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[Continued on next page]

(54) Title: FUEL INJECTOR

(57) Abstract: A fuel injector has a plunger to which a piston applies force to inject fuel and to which fuel at fuel rail pressure is also applied to provide additional injection force. The fuel which provides the additional force is recovered to increase operating efficiency.

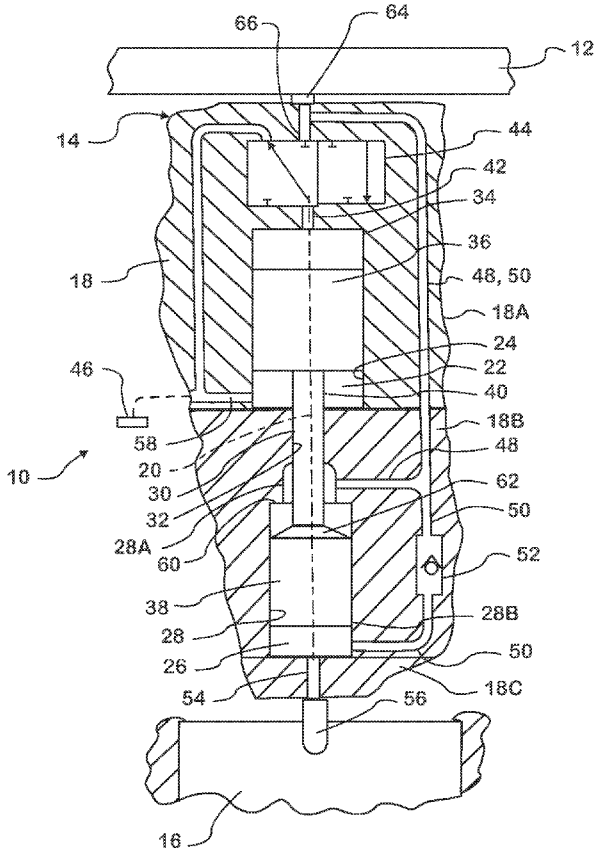


FIG. 2

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FUEL INJECTOR

Technical Field

[0001] This disclosure relates to internal combustion engines having engine cylinders into which fuel is injected and then combusted, and in particular to a fuel injector which injects liquid fuel directly into an engine cylinder.

Background

[0002] A known type of fuel injector served by a fuel rail has a reciprocal movement which is displaced distally to forcefully inject fuel out of a chamber in the fuel injector and which is displaced proximally to re-load the fuel injector chamber with fuel for a subsequent injection.

[0003] An electrically controlled injection control valve controls initiation and termination of fuel injection.

[0004] Fuel pressure in the fuel rail is at a regulated pressure, and fuel will flow from the fuel rail into the fuel injector to initiate fuel injection when the injection control valve is operated open. The pressure of the fuel acting on the movement causes the movement to force fuel already in a chamber of the fuel injector to be forced out of the chamber and through a nozzle into an engine cylinder where the fuel combusts to power the engine.

[0005] Certain fuel injectors can develop injection pressure greater than fuel pressure in a fuel rail. Such intensified injection fuel injectors generally have lower operating efficiency than fuel injectors which inject fuel at fuel rail pressure.

Summary of the Disclosure

[0006] The present disclosure relates to a fuel injector which can be configured either as an intensified pressure fuel injector or as one which injects fuel at fuel rail pressure. When configured as an intensified pressure fuel injector, it can operate more efficiently than certain other intensified pressure fuel injectors.

[0007] The fuel injector comprises a body having a longitudinal axis and containing a first chamber bounded circumferentially of the axis by a first wall, a second chamber spaced axially distally of the first chamber and bounded circumferentially of the axis by a second wall, and a connecting hole which has an axially proximal end open to an axially distal end of the first chamber and an axially distal end open to an axially proximal end of the second chamber and which is bounded circumferentially of the axis by a third wall which is cylindrical about the axis.

[0008] A movement is reciprocal within the body along the axis and comprises a piston in the first chamber which has a sliding seal to the first wall, a plunger in the second chamber which has a sliding seal to the second wall, and a rod which extends through the connecting hole to operatively couple the piston and the plunger for transmitting distal displacement of the piston to the plunger and proximal displacement of the plunger to the piston and which confronts, and has a sliding seal to, the third wall. The plunger has a proximal end surface surrounding the rod and a distal end surface axially opposite the proximal end surface.

[0009] A first fuel passage in the body is open to the first chamber at a location proximal to the piston.

[0010] An injection control valve is operable to initiate and terminate injection by selectively opening and closing the first fuel passage to a fuel rail port while respectively closing and opening the first fuel passage to a drain.

[0011] A second fuel passage in the body is continuously open from the fuel rail port to the second chamber at a location proximal to the plunger.

[0012] A third fuel passage in the body is continuously open from the fuel rail port to an inlet of a one-way valve whose outlet is continuously open to the second chamber at a location distal to the plunger. The one-way valve allows fuel flow from the fuel rail port into the second chamber but not out of the second chamber.

[0013] An outlet passage in the body extends from a location in the second chamber distal to the plunger to a nozzle through which fuel is injected out of the fuel injector.

[0014] When the injection control valve opens the first fuel passage to the fuel rail port, fuel from a fuel rail connected to the fuel rail port enters the first chamber and acts on the piston to displace the movement distally and cause the plunger to force fuel out of the second chamber through the outlet passage and the nozzle while fuel from the fuel rail port enters the second chamber through the second fuel passage.

[0015] When the injection control valve closes the first fuel passage to the fuel rail port, the movement is displaced proximally by

fuel pressure in the second chamber acting on the proximal end surface of the plunger and the distal end surface of the plunger surrounding the rod to impart proximal force to the movement and cause the plunger to force a majority of fuel that entered through the second fuel passage during distal displacement back into the second fuel passage.

[0016] The foregoing summary, accompanied by further detail of the disclosure, will be presented in the Detailed Description below with reference to the following drawings that are part of this disclosure.

Brief Description of the Drawings

[0017] Figure 1 is a diagram of a portion of an engine fuel system including a fuel injector shown in cross section, the fuel injector being shown when not injecting fuel.

[0018] Figure 2 is a view identical to Figure 1 but showing the fuel injector upon termination of a fuel injection.

[0019] Figure 3 is an enlarged view of a modified portion of the fuel injector shown in Figure 1 when injecting fuel.

[0020] Figure 4 is a view like Figure 3 but showing the modified portion after having completed injecting fuel.

[0021] Figure 5 is a view similar to a portion of Figure 1 showing another embodiment.

[0022] Figure 6 is a view similar to a portion of Figure 1 showing another embodiment.

[0023] Figure 7 is a fragmentary view showing a modification applicable to both Figure 5 and Figure 6.

Detailed Description

[0024] Figure 1 shows a portion of a fuel system of an internal combustion engine 10 comprising a fuel rail 12 containing fuel at regulated pressure and a fuel injector 14 which is served by fuel rail 12 for injecting fuel into an engine cylinder 16.

[0025] Fuel injector 14 comprises a body 18 having a longitudinal axis 20 and containing a first chamber 22 bounded circumferentially of axis 20 by a first wall 24, a second chamber 26 spaced axially distally of first chamber 22 and bounded circumferentially of axis 20 by a second wall 28, and a connecting hole 30 which has an axially proximal end open to an axially distal end of first chamber 22 and an axially distal end open to an axially proximal end of second chamber 26, and which is bounded circumferentially of axis 20 by a third wall 32 which is cylindrical about axis 20. Second wall 28 has a first zone 28A and a second zone 28B which is distal to first zone 28A.

[0026] A movement 34 is reciprocal within body 18 along axis 20 and is shown at a proximal limit of movement reciprocation. Movement 34 comprises a piston 36 in first chamber 22 having a sliding seal to first wall 24, a plunger 38 in second chamber 26 having a sliding seal to zone 28B of second wall 28, and a rod 40 which extends from piston 36 through connecting hole 30 to plunger 38. Rod 40 has a cylindrical surface of constant diameter throughout its axial length providing a sliding seal of the rod to third wall 32.

[0027] A first fuel passage 42 in body 18 is open to first chamber 22 at a location proximal to piston 36. Fuel injector 14 comprises an injection control valve 44 which can be either mounted on or integrated with body 18. Figure 1 shows injection control valve 44 schematically integrated with body 18. Injection control valve 44 is operable to initiate and terminate injection by selectively opening and closing first fuel passage 42 to fuel rail 12 while respectively closing and opening first fuel passage 42 to a drain 46.

[0028] A second fuel passage 48 is continuously open from fuel rail 12 to second chamber 26 through zone 28A of second wall 28 at a location proximal to plunger 38.

[0029] A first portion of a third fuel passage 50 is continuously open from fuel rail 12 to an inlet of a one-way valve 52 whose outlet is continuously open through a second portion of third fuel passage 50 to second chamber 26 at a location distal to plunger 38. One-way valve 52 allows fuel flow from fuel rail 12 into second chamber 26 but not out of second chamber 26. Passages 48, 50 share a common path through body 18 from fuel rail 12 until splitting into respective branches to second chamber 26.

[0030] An outlet passage 54 is open from a location in second chamber 26 distal to plunger 38 to a nozzle 56 through which fuel is injected out of fuel injector 14 into engine cylinder 16. A fuel drain passage 58 is open from first chamber 22 at a location distal to piston 34 to drain 46.

[0031] First zone 28A of second wall 28 is cylindrical about axis 20 and circumscribes a cross-sectional area perpendicular to axis 20 which is smaller than a cross-sectional area of second zone 28B perpendicular to axis 20.

[0032] A distally facing first shoulder 60 joins first zone 28A of second wall 28 and second zone 28B of second wall 28. Plunger 38 comprises a second shoulder 62 which faces proximally and abuts first shoulder 60 to limit proximal displacement of movement 34. At least one of shoulders 60, 62 has a frustoconical shape about axis 20.

[0033] Figure 1 shows body 18 having a fuel rail port 64 which connects fuel injector 14 to fuel rail 12. Fuel rail port 64 is continuously open to an inlet port 66 of injector control valve 44 and to fuel passages 48, 50.

[0034] Figure 1 shows fuel injector 14 in a non-injection condition ready to initiate injection of fuel. Movement 34 is at a proximal limit of reciprocation with shoulders 60, 62 in mutual abutment. The volume of second chamber 26 distal to plunger 38 is filled with fuel which has entered through passage 50.

[0035] Injection is initiated by operating injection control valve 44 to open first fuel passage 42 to fuel in fuel rail 12 and close drain 46 to first fuel passage 42, allowing fuel to flow from fuel rail 12 through injection control valve 44 into first chamber 22 and act on piston 36 to initiate distal displacement of movement 34, including distal displacement of plunger 38 in second chamber 26 to force fuel out of second chamber 26 through outlet passage 54 and nozzle 56 into engine cylinder 16. One-

way valve 52 blocks fuel from leaving second chamber 26 through third fuel passage 50.

[0036] During distal displacement of movement 34, the volumetrically increasing space in second chamber 26 proximal to plunger 38 fills with fuel from fuel rail 12 via second fuel passage 48. The distance over which movement 34 is displaced determines the quantity of fuel injected.

[0037] Figure 2 shows the condition of fuel injector 10 at termination of a fuel injection. Injection of fuel is terminated by returning injection control valve 44 to the condition shown in both Figure 1 and Figure 2 which closes first fuel passage 42 to fuel in fuel rail 12 while opening first fuel passage 42 to drain 46 so that further distal displacement of movement 34 ceases. As a result, the pressure drops in second chamber 26 distal to plunger 38, allowing fuel rail pressure to open one-way valve 52 and fuel to flow into second chamber 26 distal to plunger 38 thereby applying pressure to the distal end surface of plunger 38. That pressure forces movement 34 to move proximally as will be more fully explained hereinafter.

[0038] As movement 34 moves proximally, piston 36 forces fuel which had entered first chamber 22 through injection control valve 44 to now drain through injection control valve 44 to drain 46. At the same time plunger 38 forces a majority of fuel which had entered second chamber 26 through second fuel passage 48 during injection back through second fuel passage 48. A minority of fuel may be forced into first chamber 22 through clearance between rod 40 and connecting hole 30. Fuel

that is forced back through second fuel passage 48 is returned through one-way valve 52 into second fuel chamber 26 distal to plunger 38, reducing the quantity of fuel needed from fuel rail 12 to displace movement 34 proximally. Proximal displacement of movement 34 ceases when shoulder 62 abuts shoulder 60. The next injection of fuel will occur when injection control valve 44 is once again operated to open first fuel passage 42 to fuel in fuel rail 12 and close drain 46 to first fuel passage 42.

[0039] Because fuel pressure in second chamber 26 proximal to plunger 38 is approximately equal to fuel pressure in second chamber 26 distal to plunger 38, it is the difference between the larger area of the circular distal end of plunger 38 and the smaller area of the proximal end of plunger 38 surrounding rod 40 which creates proximal force on movement 34 sufficient to displace the movement proximally until shoulders 60, 62 mutually abut while at the same time forcing fuel back through second fuel passage 48. That capability increases efficiency of fuel injector operation because a majority of fuel from fuel rail 12 which applied additional pressure on plunger 38 during injection is reused in fuel injector 14 instead of being drained from the fuel injector.

[0040] In the embodiment of Figures 1 and 2, the pressure of fuel proximal to plunger 38 acts on shoulder 62 of plunger 38. Although shoulder 62 is frustoconical, the fuel pressure acting on it creates a force equivalent to that which would be applied if shoulder 62 were flat and perpendicular to axis 20.

[0041] The presence of second fuel passage 48 also allows fuel rail pressure to be applied to shoulder 62 during injection, and the resulting distal force is additive to force being applied to the plunger by fuel rail pressure acting on piston 36. That capability can have favorable implications on fuel injector sizing such as increasing pressure intensification of injection without the necessity of making the diameter of the piston chamber greater than that of the plunger chamber although the piston chamber may have a larger diameter as shown by Figure 1.

[0042] Body 18 comprises a first body part 18A and a second body part 18B. First chamber 22 is cooperatively defined by first body part 18A and second body part 18B. Second chamber 26 and connecting hole 30 are contained entirely in second body part 18B. In the embodiment shown in Figures 1 and 2, movement 34 comprises two parts. Piston 36 is one of those two parts while plunger 38 and rod 40 are the other. By having second chamber 26 and connecting hole 30 in one body part, that body part can be manufactured to close tolerances on second chamber 26 and connecting hole 30, reducing leakage through connecting hole 30 and improving fuel injector operating efficiency. Plunger 38 and rod 40 can be integrated into a single part or they can be two separate parts which are coupled together either mechanically or hydraulically. A third body part 18C containing outlet passage 54 closes the distal end of second chamber 26.

[0043] It is not necessary that piston 36 be mechanically attached to rod 40 after rod 40 has been inserted into and through

connecting hole 30 during the injector assembly process. Fuel pressures will keep piston 36 and rod 40 in mutual abutment.

[0044] Figures 3 and 4 show the principle of hydraulic coupling between rod 40 and plunger 38.

[0045] Plunger 38 has a circular blind hole 76 extending axially inward from the radially inner perimeter of shoulder 62. Rod 40 is circular in cross section and has a close sliding fit to a circular side wall surface 78 of blind hole 76. It is the closeness of that sliding fit which enables hydraulic coupling of plunger 38 and rod 40 to each other to be achieved.

[0046] The diameter of blind hole 76 is slightly greater than that of rod 40. When movement 34 is at its proximal limit of displacement before an injection, pressure of fuel in the portion of second chamber 26 proximal to plunger 38 forces some fuel into space of hole 76 not occupied by rod 40. As piston 36 is displaced distally to begin an injection, rod 40 forces distal displacement of plunger 38 but replenishment of fuel in second chamber 26 through second fuel passage 48 keeps fuel in the space of hole 76 not occupied by rod 40 under pressure. That pressure tends to force some fuel between the distal end face of rod 40 and the bottom of hole 76.

[0047] When injection ceases, pressure of fuel in the portion of second chamber 26 distal to plunger 38 suddenly decreases, but the pressure of fuel in the portion of second chamber 26 proximal to plunger 38, and also of fuel in space of hole 76 not occupied by rod 40, does not. That creates a condition which allows the fuel in the portion of second chamber 26 proximal to

plunger 38 and in space of hole 76 not occupied by rod 40 to expand slightly. Fuel which has intruded between the distal end face of rod 40 and the bottom of hole 76 also expands and forces rod 40 and plunger 38 slightly away from each other, as shown in Figure 4 which is somewhat exaggerated for illustration.

[0048] But because a net proximal force is being applied to plunger 38 as explained above, that force causes rod 40 and plunger 38 to move back toward each other as both are being forced to move proximally. This slight back and forth movement between the rod and plunger is inherent in the hydraulic coupling of the rod and plunger to each other and continues as both are being moved toward the proximal limit of movement displacement. The back and forth movement may be described as an oscillatory disturbance within the overall movement displacement. The extent of the oscillation is a function of the clearance between rod 40 and side wall surface 78 within some limit. Beyond that limit, hydraulic coupling is lost.

[0049] Figure 5 shows an embodiment in which numeral-referenced elements which have already been described are identified by like reference numerals. The embodiment of Figure 5 differs from that of Figures 1 and 2 in that the proximal limit of displacement of movement 34 is established by mutual abutment of a frustoconical shoulder 70 of rod 40 and a flat shoulder 72 at the junction of the proximal end of second chamber 26 and the distal end of connecting hole 30. Figure 5 shows shoulders 70, 72 in mutual abutment with the annular

proximal end surface of plunger 38 surrounding rod 40 being perpendicular to axis 20 and spaced from shoulder 60.

[0050] Shoulder 70 defines a portion of a groove 74 which extends circumferentially around rod 40 and which separates a smaller diameter proximal segment 40A of rod 40 from a larger diameter distal segment 40B. Proximal segment 40A is circular in cross section and has a sliding seal to third wall 32. Distal segment 40B is closely fit to side wall surface 78 of blind hole 76 in plunger 38 to provide hydraulic coupling of the rod and plunger to each other.

[0051] By using mutual abutment of shoulders 70 and 72 to define the proximal limit of displacement of movement 34, the abutment also stops leakage from second chamber 26 through connecting hole 30 when injection is not occurring.

[0052] Figure 6 shows an embodiment in which numeral-referenced elements which have already been described are identified by like reference numerals. The embodiment of Figure 6 differs from that of Figure 5 in that first zone 28A of second wall 28 and second zone 28B of second wall 28 have the same diameter.

[0053] The functionality of second fuel passage 48 and third fuel passage 50 would remain unchanged if they were separate passages directly to the fuel rail.

[0054] Figure 7 differs from Figures 5 and 6 in that rod 40 has a shape which allows proximal segment 40A and distal segment 40B to have equal diameters. Proximal limit of displacement of movement 34 is still established by mutual abutment of a

frustoconical shoulder 70 of rod 40 and a flat shoulder 72 at the junction of the proximal end of second chamber 26 and the distal end of connecting hole 30. A further modification, not shown, could even have the diameter of distal segment 40B smaller than that of proximal segment 40A.

WHAT IS CLAIMED IS:

1. An internal combustion engine comprising:

a fuel rail containing fuel at regulated pressure;

a fuel injector having a longitudinal axis and containing a first chamber bounded circumferentially of the axis by a first wall, a second chamber spaced axially distally of the first chamber and bounded circumferentially of the axis by a second wall, and a connecting hole which has an axially proximal end open to an axially distal end of the first chamber and an axially distal end open to an axially proximal end of the second chamber and which is bounded circumferentially of the axis by a third wall which is cylindrical about the axis;

a movement which is reciprocal along the axis and which comprises a piston in the first chamber having a sliding seal to the first wall, a plunger in the second chamber having a sliding seal to the second wall, and a rod which extends through the connecting hole to operatively couple the piston and the plunger for transmitting distal displacement of the piston to the plunger and proximal displacement of the plunger to the piston and which confronts, and has a sliding seal to, the third wall;

the plunger having a proximal end surface surrounding the rod and a distal end surface axially opposite the proximal end surface;

a first fuel passage open to the first chamber at a location proximal to the piston;

an injection control valve operable to initiate and terminate injection by selectively opening and closing the first fuel passage to the fuel rail while respectively closing and opening the first fuel passage to a drain;

a second fuel passage continuously open from the fuel rail to the second chamber at a location proximal to the proximal end surface of the plunger;

a third fuel passage continuously open from the fuel rail to an inlet of a one-way valve whose outlet is continuously open to the second chamber at a location distal to the distal end surface of the plunger, the one-way valve allowing fuel flow from the fuel rail into the second chamber but not out of the second chamber; and

an outlet passage from a location in the second chamber distal to the plunger to a nozzle through which fuel is injected out of the fuel injector into an engine cylinder;

the fuel injector being operable when the injection control valve opens the first fuel passage to the fuel rail to cause fuel from the fuel rail to enter the first chamber and act on the piston to displace the movement distally and cause the plunger to force fuel out of the second chamber through the outlet passage and the nozzle while fuel from the fuel rail enters the second chamber through the second fuel passage, and when the injection control valve closes the first fuel passage to the fuel rail, to cause the movement to be displaced proximally by fuel pressure in the second chamber acting on the proximal end surface of the plunger surrounding the rod and on the distal end surface of the plunger to impart proximal force to the movement and cause the plunger to force a majority of fuel that entered through the second fuel passage during distal displacement back into the second fuel passage.

2. The internal combustion engine as set forth in Claim 1 including a fuel drain passage from the first chamber at a location distal to the piston to the drain.

3. The internal combustion engine as set forth in Claim 1 in which the rod and the plunger are operatively coupled by a hydraulic coupling.

4. The internal combustion engine as set forth in Claim 3 in which the hydraulic coupling is provided by the plunger comprising a blind hole having a circular side wall and the rod having a sliding fit to the circular side wall of the blind hole.

5. The internal combustion engine as set forth in Claim 1 in which a proximal limit of displacement of the movement is defined by mutual abutment of a shoulder of the movement with a shoulder of a part which contains the second chamber.

6. The internal combustion engine as set forth in Claim 5 in which the part contains both the second chamber and the connecting hole.

7. The internal combustion engine as set forth in Claim 6 in which the shoulder of the movement is on the rod and the shoulder of the part which contains both the second chamber and the connecting hole is at the distal end of the connecting hole.

8. The internal combustion engine as set forth in Claim 1 in which the majority of fuel that entered the second chamber through the second fuel

passage during distal displacement flows through the one-way valve back into the second chamber.

9. A fuel injector comprising:

a body having a longitudinal axis and containing a first chamber bounded circumferentially of the axis by a first wall, a second chamber spaced axially distally of the first chamber and bounded circumferentially of the axis by a second wall, and a connecting hole which has an axially proximal end open to an axially distal end of the first chamber and an axially distal end open to an axially proximal end of the second chamber and which is bounded circumferentially of the axis by a third wall which is cylindrical about the axis;

a movement which is reciprocal within the body along the axis and which comprises a piston in the first chamber having a sliding seal to the first wall, a plunger in the second chamber having a sliding seal to the second wall, and a rod which extends through the connecting hole to operatively couple the piston and the plunger for transmitting distal displacement of the piston to the plunger and proximal displacement of the plunger to the piston and which confronts, and has a sliding seal to, the third wall;

the plunger having a proximal end surface surrounding the rod and a distal end surface axially opposite the proximal end surface;

a first fuel passage in the body open to the first chamber at a location proximal to the piston;

an injection control valve operable to initiate and terminate injection by selectively opening and closing the first fuel passage to a fuel rail port while respectively closing and opening the first fuel passage to a drain;

a second fuel passage in the body continuously open from the fuel rail port to the second chamber at a location proximal to the plunger;

a third fuel passage in the body continuously open from the fuel rail port to an inlet of a one-way valve whose outlet is continuously open to the second chamber at a location distal to the plunger, the one-way valve allowing fuel flow from the fuel rail port into the second chamber but not out of the second chamber; and

an outlet passage in the body from a location in the second chamber distal to the plunger through which fuel is injected;

the fuel injector being operable when the injection control valve opens the first fuel passage to the fuel rail port to cause fuel to enter the first chamber and act on the piston to displace the movement distally and cause the plunger to force fuel out of the second chamber through the outlet passage while fuel from the fuel rail port enters the second chamber through the second fuel passage, and when the injection control valve closes the first fuel passage to the fuel rail port, to cause the movement to be displaced proximally by fuel pressure in the second chamber acting on the proximal end surface of the plunger surrounding the rod and on the distal end surface of the plunger to impart proximal force to the movement and cause the plunger to force a majority of fuel that entered through the second fuel passage during distal displacement back into the second fuel passage.

10. The fuel injector as set forth in Claim 9 including a fuel drain passage in the body from the first chamber at a location distal to the piston to the drain.

11. The fuel injector as set forth in Claim 9 in which the rod and the plunger are operatively coupled by a hydraulic coupling.

12. The fuel injector as set forth in Claim 11 in which the hydraulic coupling is provided by the plunger comprising a blind hole having a circular side wall and the rod having a sliding fit to the circular side wall of the blind hole.

13. The fuel injector as set forth in Claim 9 in which in which a proximal limit of displacement of the movement is defined by mutual abutment of a shoulder of the movement with a shoulder of a part which contains the second chamber.

14. The fuel injector as set forth in Claim 13 in which the part contains both the second chamber and the connecting hole, and the shoulder of the movement is on the rod and the shoulder of the part which contains both the second chamber and the connecting hole is at the distal end of the connecting hole.

15. The fuel injector as set forth in Claim 9 in which the majority of fuel that entered the second chamber through the second fuel passage during distal displacement flows through the one-way valve back into the second chamber.

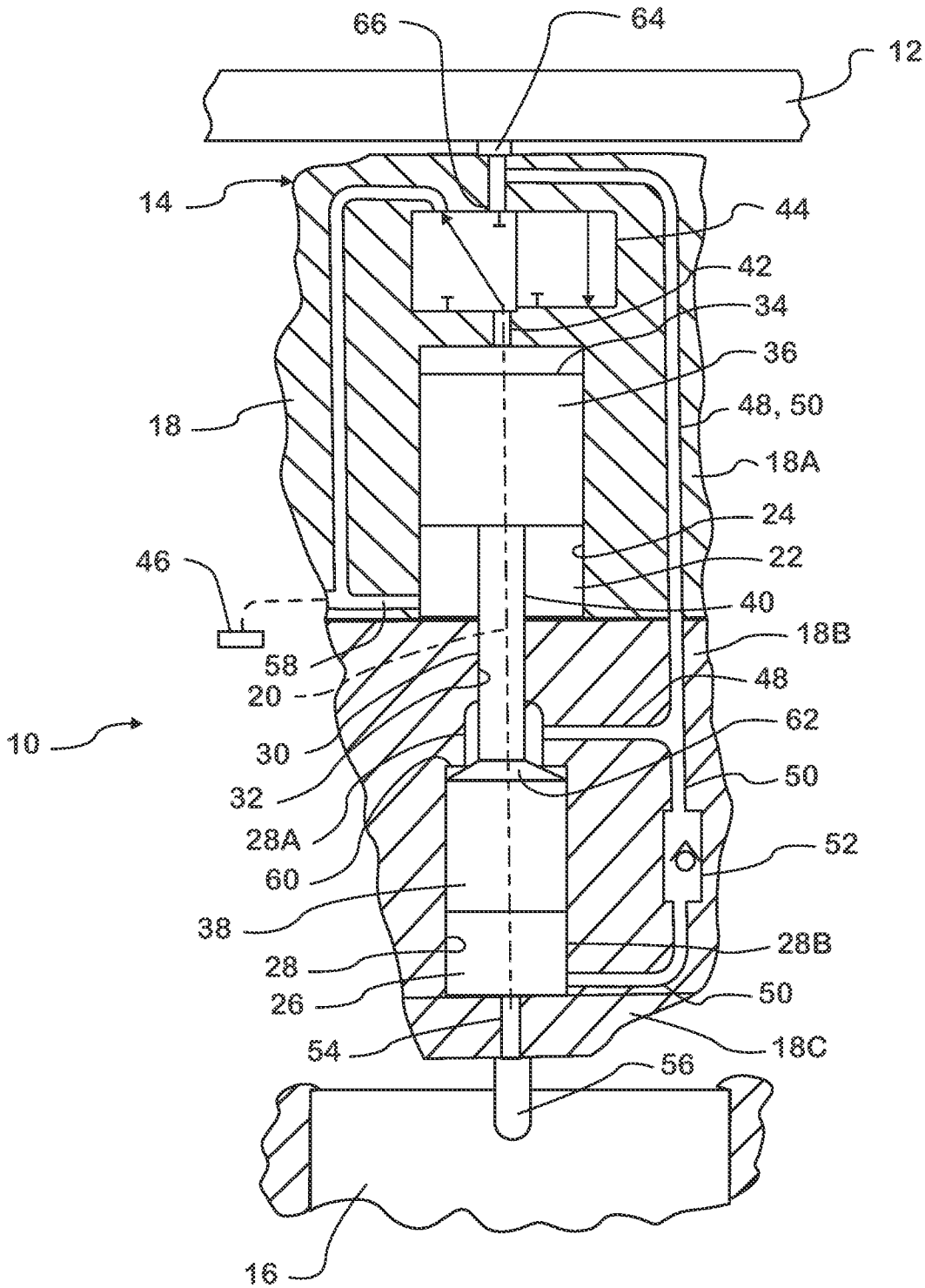

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FIG. 1

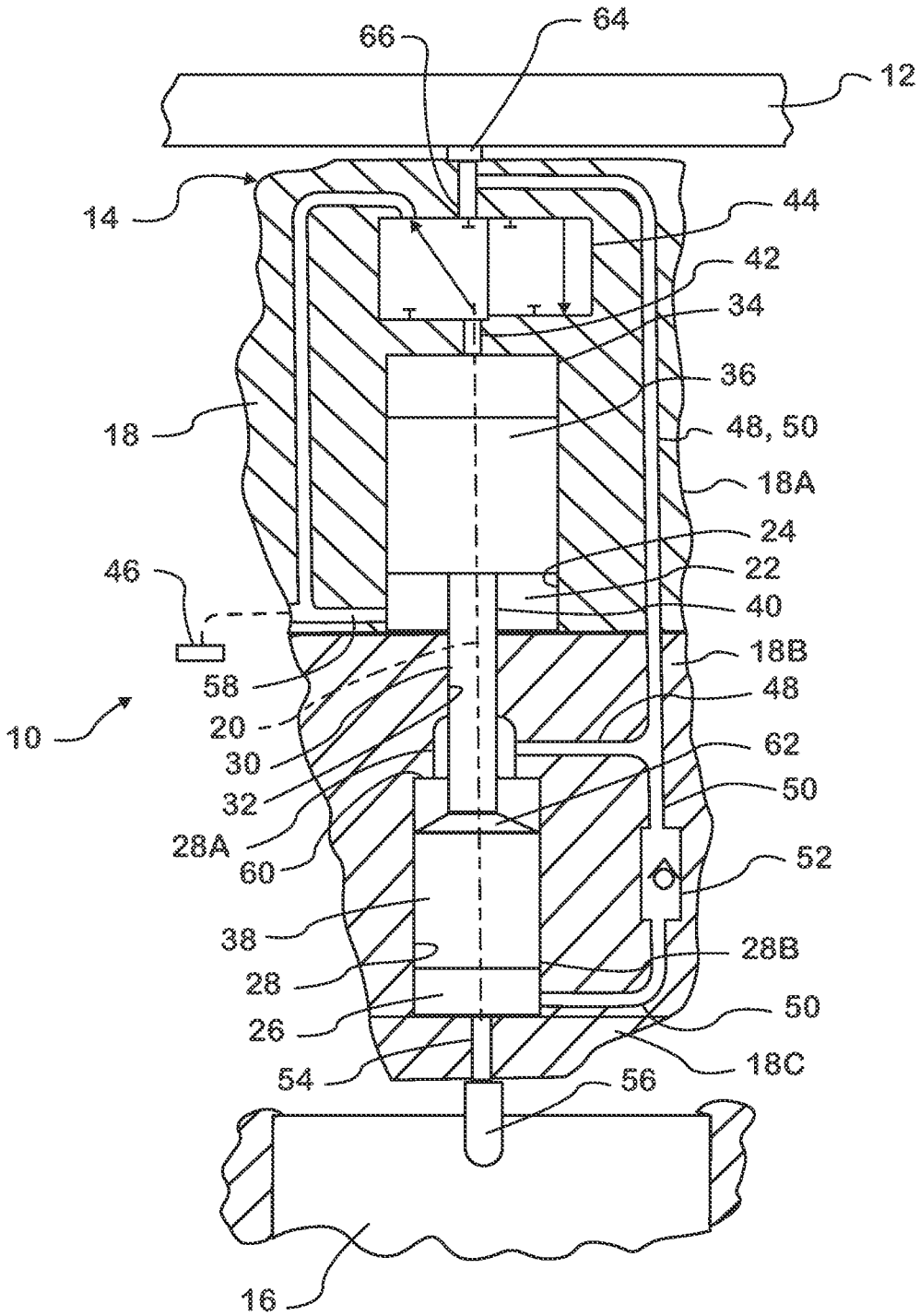

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FIG. 2

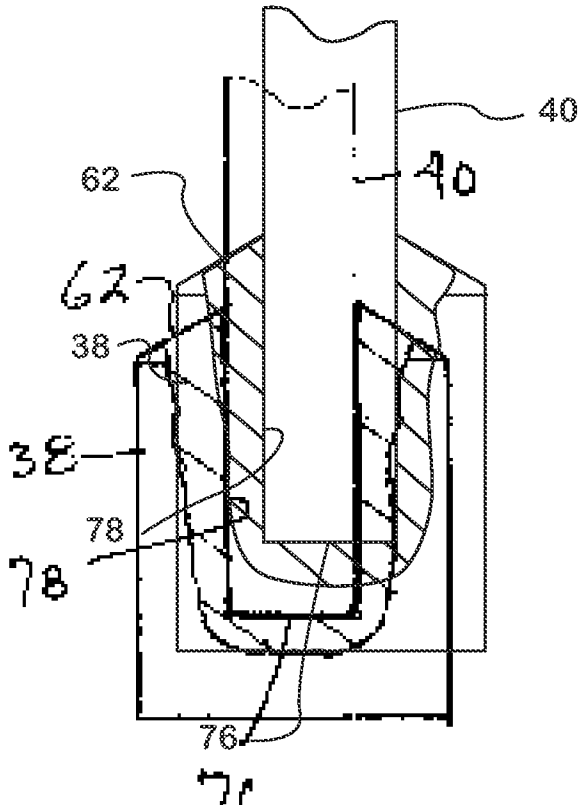


FIG. 3

Figure 3

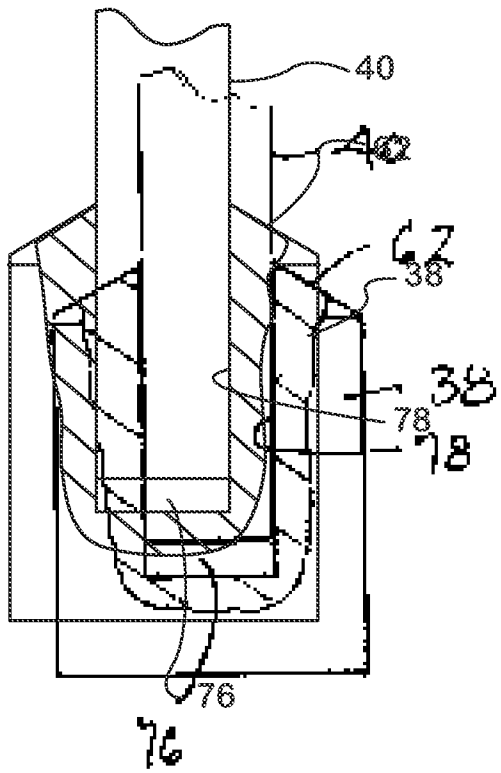


FIG. 4

Figure 4

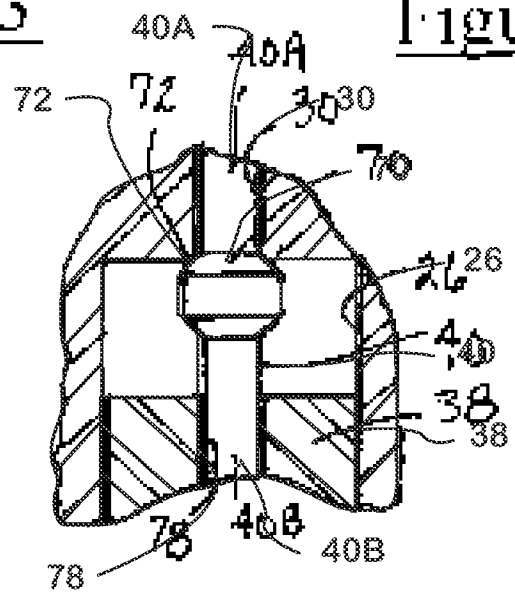


FIGure 7

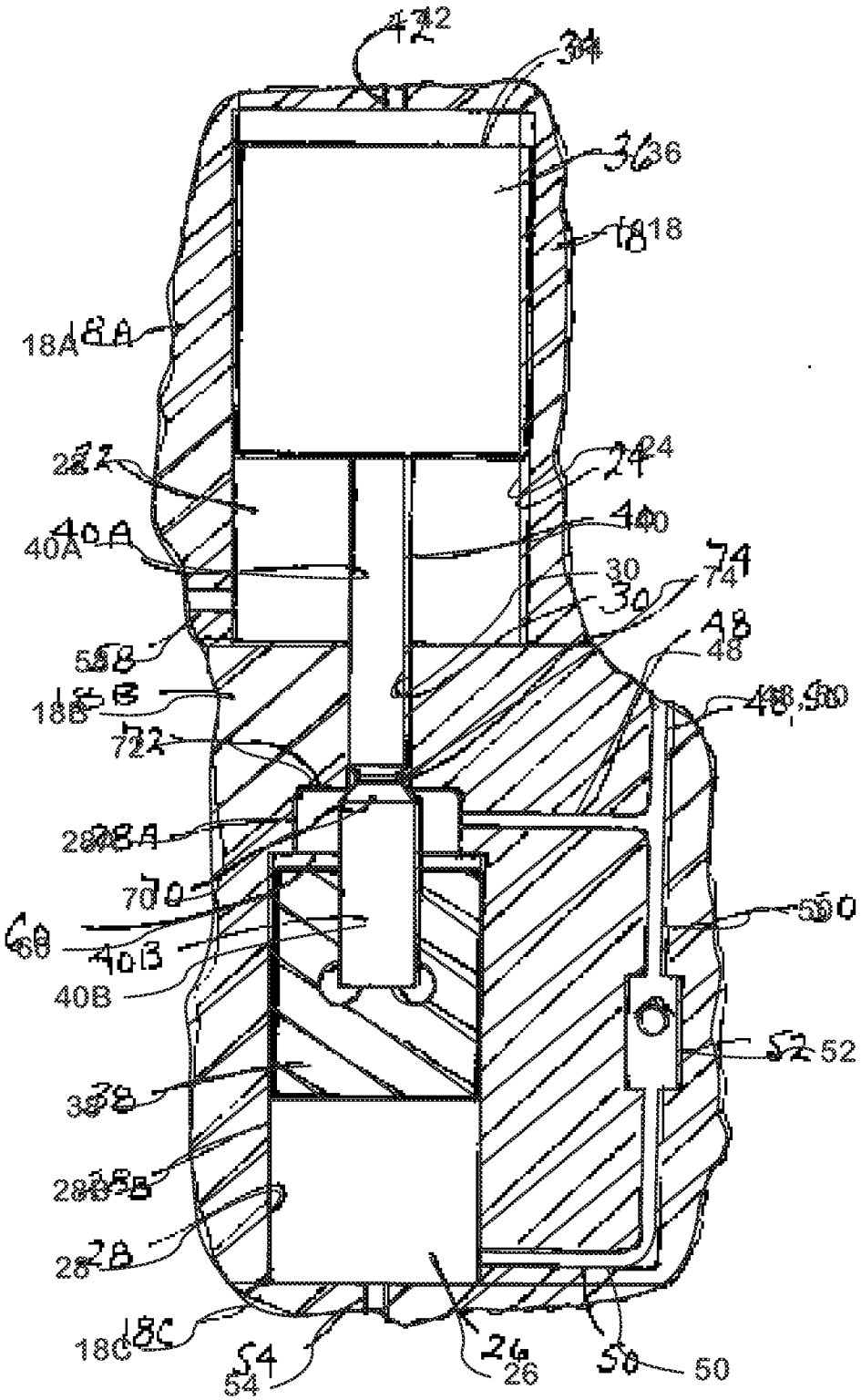


FIG. 5
Figure 5

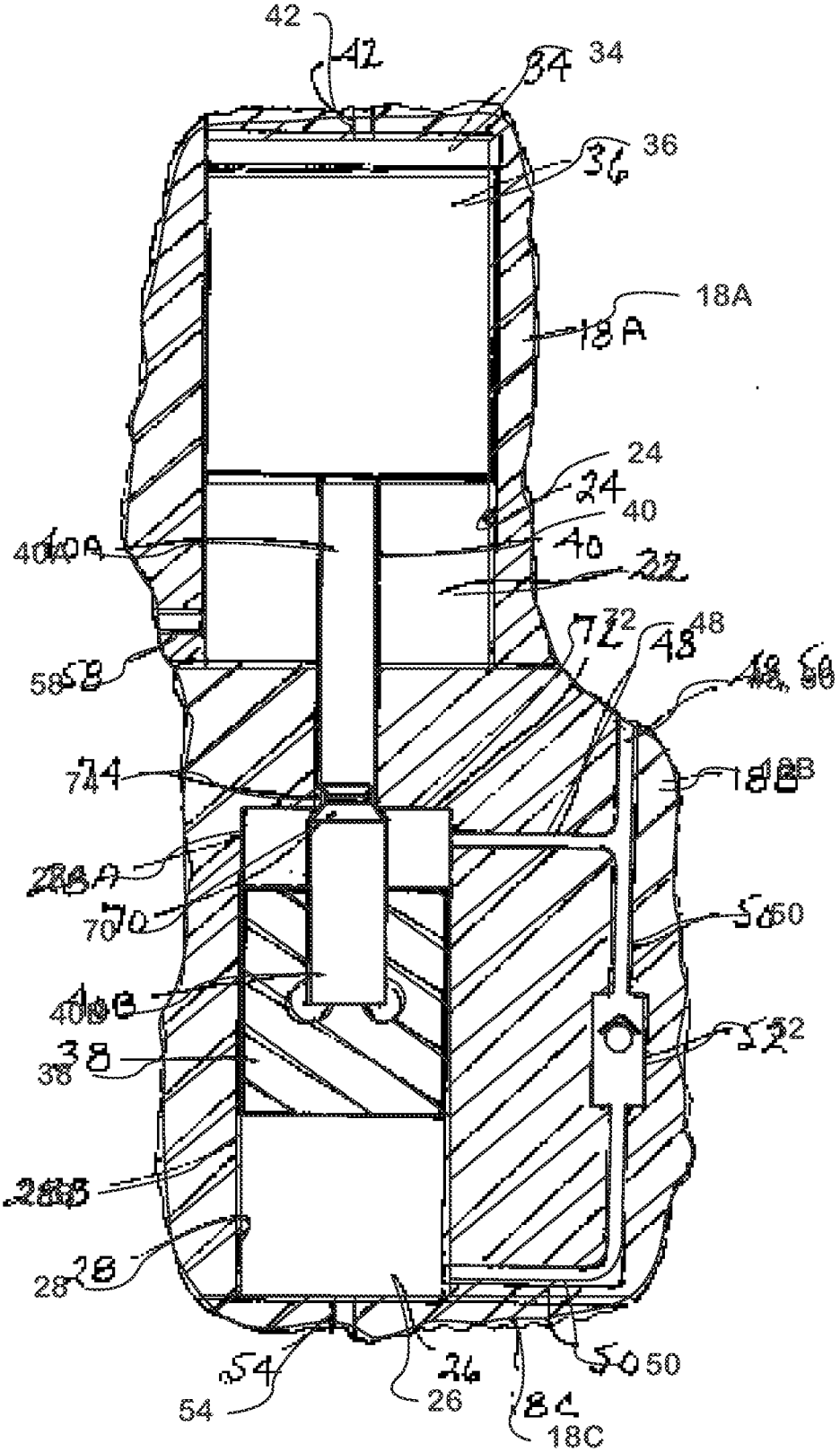


FIG. 6
Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/043017

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F02M 47/02 (2013.01)
USPC - 239/533.2
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - F02M 47/02, 63/02 (2013.01)
USPC - 123/445, 446, 447, 456; 239/88, 89, 90, 91, 533.2, 533.3, 533.4, 533.5, 533.7, 533.8, 583, 584; 251/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - F02M 47/02 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2002/0056761 A1 (BOECKING) 16 May 2002 (16.05.2002) entire document	1-15
Y	US 4,463,901 A (PERR et al) 07 August 1984 (07.08.1984) entire document	1-15
Y	US 5,443,209 A (VANALLSBURG) 22 August 1995 (22.08.1995) entire document	4, 12

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 October 2013	17 OCT 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774