assembly (1) of any preceding claim, wherein the interlocking means comprises: at least one male member (29) associated with one or more of the spring seat (40), the base portion (38) and the side wall portion (36); and at least one female member (35) associated with one or more of the spring seat (40), the base portion (38) and the side wall portion (36); the at least one male member (29) and the at least one female member (35) arranged in use to interlock between the spring seat (40) and the base portion (38) and/or side wall portion (36).

10. The intermediate drive assembly (1) of any preceding claim, wherein the interlocking means comprises a pin and hole, a keyed arrangement, or a splined shaft

11. The intermediate drive assembly (1) of any preceding claim, wherein the base portion (38) is provided with a pin (29) protruding from the surface thereof, and the spring seat (40) is provided with a hole (35) adapted to receive the pin (29) of the base portion (38); and wherein the pin (29) and hole (31) are spaced from the central axis of the base portion (38),

spring seat (40) and plunger (30) in use.

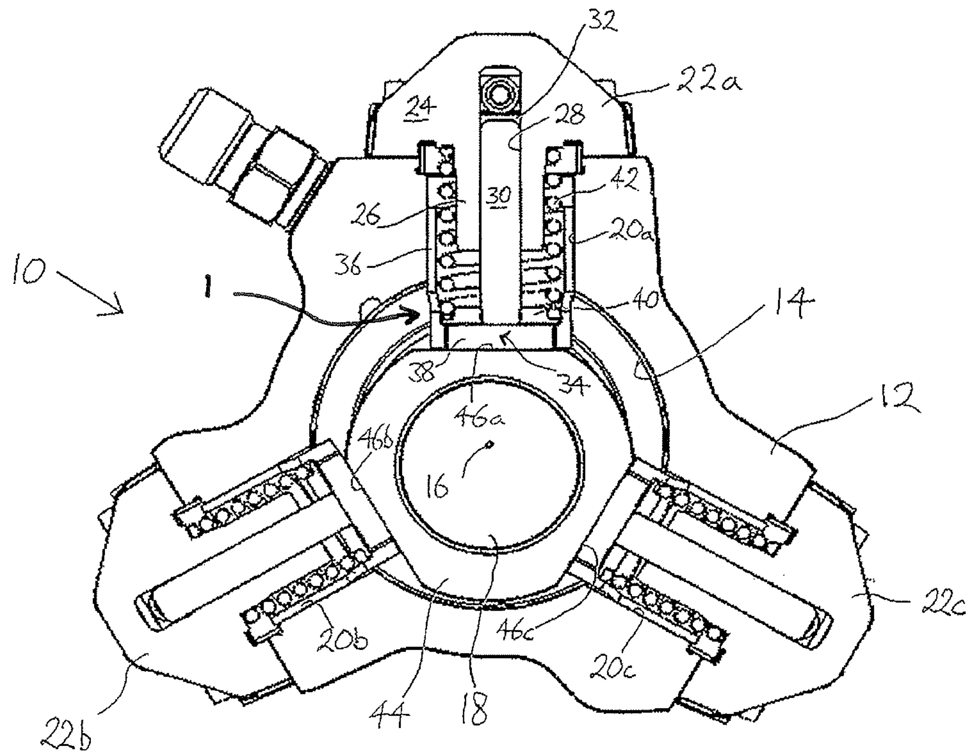
12. The intermediate drive assembly (1) of Claim 10, wherein pin (29) and hole (31) are spaced from the central axis of the base portion (38), spring seat (40) and plunger (30) in use.

13. The intermediate drive assembly (1) of any preceding claim, wherein the base portion (38) and/or side wall portion (36) are provided with a plurality of vents (50), in use, for allowing the passage of fluid.

14. The intermediate drive assembly (1) of any preceding claim, which further includes a pumping plunger (30).

15. A pump assembly (10) comprising:

a pump housing (12) having an axially extending opening (14) for receiving a drive arrangement (2) and at least one bore (20a, 20b, 20c) extending generally radially from said axially extending opening (14);
a pumping plunger (30), which is driven in use by the drive arrangement (2) to pressurise fluid in a pumping chamber (32);
an intermediate drive assembly (1) received for reciprocating sliding movement in said bore (20a, 20b, 20c) and being arranged so as to cooperate between the drive arrangement (2) and the pumping plunger (30);
the drive arrangement (2) comprising a cam rider (44) received in said axially extending opening (14) and having an inner surface co-operable with a cam drive shaft and an outer surface cooperable with said intermediate drive assembly (1) such that rotation of said drive shaft causes said cam rider (44) to drive reciprocating sliding movement of said intermediate drive assembly (1) in said bore (20a, 20b, 20c); and
wherein said intermediate drive assembly (1) is as defined in any preceding claim.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22a
24
28
30
42
26
20a
36
10
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34
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46a
46b
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22c
46c
20b
20c
22b
44
18

Figure 1

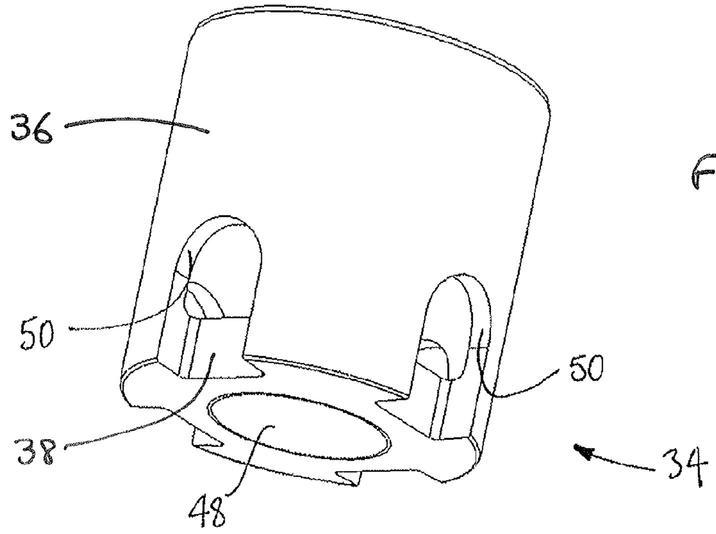

Figure 2

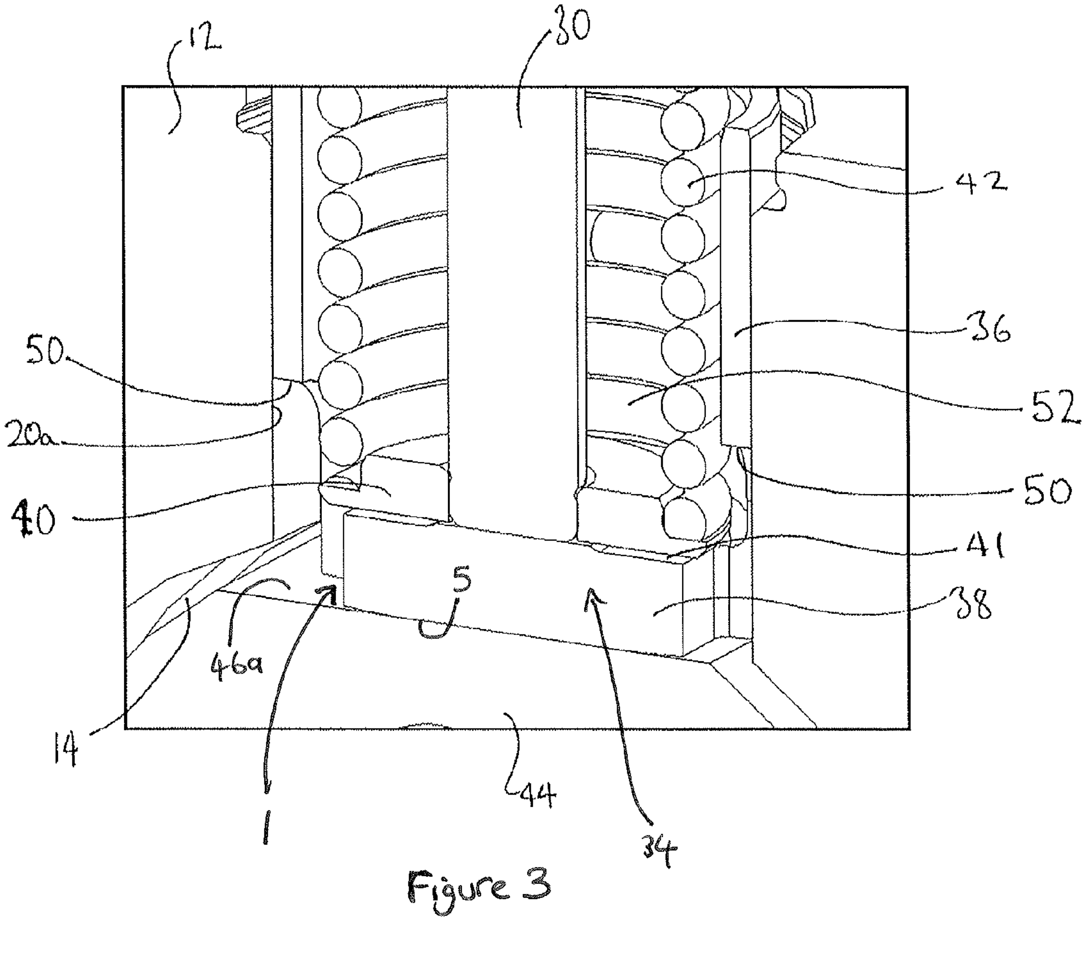

Figure 3

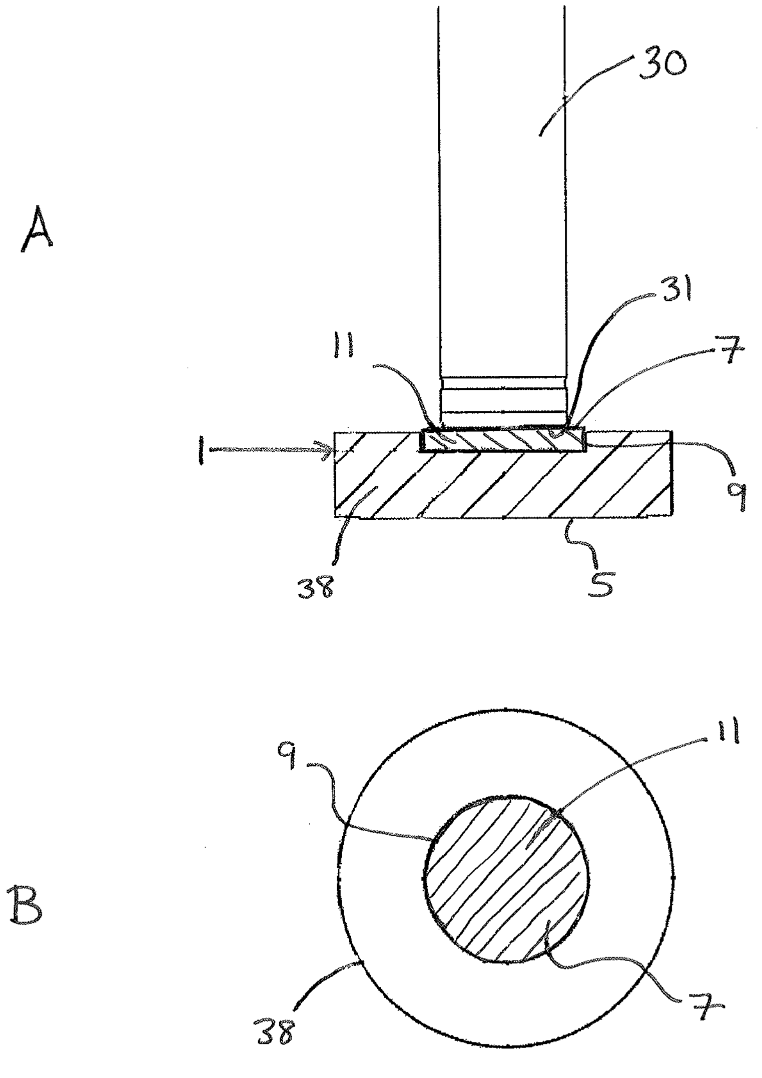

Figure 4

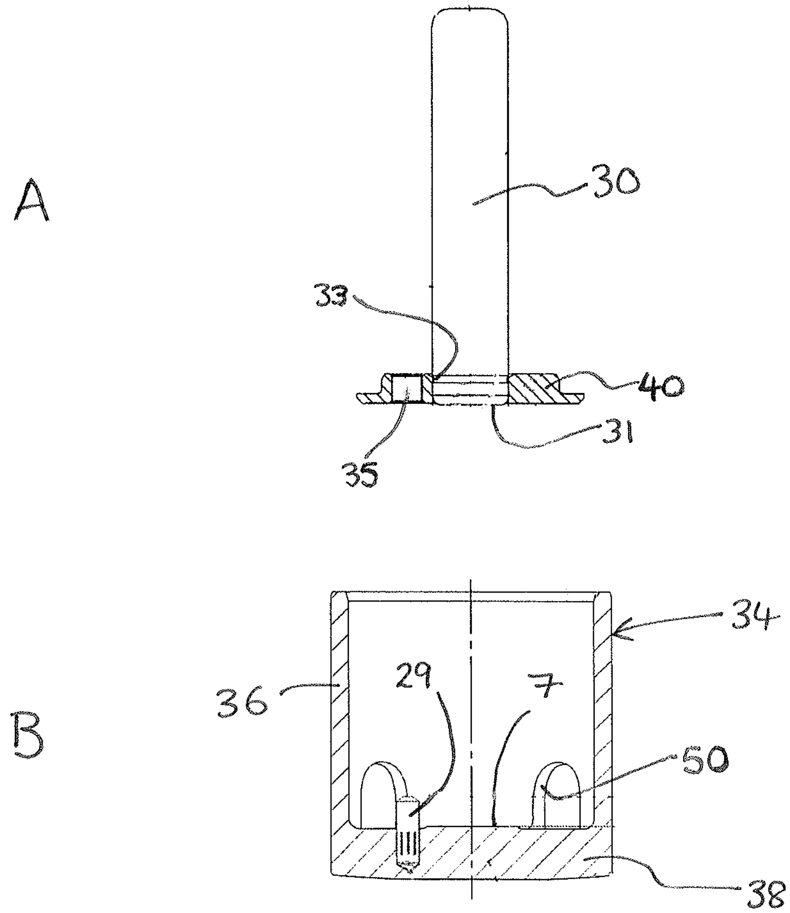

Figure 5

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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