

Defendant & Counterclaim Plaintiff's Technology Tutorial

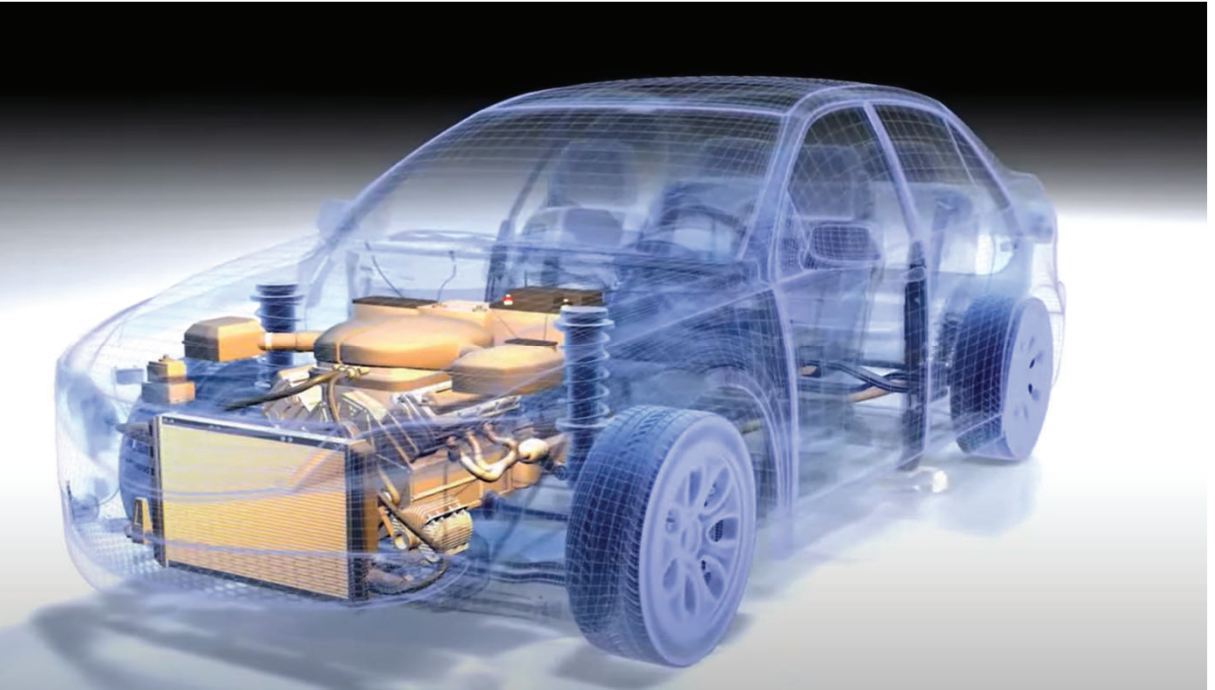
*Robert Bosch, LLC v. Westport Fuel Systems Canada Inc.,
Case No. 2:23-cv-00038-JRG-RSP (E.D. Tex.)*



Westport Fuel Systems Canada Inc.

The logo for Westport Fuel Systems is displayed on a blue background with a subtle, wavy texture. The word "Westport" is in a large, white, sans-serif font, with a small "TM" trademark symbol to its upper right. Below it, the words "Fuel Systems" are in a smaller, white, sans-serif font. A white circular icon, resembling a stylized flame or a fuel nozzle, is positioned to the left of the word "Fuel".

WestportTM
Fuel Systems



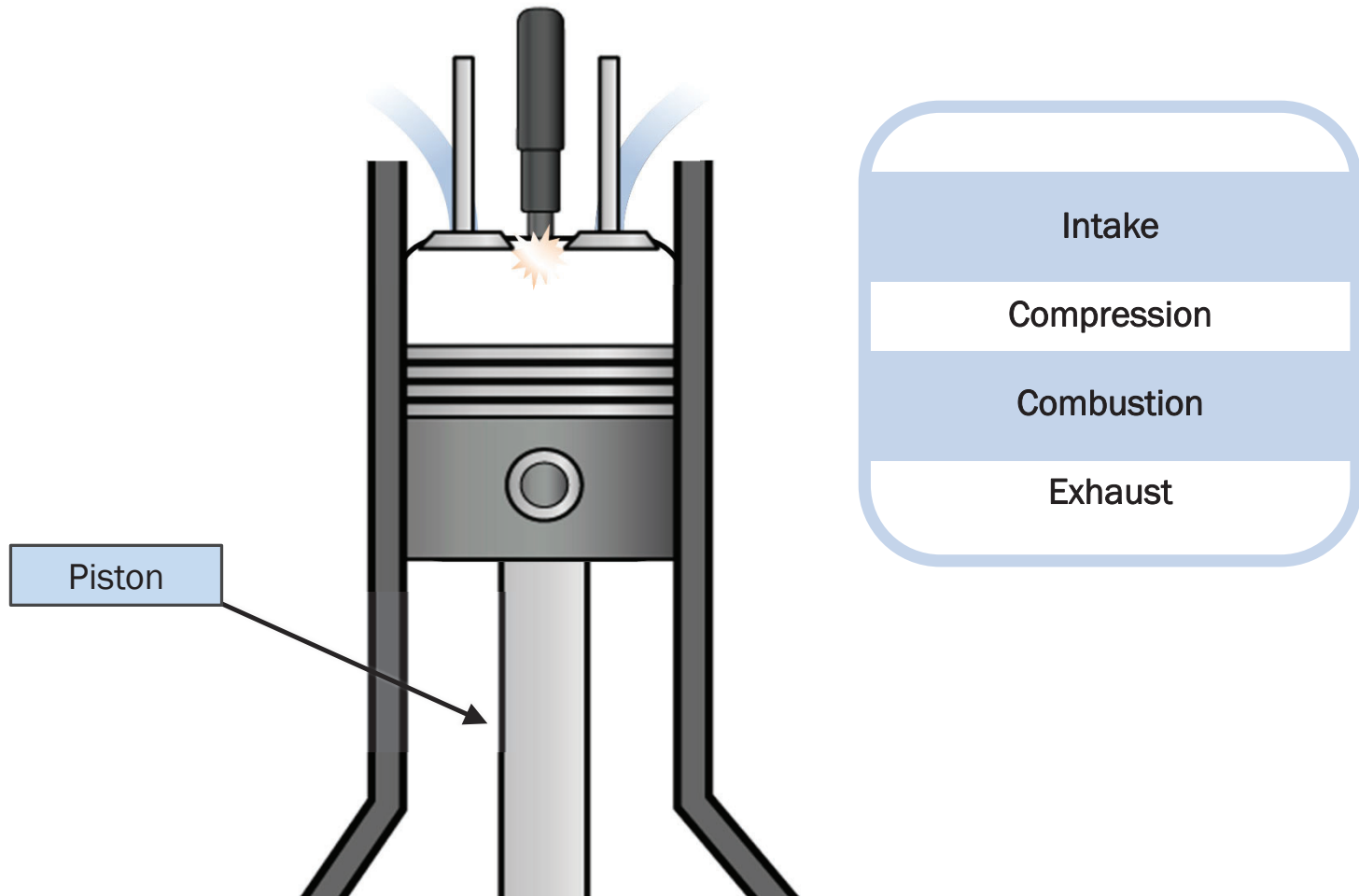
1. Overview of Combustion Engine Technology and Fuel Injectors

2. '829 Patent and '138 Patent

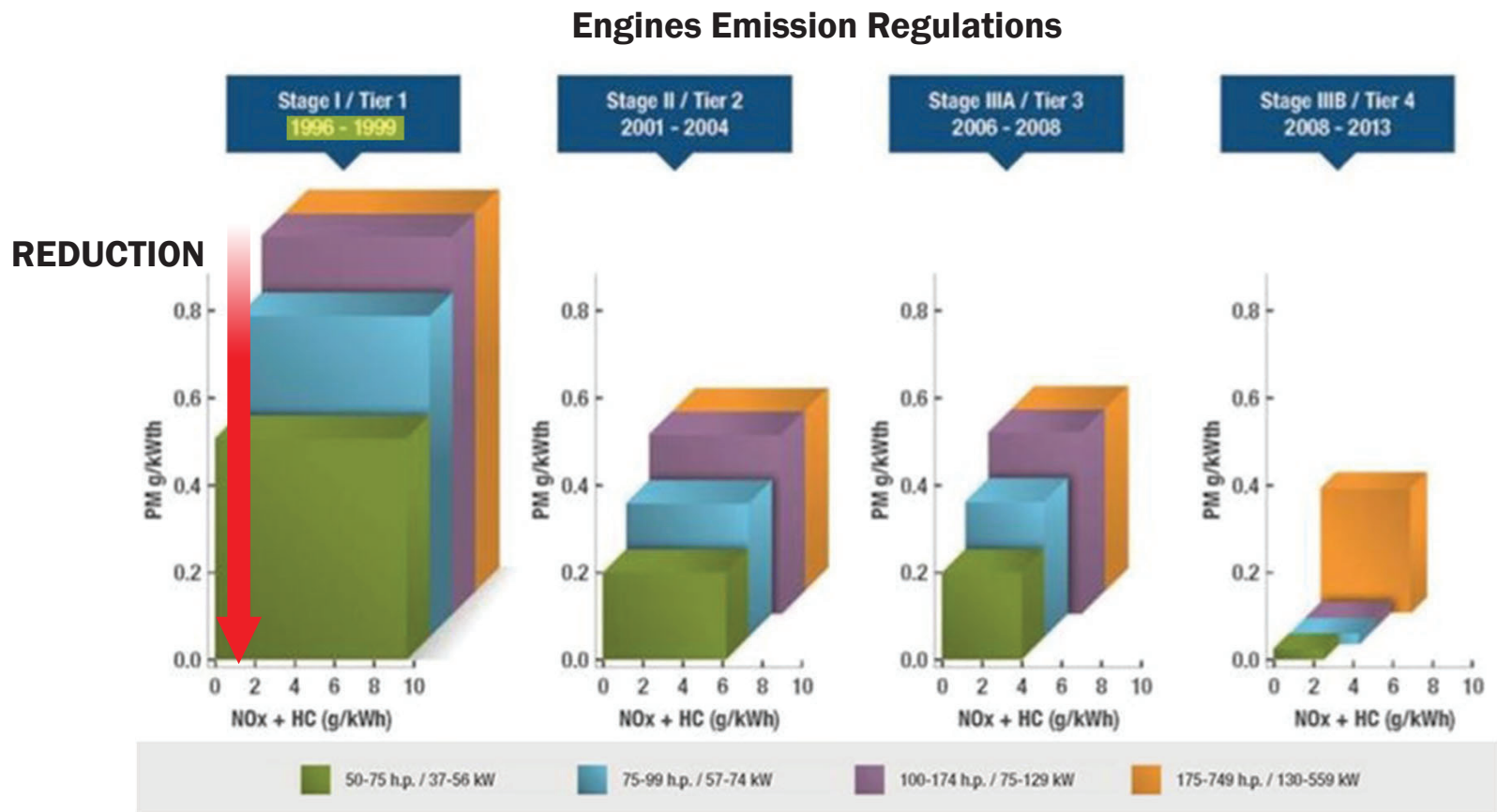
Combustion Engine Technology and Fuel Injectors



4-Cycle Operation of Combustion Engines

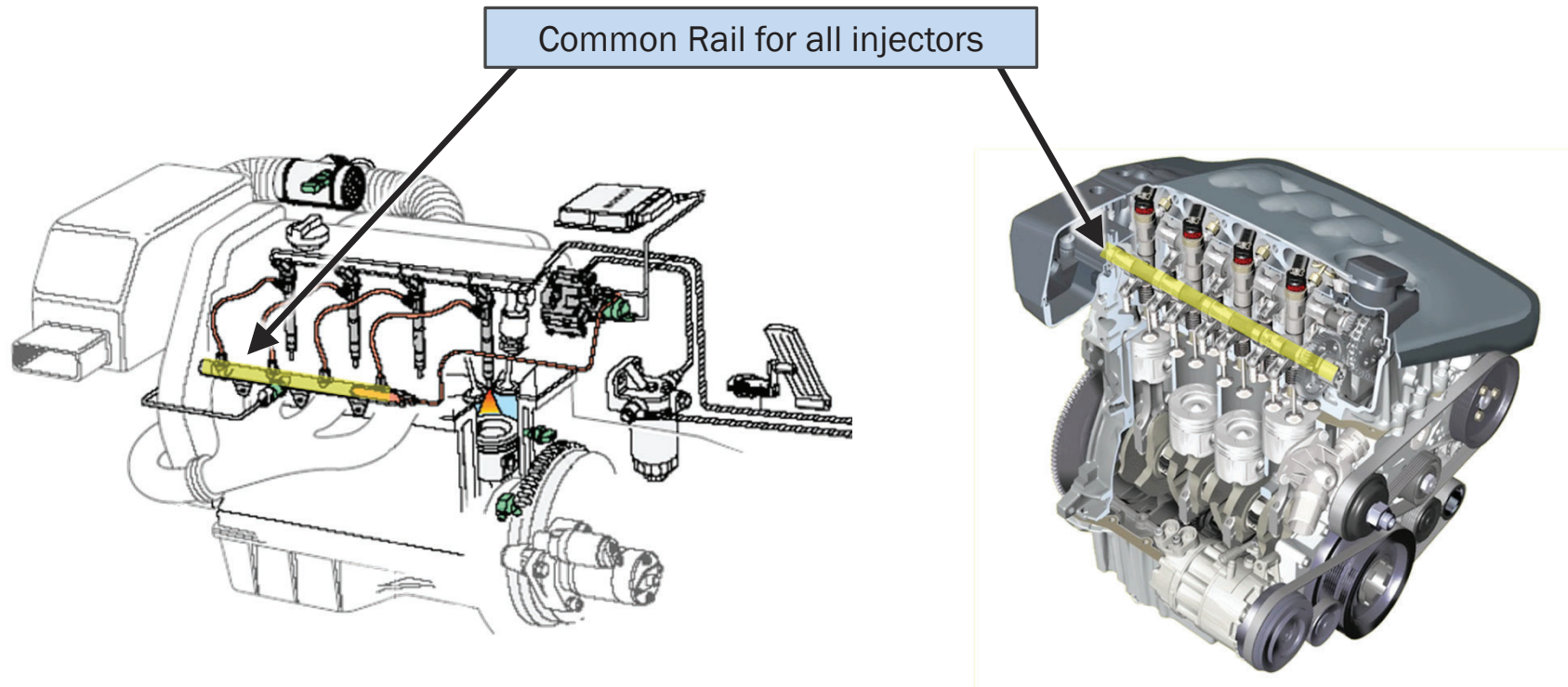


Modernization of Engine Technology Emission Standards

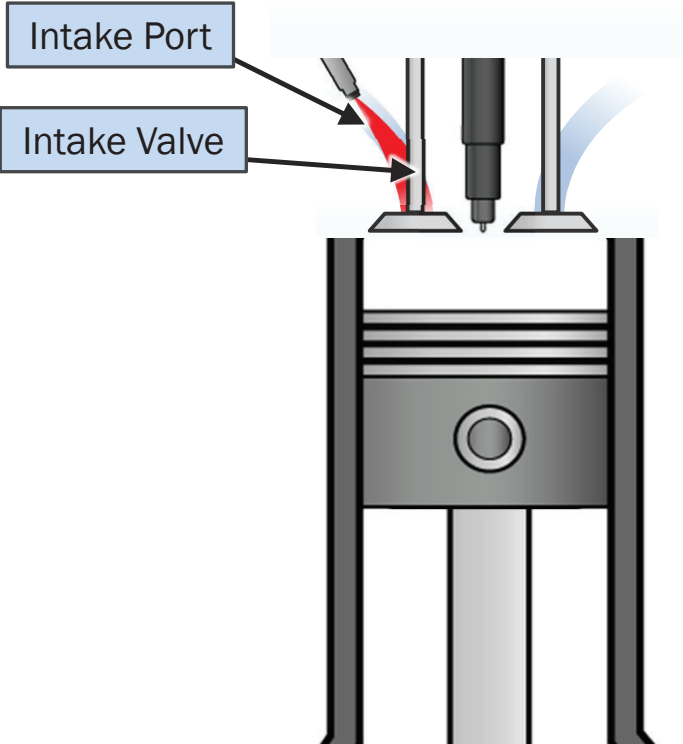


Davis, L. Impact of the stage V off-road emissions standard on agricultural ... <https://www.lube-media.com/wp-content/uploads/FINAL-Lubrizol-Lube-WEB-ONLY-Article-Mar20-Stage-Vd.pdf> (accessed Jan 4, 2023).

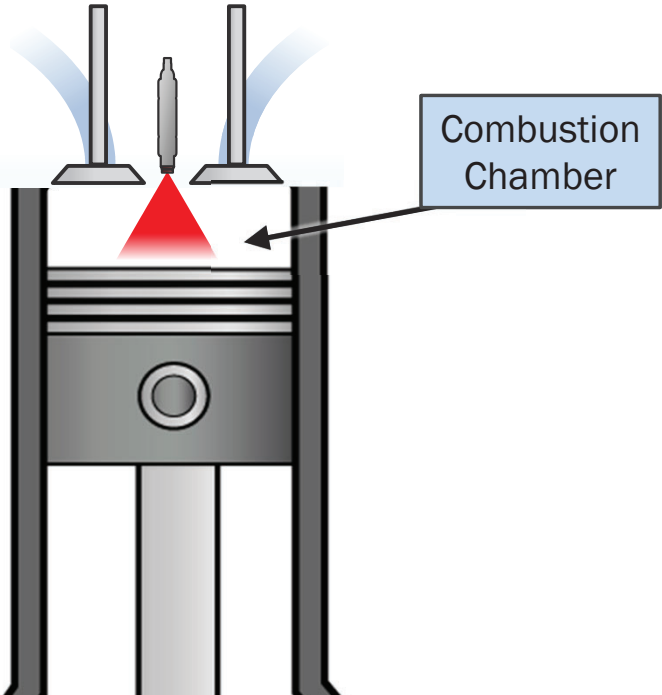
Common Rail Systems



Port Injection and Direct Injection

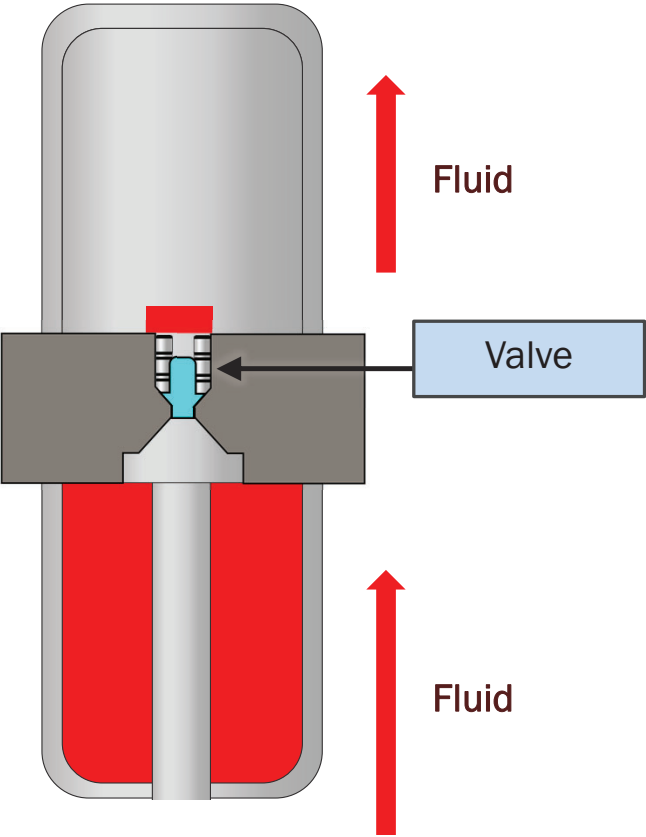


Port Injection: 40-75 psi



Direct Injection: 2000+ psi

Overview of Actuation for Fuel Injectors



Hydraulic Actuation

Nearly all prior direct fuel injection systems in internal combustion engines have been hydraulically-actuated.

These systems rely on a hydraulic fluid to provide the force that is needed to open an injection valve (or valves, when the engine comprises a plurality of combustion chambers). Accordingly, at typical engine operating speeds, hydraulically actuated injectors rely on rapid changes in the hydraulic fluid pressure to open and close the injection valve(s).

'829 Col. 1:56-63

Hydraulic Actuation

out of the active hydraulic operator. Active hydraulic actuators employ hydraulic fluid that is moved in and out of a hydraulic cylinder and when the hydraulic cylinder is fluidly connected to a source of high pressure hydraulic fluid, the high pressure hydraulic fluid that flows into the hydraulic cylinder generates the actuating force that is used to move the valve needle. The actuating force is removed when the hydraulic cylinder is disconnected from the source of high-pressure hydraulic fluid and the hydraulic fluid is drained from the hydraulic cylinder. A disadvantage of active hydraulic actuators of this type is that there is a lag time associated with moving the hydraulic fluid into and out of the hydraulic cylinder.

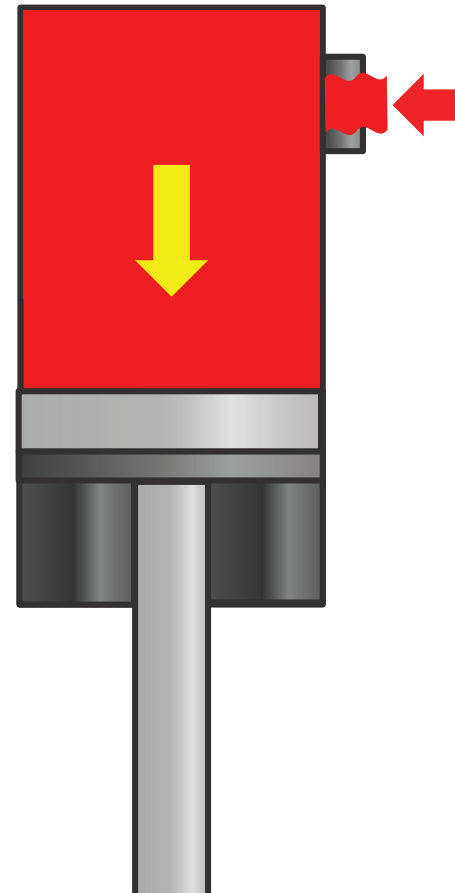
'829 Col. 7:30-42

Moreover, the degree of controllability of the movement of the injection valve is low when the motive force is provided by a pressurized fluid rather than by a directly controllable source.

'829 Col. 2:14-16

Additionally, there is only a small window of time during which the fuel can be injected. For example, at 4500 revolutions per minute (RPM), at full load, all of the fuel is preferably injected in less than 2-3 milliseconds.

'829 Col. 1:52-55



Hydraulic Forces Do Not Necessarily Provide Hydraulic Actuation

- (c) a needle spring associated with the valve needle, wherein the needle spring applies a closing force to the valve needle for biasing the valve needle in the closed position;
- (d) an actuator assembly associated with the valve needle, wherein the actuator assembly may be activated to apply an opening force to the valve needle stronger than the closing force, for moving the valve needle to the open position; and

'829 Col. 7:30-42

Nozzle Technology

Valve housing 102 may further comprise features for influencing how the fuel is introduced into the combustion chamber. For example, FIG. 2a shows an embodiment of valve housing 102 that comprises nozzle tip 202 below where valve member 114 seats against valve seat 112. Nozzle tip 202 provides a chamber that is connected to the combustion chamber by nozzle ports or orifices 203. In this embodiment the chamber and orifices 203 may be advantageously sized to slow down the fuel injection velocity to improve ignitability.

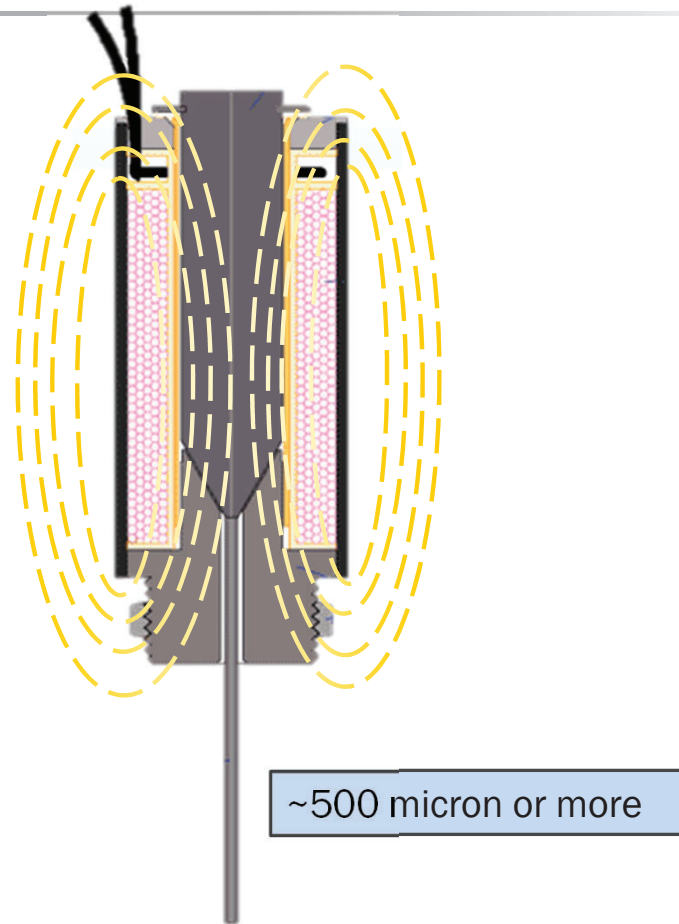
'138 Pat. at Col. 9:40-44



Solenoid Actuator

Thus solenoid actuators are not suitable for applications that require a combination of fast response times and high actuating forces, such as, for example, injectors used for high-pressure fuels. Solenoids also do not effectively deliver small amounts of fuel, such as the amount needed at low loads, and particularly at high-speed. For higher speed engines (for example, engines running at 3000 RPM and higher), the minimum opening time of the needle tends to be too long for delivering only a small amount of fuel. The shortest known opening time for solenoid actuated injection valves is about 700 microseconds. Additionally, while solenoid actuators are capable of substantial lift, of the order of 20-thousandths of an inch (500 micron) or more, they do not permit control of the lift. Conventional solenoid technology is only known to be able to offer duration control (how long the valve is open for) and not position control (how much the valve is lifted).

'829 Col. 2:54-58



Piezoelectric Actuator

When the actuator assembly employs a piezoelectric stack, the control pulse is a modulated voltage applied to the piezoelectric stack.

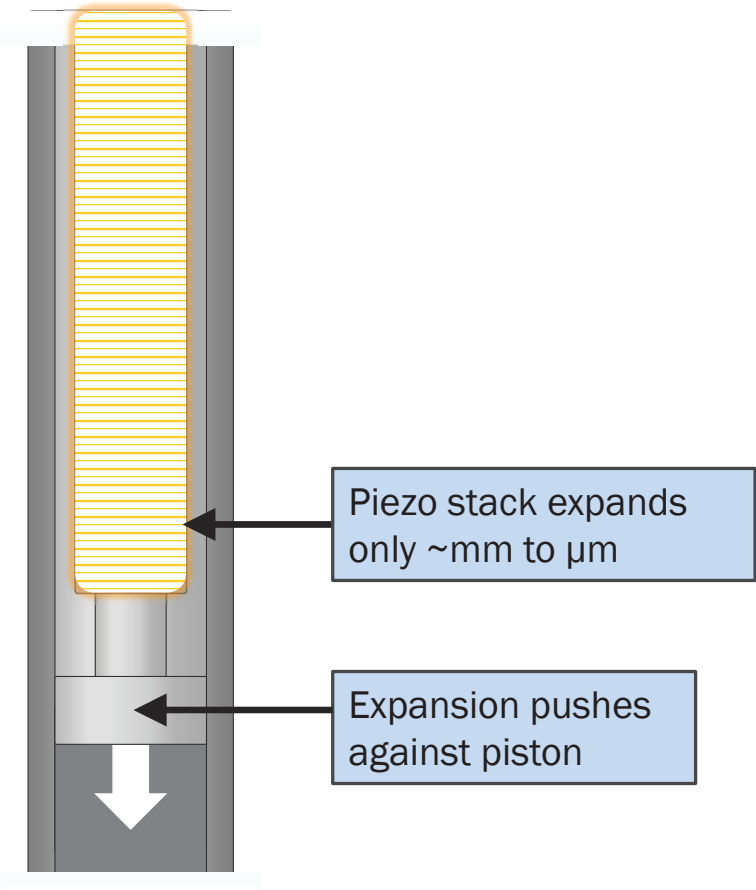
'829 Col. 6:59-61

In a preferred embodiment, the valve needle, actuated by a magnetostrictive or piezoelectric actuator assembly is controllable to move between the closed and open positions in less than about 250 microseconds.

'829 Col. 5:11-14

The amount of lift may be controlled by shaping the control pulse to control the amount of electrical current or voltage directed to the respective magnetostrictive or piezoelectric actuator assembly.

'829 Col. 8:7-11



Westport's Patented Solution



Problems Addressed

Direct injection at high pressures presents several challenges. The use of high pressure fuels for direct injection results in high fuel pressures existing within the injection valve or injector. As a result, the injection valve must typically be strongly seated to avoid leakage of the fuel into the combustion chamber between injection events. The valve is “seated” when the valve is closed, for example, in a needle valve, when the sealing surfaces of the valve needle and the valve seat are in fluid-tight contact with each other. Moreover, compared to low-pressure systems, higher forces are needed to open the injection valve. For example, for a needle valve that employs an inwardly opening valve needle, when the needle is in the open position it may be subjected to high forces from the pressurized fuel. Additionally, there is only a small window of time during which the fuel can be injected. For example, at 4500 revolutions per minute (RPM), at full load, all of the fuel is preferably injected in less than 2–3 milliseconds.

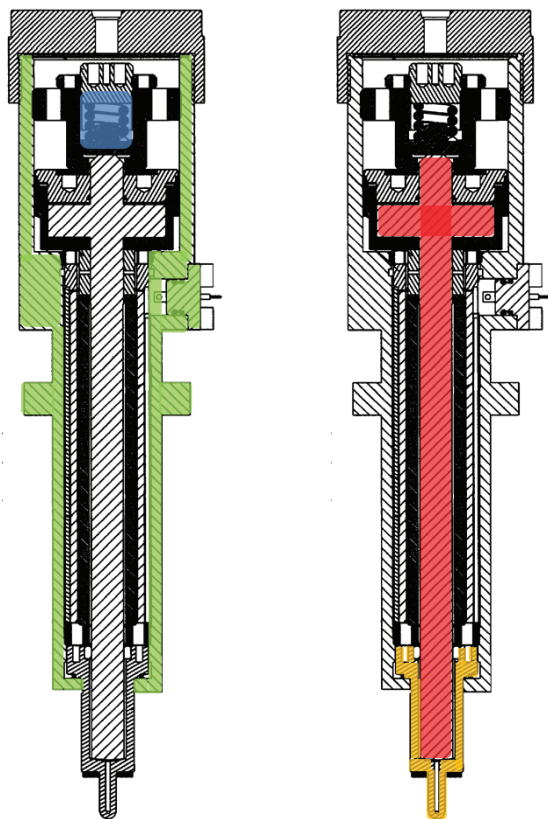
'829 Col. 1:38-55

Conventional solenoid technology is only known to be able to offer duration control (how long the valve is open for) and not position control (how much the valve is lifted).

'829 Col. 2:59-61

- Greater forces to open and close the valve
- Greater impact forces
- High speed injection
- Duration control and position control

Problems Addressed



Differential thermal expansion or contraction may be caused by differences in thermal expansion coefficients or uneven heat distribution between the components.

'829 Col. 11:58-60

ensure the desired valve needle lift is achieved. The effects of thermal expansion and contraction may be amplified if the injection valve is exposed to a wide range of temperatures. For injection valves used in vehicles it would not be uncommon to expect a temperature range between -40°C . (in cold climates) and $+125^{\circ}\text{C}$. (when the engine is running). An uneven temperature distribution may be the result of many factors, including, for example, the influence of (1) heat generated at coils 132; (2) magnetic hysteresis in the actuator assembly; and (3) heat transfer from the cylinder head or the combustion chamber via valve tip 106. If unaccounted for, the total effect of differential thermal expansion or contraction on the displacement of valve needle 114 may be greater than the targeted lift.

'829 Col. 12:1-14

Directly Actuated Injection Valve



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Westport's patented solution



The present invention relates generally to high pressure fuel injection valves or injectors for internal combustion engines, and, more specifically, to an injection valve that is directly controllable by a position activating material (such as, for example, a piezoelectric or magnetostrictive material) and which includes a passive hydraulic link.

'829 Col. 1:12-17

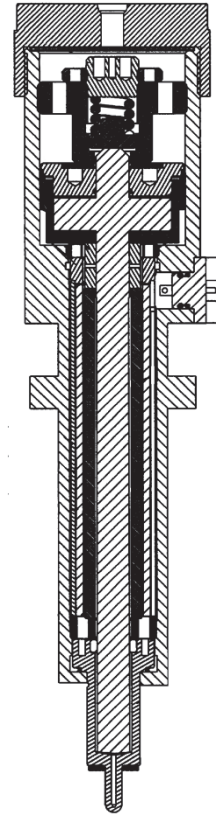
Focus of the Tutorial

- High pressure fuel injection valves or injectors
- Combustion engines
- Directly controllable actuator
- Passive hydraulic link

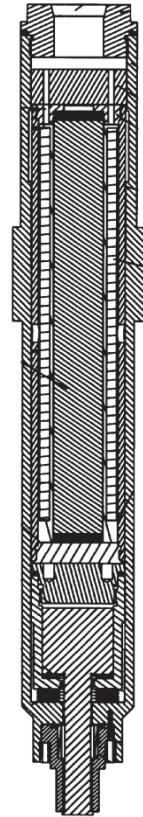
The '829 and '138 Patents

Focus of the Tutorial

- The injection valve
- The nozzle of the injection valve
- The valve needle
- The valve lift and
- The passive hydraulic link



'829 Fig.1



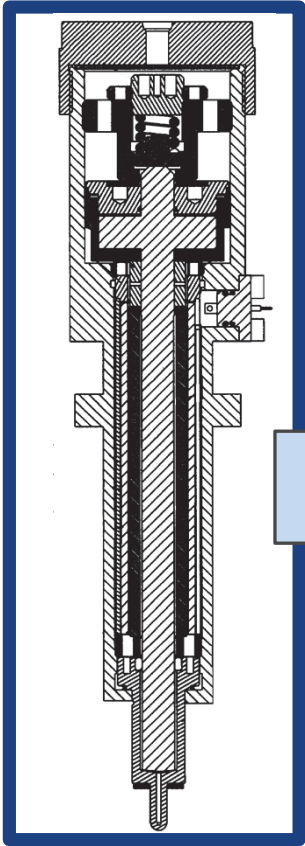
'138 Fig.3

The '829 and '138 Patents: Exemplary Illustrations

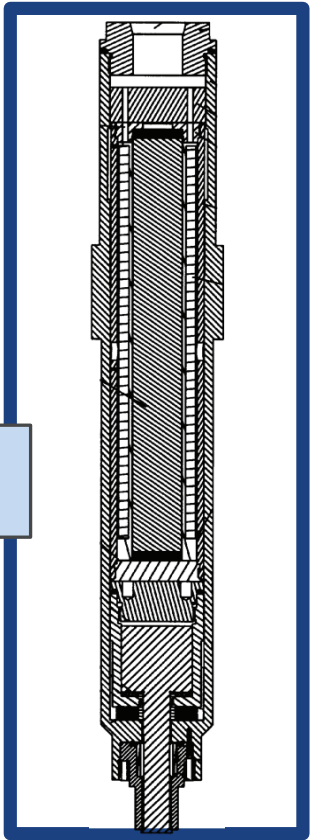
Claim 1 of the '829 Patent	Claim 1 of the '138 Patent
An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:	An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:
(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; a nozzle comprising a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;	(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; and a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;
(b) a valve needle disposed within said valve housing wherein said valve	(b) said valve member having one end disposed within said valve

The present invention relates generally to high pressure fuel injection valves or injectors for internal combustion engines, and, more specifically, to an injection valve that is directly controllable by a position activating material (such as, for example, a piezoelectric or magnetostrictive material) and which includes a passive hydraulic link.

(c) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is activated and wherein said thickness of said hydraulic link is adjustable while said actuator is not activated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift upon activation of said actuator assembly.	(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.
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'829 Fig.1

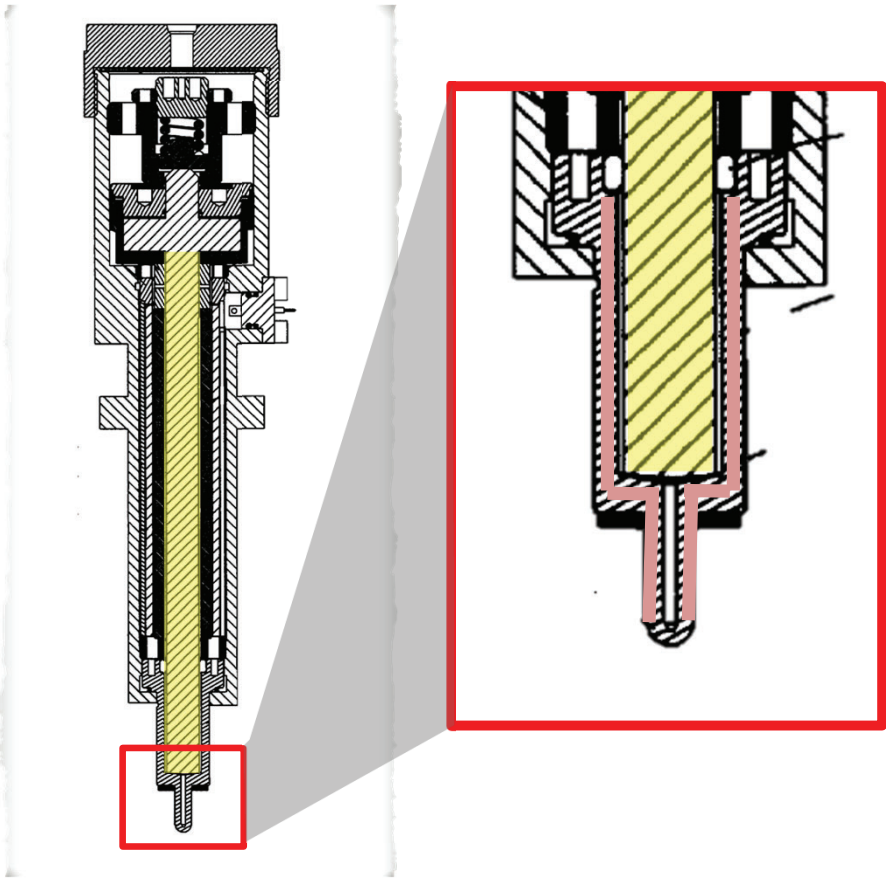


'138 Fig.3

Injection Valve

The '829 and '138 Patents: Exemplary Illustrations

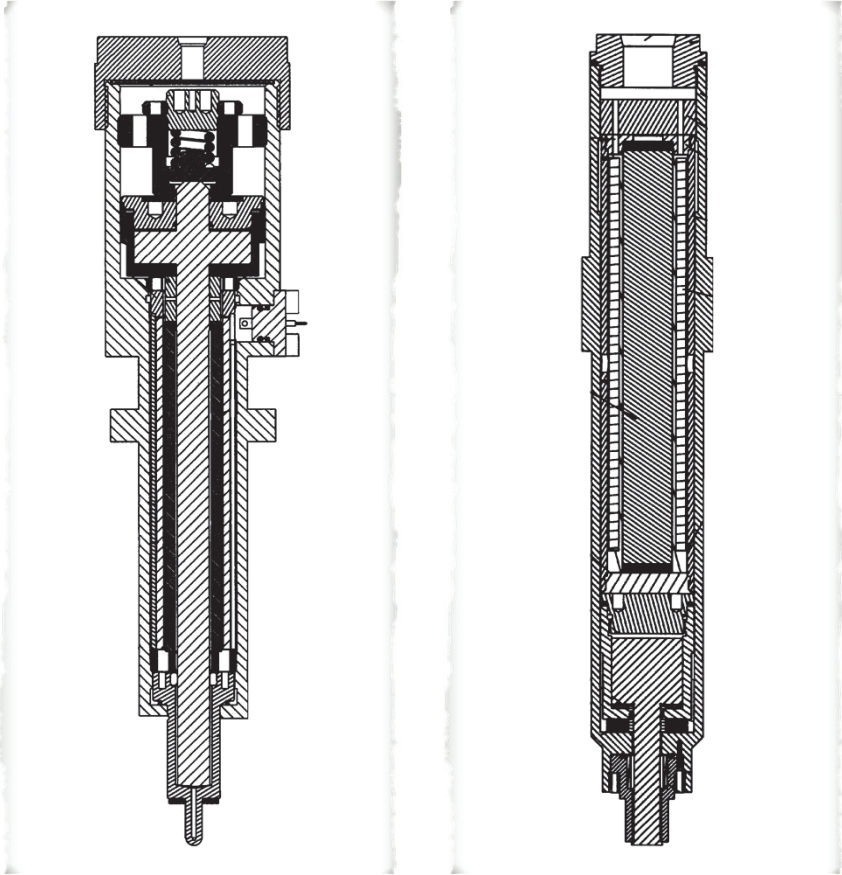
Claim 1 of the '829 Patent	Claim 1 of the '138 Patent
An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:	An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:
(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; a nozzle comprising a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;	(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; and a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;
(b) a valve needle disposed within said valve housing wherein said valve needle is movable between a closed position at which a sealing end of said valve needle contacts a valve seat to fluidly seal said interior chamber from said nozzle orifice, and an open position at which said sealing end of said valve needle is spaced apart from said valve seat whereby said interior chamber is fluidly connected with said nozzle orifice, wherein valve needle lift equals the distance traveled by said sealing end away from said valve seat;	(b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;
(c) a needle spring associated with said valve needle, wherein said needle spring applies a closing force to said valve needle for biasing said valve needle in said closed position;	(c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;
(d) an actuator assembly associated with said valve needle, wherein said actuator assembly may be activated to apply an opening force to said valve needle stronger than said closing force, for moving said valve needle to said open position; and	(d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position; and
(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is activated and wherein said thickness of said hydraulic link is adjustable while said actuator is not activated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift upon activation of said actuator assembly.	(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.



'829 Fig.1

The '829 and '138 Patents: Exemplary Illustrations

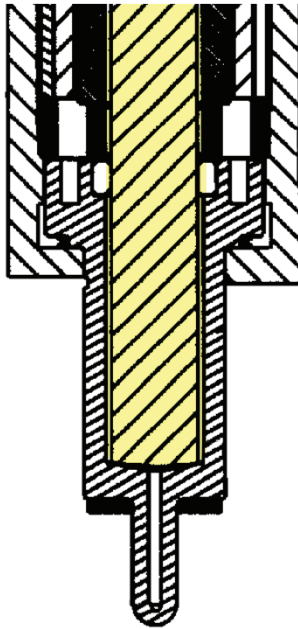
Claim 1 of the '829 Patent	Claim 1 of the '138 Patent
An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:	An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:
(a) a valve housing comprising:	(a) a valve housing comprising:
a fuel inlet port;	a fuel inlet port;
an interior chamber fluidly connected to said fuel inlet port;	an interior chamber fluidly connected to said fuel inlet port; and
a nozzle comprising a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;	a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;
(b) a valve needle disposed within said valve housing wherein said valve needle is movable between a closed position at which a sealing end of said valve needle contacts a valve seat to fluidly seal said interior chamber from said nozzle orifice, and an open position at which said sealing end of said valve needle is spaced apart from said valve seat whereby said interior chamber is fluidly connected with said nozzle orifice, wherein valve needle lift equals the distance traveled by said sealing end away from said valve seat;	(b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;
(c) a needle spring associated with said valve needle, wherein said needle spring applies a closing force to said valve needle for biasing said valve needle in said closed position;	(c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;
(d) an actuator assembly associated with said valve needle, wherein said actuator assembly may be activated to apply an opening force to said valve needle stronger than said closing force, for moving said valve needle to said open position; and	(d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position; and
(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is activated and wherein said thickness of said hydraulic link is adjustable while said actuator is not activated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift upon activation of said actuator assembly.	(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.



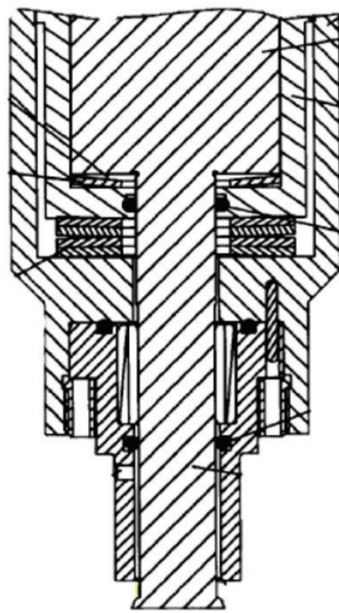
'829 Fig.1

'138 Fig.3

Exemplary Valve Needle (Valve Member) Embodiments



'829 Fig. 1



'138 Fig. 2

In the preferred embodiment illustrated by FIG. 1 valve member 114 further comprises an integral piston 114b. In another embodiment (not shown) a separate piston member may cooperate with valve member 114 to provide the same effect.

'138 Col. 10:8-11

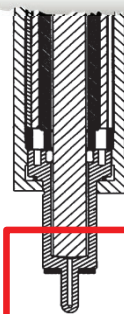
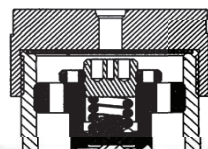
In the preferred embodiment illustrated by FIG. 1 valve needle 114 further comprises a separate piston member may cooperate with valve needle 114 to provide the same effect. In an alternative arrangement (not shown), a poppet-type valve tip may be used so that downward movement of the valve needle causes it to open. In this alternative arrangement, the actuator assembly is preferably positioned above valve needle 114 so that when the actuator is energized to open the injection valve, a downward force is applied to valve needle 114.

'829 Col. 9:4-14

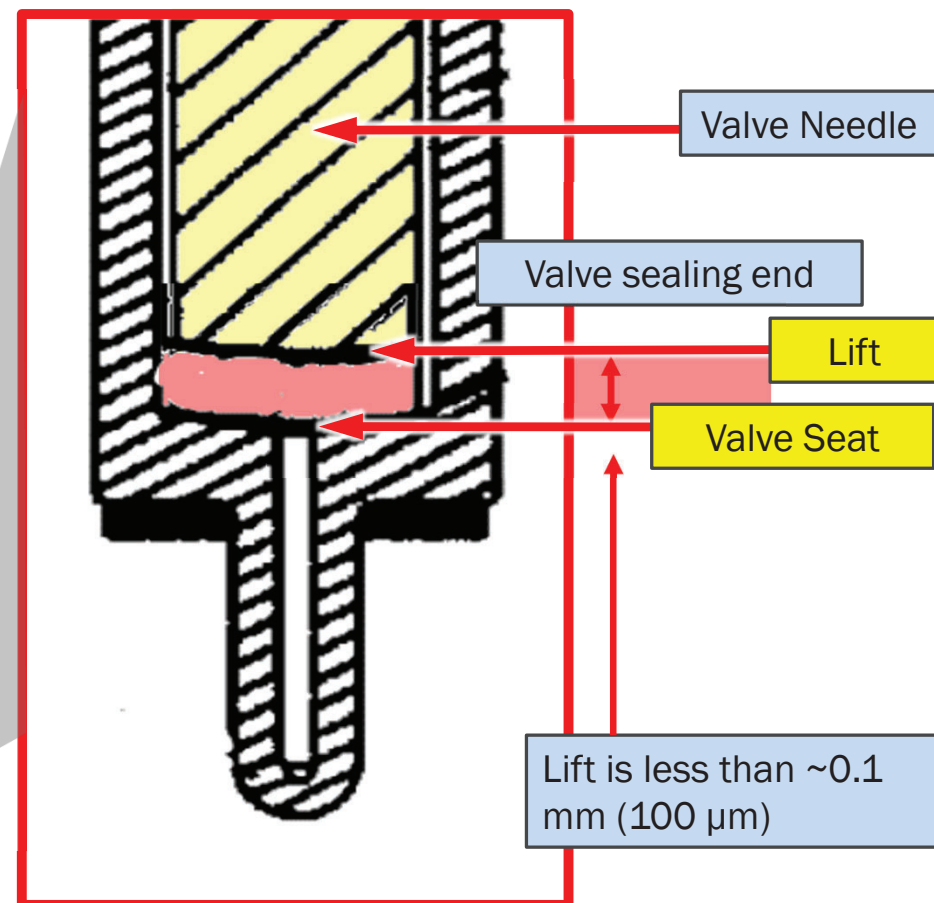
Valve lift: Annotated Figure 1 of the '829 Patent

Still another advantage of the disclosed injection valve is that the actual valve needle lift is very small (typically much less than 0.1 millimeter), so that compared to valves designed for greater valve needle lift, the valve needle velocity required to open the present injection valve is much less.

'829 Col. 8:12-17

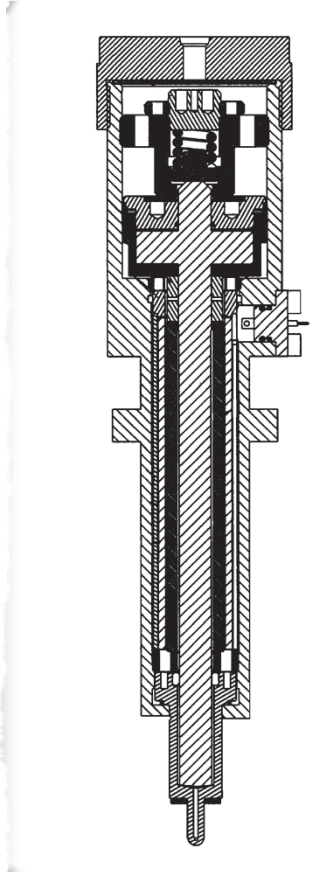


'829 Fig.1

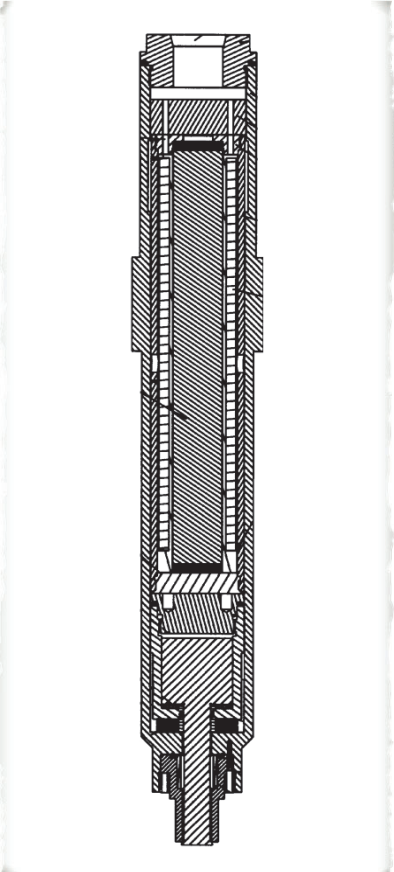


The '829 and '138 Patents: Exemplary Illustrations

Claim 1 of the '829 Patent	Claim 1 of the '138 Patent
An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:	An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:
(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; a nozzle comprising a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;	(a) a valve housing comprising: a fuel inlet port; an interior chamber fluidly connected to said fuel inlet port; and a valve seat for cooperating with a valve member to seal said interior chamber from said combustion chamber when said injection valve is closed;
(b) a valve needle disposed within said valve housing wherein said valve needle is movable between a closed position at which a sealing end of said valve needle contacts a valve seat to fluidly seal said interior chamber from said nozzle orifice, and an open position at which said sealing end of said valve needle is spaced apart from said valve seat whereby said interior chamber is fluidly connected with said nozzle orifice, wherein valve needle lift equals the distance traveled by said sealing end away from said valve seat;	(b) said valve member having one end disposed within said valve housing and an opposite end extendable from said valve seat toward said combustion chamber, wherein said valve member comprises a sealing surface that fluidly seals against said valve seat when said injection valve is closed and that is liftable away from said valve seat when said injection valve is open;
(c) a needle spring associated with said valve needle, wherein said needle spring applies a closing force to said valve needle for biasing said valve needle in said closed position;	(c) a biasing mechanism associated with said valve member, said biasing mechanism applying a closing force to said valve member when said valve member is in said closed position;
(d) an actuator assembly associated with said valve needle, wherein said actuator assembly may be activated to apply an opening force to said valve needle stronger than said closing force, for moving said valve needle to said open position; and	(d) an actuator assembly associated with said valve member, wherein said actuator assembly may be actuated to apply an opening force to said valve member stronger than said closing force, for moving said valve member to said open position; and
(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is activated and wherein said thickness of said hydraulic link is adjustable while said actuator is not activated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift upon activation of said actuator assembly.	(e) a hydraulic link assembly comprising a passive hydraulic link having a hydraulic fluid thickness through which said opening and closing forces are transmitted, whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is actuated and wherein said thickness of said hydraulic link is adjustable while said actuator assembly is not actuated in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve lift upon actuation of said actuator assembly.



'829 Fig.1

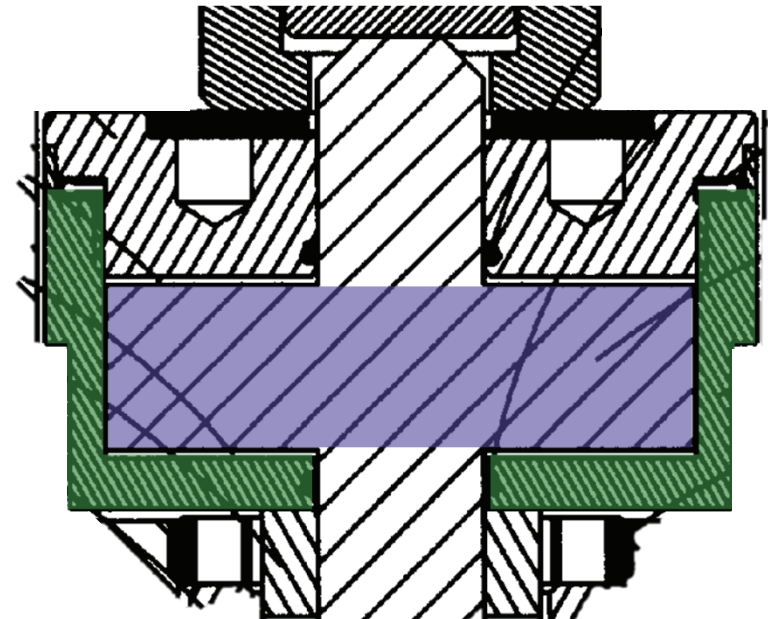
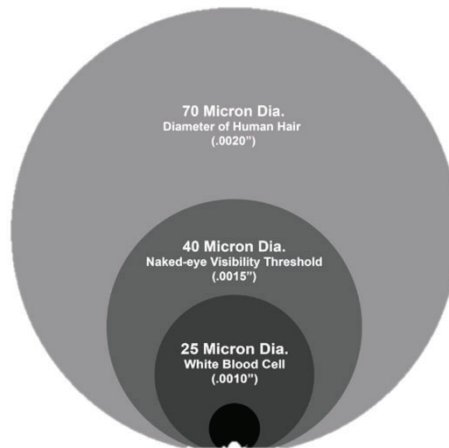


'138 Fig.3

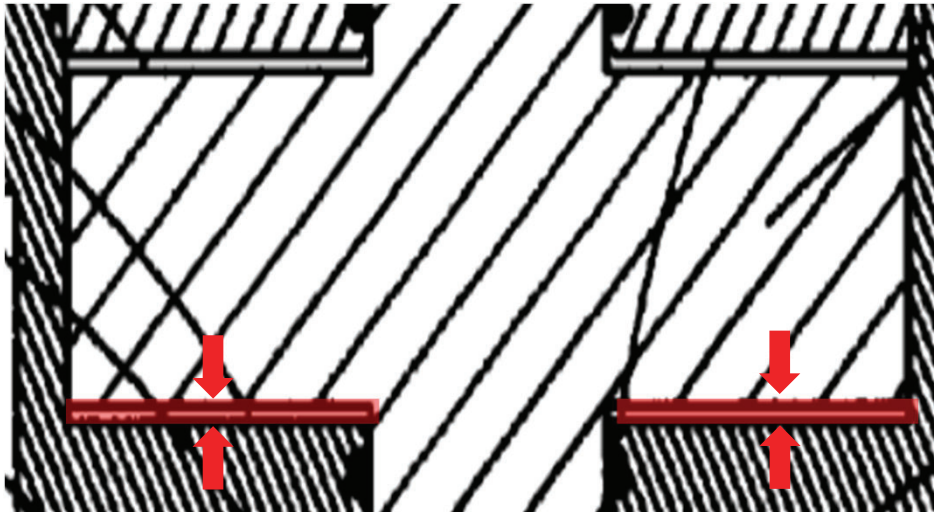
Micron Precision Components

The **diametrical clearance gap** between the outside diameter of hydraulic piston **114b** and the inside diameter of hydraulic cylinder **160** is extremely small (**on the order of 50 to 250 microns**).

'829 Col. 11:11-14



Hydraulic Fluid Thickness



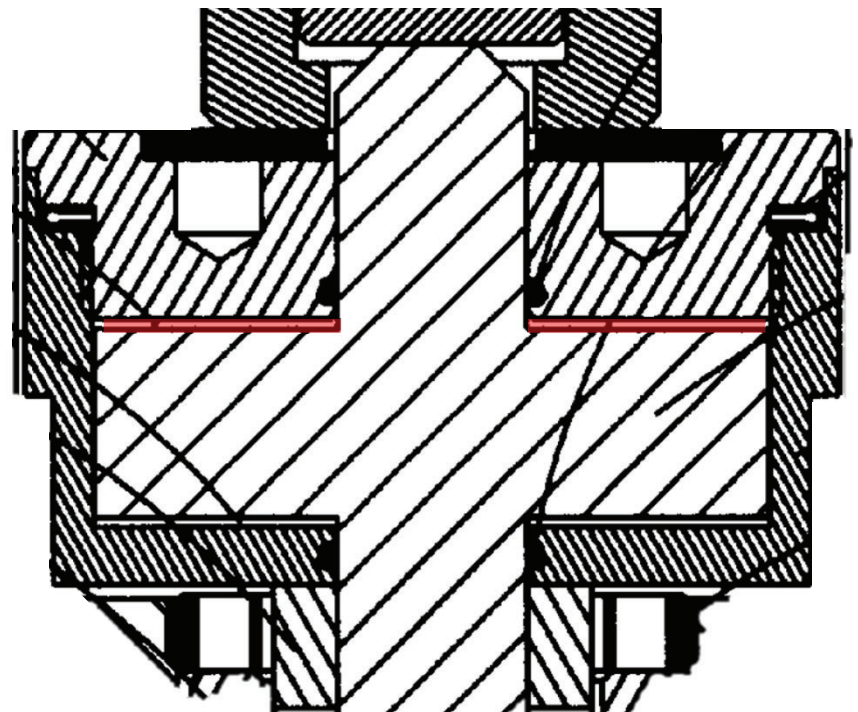
In the preferred embodiment, the thickness of the hydraulic fluid trapped between the piston and cylinder head or base is automatically adjustable in response to changes in the dimensional relationship between components of the injection valve to maintain a desired valve needle lift when the actuator assembly is activated.

'829 Abstract

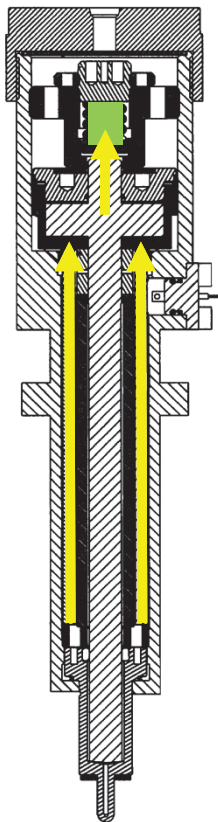
Passive Hydraulic Link

As previously discussed, because valve actuation occurs suddenly (on the order of $200\ \mu\text{s}$), hydraulic fluid **164b** does not have time to flow through the narrow clearance gap between piston **114b** and hydraulic cylinder **160**. Instead, hydraulic fluid **164b** acts as a solid and transfers the movement of magnetostrictive member **130** to valve needle **114** via piston **114b**, causing valve needle **114** to lift away from valve seat **112**. Because injection valve **100** stays open for such a brief period (typically less than 3 milliseconds), as long as the viscosity of hydraulic fluid **164** is properly selected and the clearance gap is suitably sized, the flow of hydraulic fluid **164** through the clearance gap while injection valve **100** is open is insignificant so that any displacement caused by such flow is much less than the total displacement of valve needle **114**.

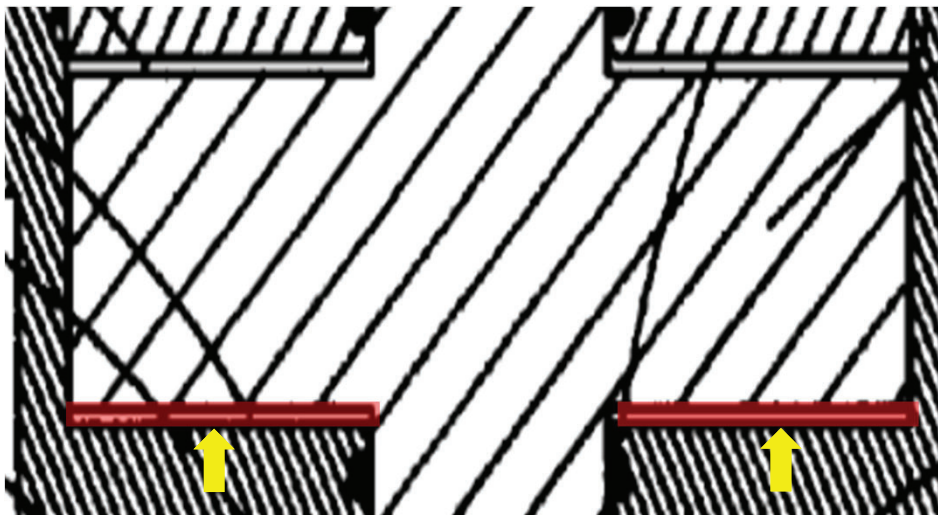
'829 Col. 12:57-13:4



Passive Hydraulic Link: Transfers Actuation Forces



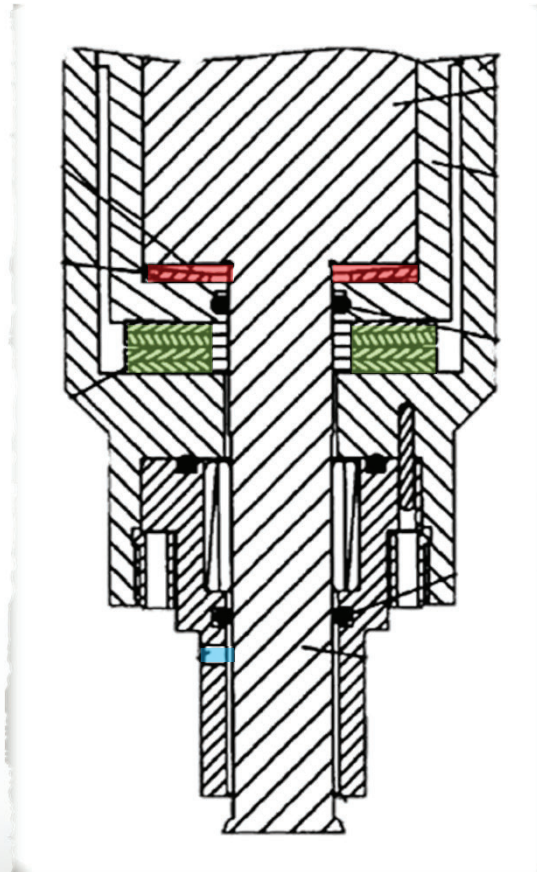
'829 Fig.1



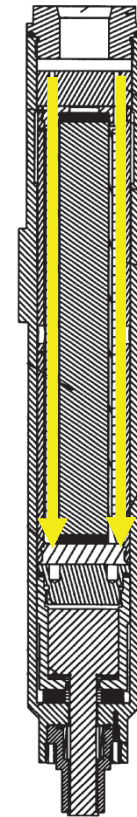
Rather, the purpose of the hydraulic link is to provide a load path for the opposing actuating forces that originate from at least one spring member and the actuator assembly.

'829 Col. 7:20-22

Another Example of Passive Hydraulic Link



'138 Fig. 2



'138 Fig.3

Benefits of the Passive Hydraulic Link

When injection valve **100** is closed and at rest, the closing force is transmitted through the hydraulic fluid held between cylinder cap **162** and hydraulic piston **114b**. Typically, during engine operation, injection valve **100** is closed most of the time (normally over 90% of the time). Accordingly, there is enough time between injection events for the hydraulic fluid to redistribute itself by flowing through the clearance gap so that hydraulic cylinder **160** moves relative to piston **114b** to automatically “re-zero” itself. The initial zero-position is the position of hydraulic piston **114b** within hydraulic cylinder **160** after assembly of injection valve **100**. The initial zero position may not be the same for all injectors due to variation in the length of components within manufacturing tolerances. Also, during operation, the zero-position auto-adjusts to change depending, for example, upon component wear or upon the effects of thermal expansion on the dimensional relationship between components.

'829 Col. 11:41-57

A further advantage of the passive hydraulic link is that it may be employed to correct for differential thermal expansion, wear and dimensional variability within permitted manufacturing and assembly tolerances. The disclosed passive hydraulic link accomplishes this by auto-adjusting itself in response to these effects by allowing movement of hydraulic fluid between opposite sides of the hydraulic piston. The actuator assembly thus re-zeroes itself to ensure that the desired valve needle lift is maintained.

'829 Col. 7:43-51

Thank you.