

FILE HISTORY
US 6,298,829

PATENT: 6,298,829
INVENTORS: WELCH ALAN B
RAHARDJA IRAWAN
HEBBES MIKE

TITLE: Directly actuated injection valve

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FILED: 09 MAR 2000
ISSUED: 09 OCT 2001

COMPILED: 13 JAN 2022

123	467
Class	Subclass

ISSUE CLASSIFICATION

PATENT NUMBER

6298829



6298829

U.S. **UTILITY** Patent Application

SS O.I.P.E. PATENT DATE
SCANNED Q.A. OCT 09 2011

APPLICATION NO. 09/522130	CONT/PRIOR D	CLASS 123	SUBCLASS 3747	ART UNIT 3747	EXAMINER
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APPLICANTS

Alan Welch
Irawan Rahardja
Mike Hebbes

Directly actuated injection valve

TITLE

CONFIDENTIAL

Aug 6 2002

CONFIDENTIAL

PTO-2040
12/99

ISSUING CLASSIFICATION									
ORIGINAL		CROSS REFERENCE(S)							
CLASS	SUBCLASS	CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)						
123	467	123	472						
INTERNATIONAL CLASSIFICATION									
FO2M	4100								

☐ Continued on Issue Slip Inside File Jacket

9-6-01 Formal Drawings (5 shts) set / 3 9 00

☐ TERMINAL DISCLAIMER	DRAWINGS			CLAIMS ALLOWED	
	Sheets Drwg. 5	Figs. Drwg. 5	Print Fig. 1,2	Total Claims 32	Print Claim for O.G. 1
☐ The term of this patent subsequent to _____ (date) has been disclaimed.	MAHMOUD GEMIE 8/6/01 (Assistant Examiner) (Date)			NOTICE OF ALLOWANCE MAILED	
	Henry C. Yuan 8/6/01 Supervisory Patent Examiner Group 3700 (Primary Examiner) (Date)			8/7/01	
ISSUE FEE					
☐ The term of this patent shall not extend beyond the expiration date of U.S. Patent. No. _____				Amount Due 1240.00	Date Paid 8-23-01
☐ The terminal _____ months of this patent have been disclaimed.	J.E. 8-8-01 (Legal Instruments Examiner) (Date)			ISSUE BATCH NUMBER K21	
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ISSUE FEE IN FILE

Formal Drawings (FACE) 30

Petitioner Ex. 1002, p. 2
Robert Bosch et al v. Westport
IPR2023-00292

6,298,829

Directly actuated injection valve

Transaction History

Date	Transaction Description
03-09-2000	Workflow - Drawings Finished
03-09-2000	Workflow - Drawings Matched with File at Contractor
03-09-2000	Workflow - Drawings Received at Contractor
03-09-2000	Initial Exam Team nn
05-17-2000	Notice Mailed--Application Incomplete--Filing Date Assigned
05-17-2000	Correspondence Address Change
06-26-2000	Application Dispatched from OIPE
06-26-2000	Application Is Now Complete
07-19-2000	Information Disclosure Statement (IDS) Filed
07-19-2000	Information Disclosure Statement (IDS) Filed
08-04-2000	Case Docketed to Examiner in GAU
03-14-2001	Information Disclosure Statement (IDS) Filed
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03-20-2001	Non-Final Rejection
03-21-2001	Mail Non-Final Rejection
06-22-2001	Information Disclosure Statement (IDS) Filed
06-22-2001	Information Disclosure Statement (IDS) Filed
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06-27-2001	Date Forwarded to Examiner
08-07-2001	Mail Notice of Allowance
08-07-2001	Notice of Allowance Data Verification Completed
08-09-2001	Workflow - File Sent to Contractor
08-23-2001	Issue Fee Payment Verified
09-06-2001	Workflow - Complete WF Records for Drawings
09-11-2001	Application Is Considered Ready for Issue
09-21-2001	Issue Notification Mailed
10-09-2001	Recordation of Patent Grant Mailed
10-09-2001	Patent Issue Date Used in PTA Calculation
07-22-2002	Post Issue Communication - Certificate of Correction
03-26-2003	Correspondence Address Change
07-23-2012	Correspondence Address Change
07-24-2012	Change in Power of Attorney (May Include Associate POA)
01-27-2015	Correspondence Address Change
03-31-2017	Correspondence Address Change

PATENT APPLICATION



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03/09/00

INITIALS

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CONTENTS

	Date Received (Incl. C. of M.) or Date Mailed	Date Received (Incl. C. of M.) or Date Mailed
1. Application <u>5</u> papers.	8-9-00	42.
2. <u>PRELIM</u>	5-17-00	43.
3. <u>Response</u>	6-19-00	44.
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7. <u>Amended</u>	6-22-01	48.
8. <u>Suppl. IDS</u>	6-22-01	49.
9. <u>Notice of Allowability</u>	8/7/01	50.
10. <u>GfG</u> 1,322	1-30-02	51.
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ISSUE SLIP STAPLE AREA (for additional cross references)

POSITION	INITIALS	ID NO.	DATE
FEE DETERMINATION	BA	70385	
O.I.P.E. CLASSIFIER		12	3/23
FORMALITY REVIEW	SH	60215	5-17-00
RESPONSE FORMALITY REVIEW	SH	60245	6-26-00

INDEX OF CLAIMS

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= Allowed I Interference
- (Through numeral)... Canceled A Appeal
÷ Restricted O Objected

Claim		Date	
Final	Original		
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SEARCHED

Class	Sub.	Date	Exmr.
123	498	3/20/01	u
123	497		
123	467		
123	472		
123	478		
251	129.06		
239	533.2		
239	533.9		
293	102.2	3/20/01	u
updated		8/6/01	u

SEARCH NOTES
(INCLUDING SEARCH STRATEGY)

	Date	Exmr.
See BRS sheet	3/20/01	u

INTERFERENCE SEARCHED

Class	Sub.	Date	Exmr.
123	498	8/6/01	u
	497		
	467		
	472		
123	478		
251	129.06		
239	533.2		
239	533.9		
239	102.2	8/6/01	u

	Type	L #	Hits	Search Text	DBs	Time Stamp
1	BRS	L1	280	fuel and (injection or injector) and (direct or directly) and (actuation or actuated) and (piezoelectric or magnetostrictive)	USPAT	2001/03/20 08:11
2	BRS	L2	283	fuel and (injection or injector) and (direct or directly) and (actuation or actuated) and (piezoelectric or magnetostrictive)	USPAT; US-PGP UB; ERO; JPO; DERWEN T; IBM TDB	2001/03/20 08:11
3	BRS	L3	60	2 and (hydraulic or fluid)with cylinder	USPAT; US-PGP UB; EPO; JPO; DERWEN T; IBM TDB	2001/03/20 08:12

03/20/2001, EAST Version: 1.02.0008



US006298829B1

(12) **United States Patent**
Welch et al.

(10) **Patent No.:** **US 6,298,829 B1**
(45) **Date of Patent:** **Oct. 9, 2001**

(54) **DIRECTLY ACTUATED INJECTION VALVE**

(75) Inventors: **Alan B. Welch; Irawan Rahardja;**
Mike Hebbes, all of Vancouver (CA)

(73) Assignee: **Westport Research Inc.**, Vancouver (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/522,130**

(22) Filed: **Mar. 9, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/159,791, filed on Oct. 15, 1999.

(51) **Int. Cl.⁷** **F02M 41/00**

(52) **U.S. Cl.** **123/467; 123/472**

(58) **Field of Search** 123/498, 497,
123/467, 472, 478; 251/129.06; 239/533.2,
533.9; 293/102.2

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5,845,852		12/1998	Waldman et al.	239/533.8
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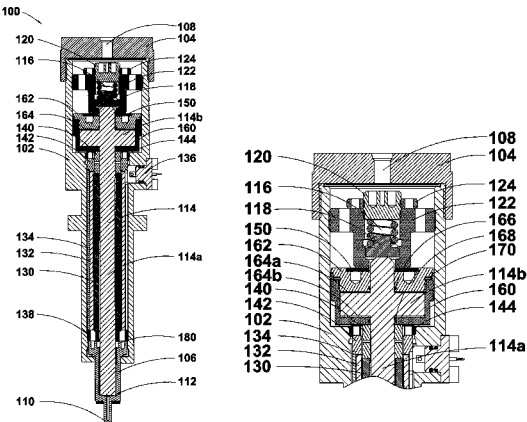
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Primary Examiner—Henry C. Yuen
Assistant Examiner—Mahmoud Gimie
(74) *Attorney, Agent, or Firm*—McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A directly actuated injection valve comprises a hollow valve housing, a valve needle disposed within the hollow interior, a needle spring, an actuator assembly, and a hydraulic link assembly. The valve needle is movable between a closed position and an open position for governing the flow of fuel into the combustion chamber of an internal combustion engine. The displacement of the valve needle from the closed position is defined as the lift. The a needle spring biases the valve needle in the closed position. The actuator assembly generates an opening force that acts against the needle spring to open the valve. The hydraulic link assembly is interposed between the valve needle and the needle spring and the actuator assembly. The hydraulic link assembly transmits respective closing and opening forces to the valve needle. The hydraulic link preferably comprises a piston disposed within a cylinder that is filled with a hydraulic fluid. The opening and closing forces are transmitted through a thickness of the hydraulic fluid that is trapped between the planar surfaces of the piston and the head and base of the hydraulic cylinder. 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. When the actuator assembly comprises a magnetostrictive or piezoelectric member, the movements of the valve needle can be controlled by the application of a shaped control pulse or waveform to improve the speed of the opening and closing motion of the valve needle, and to reduce the impact of the valve needle on the valve seat upon closing.

32 Claims, 5 Drawing Sheets



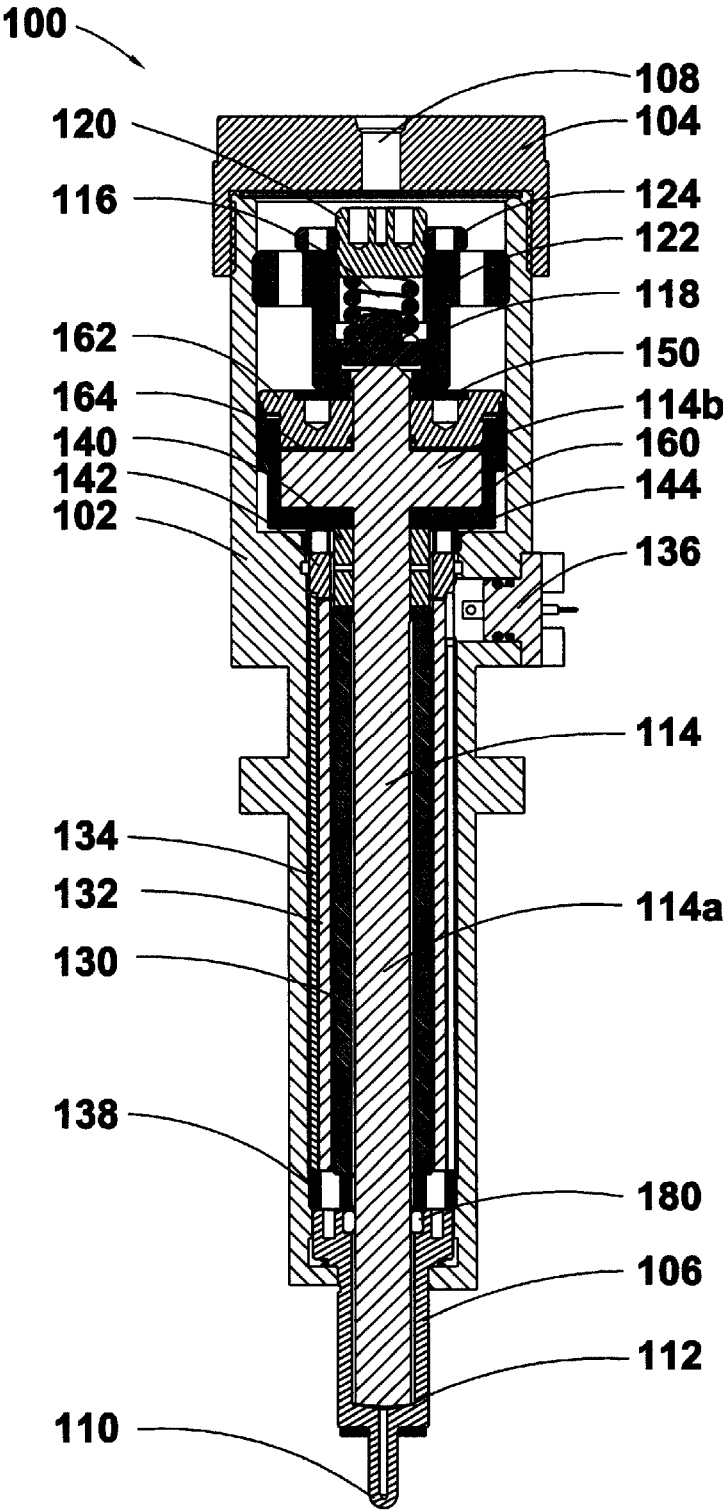


Figure 1

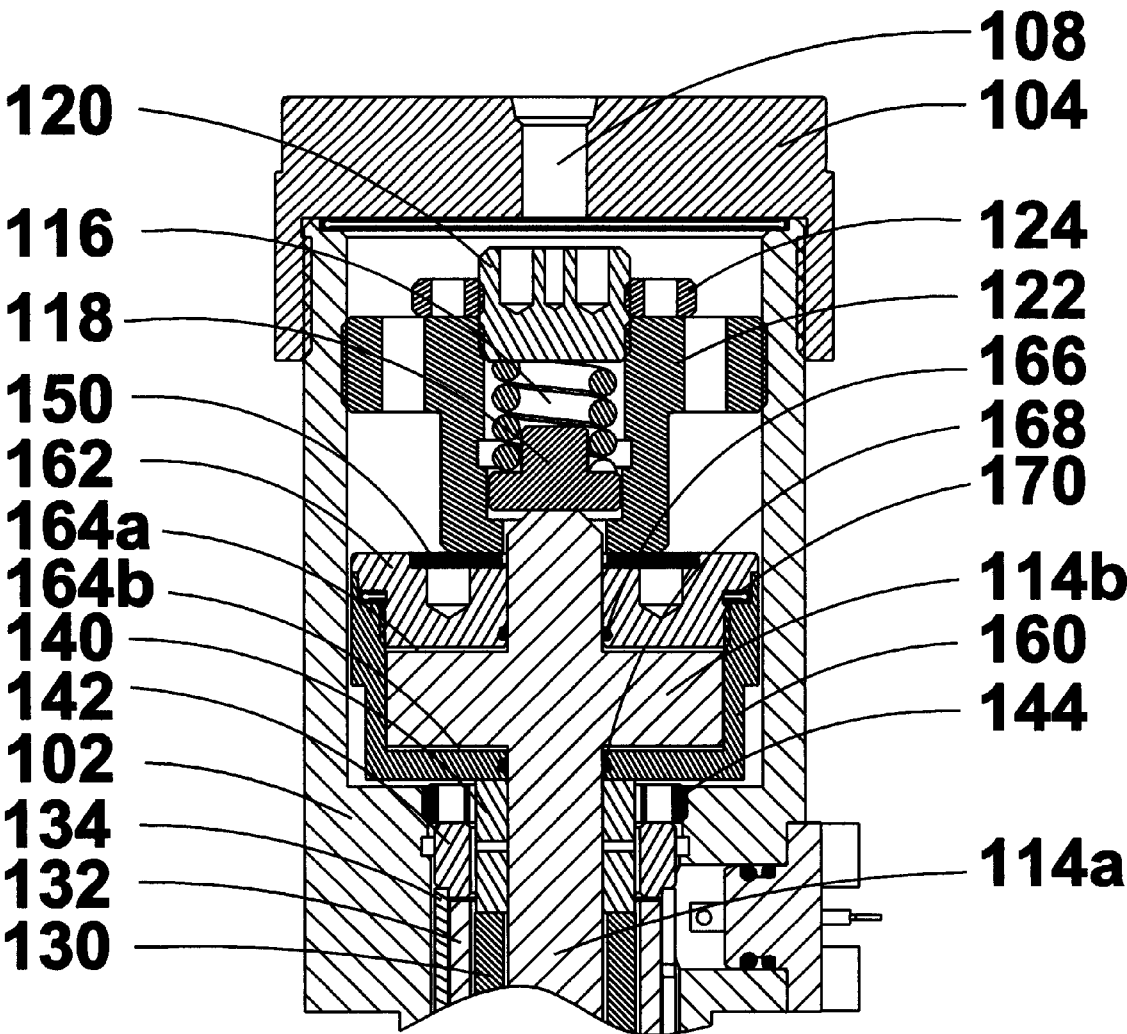


Figure 2

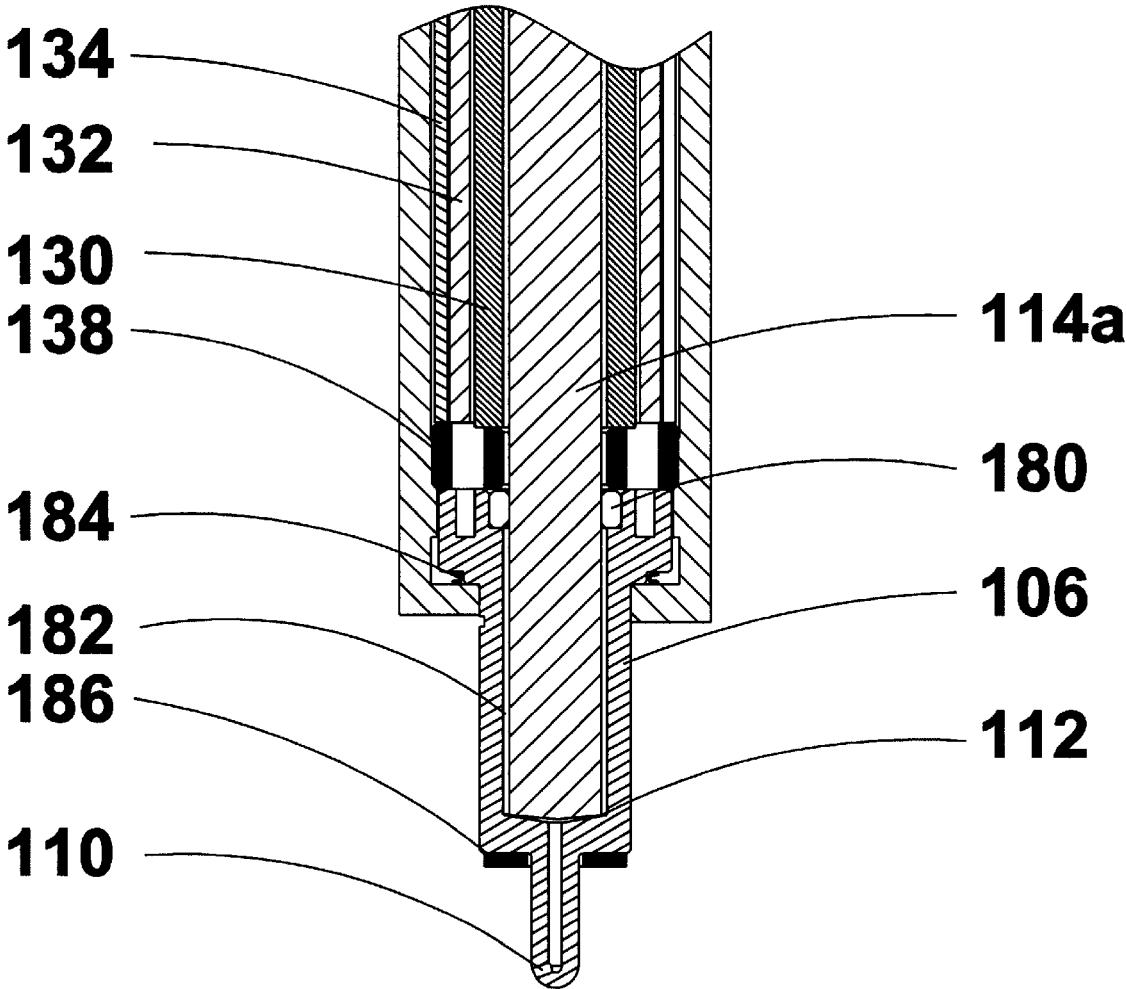


Figure 3

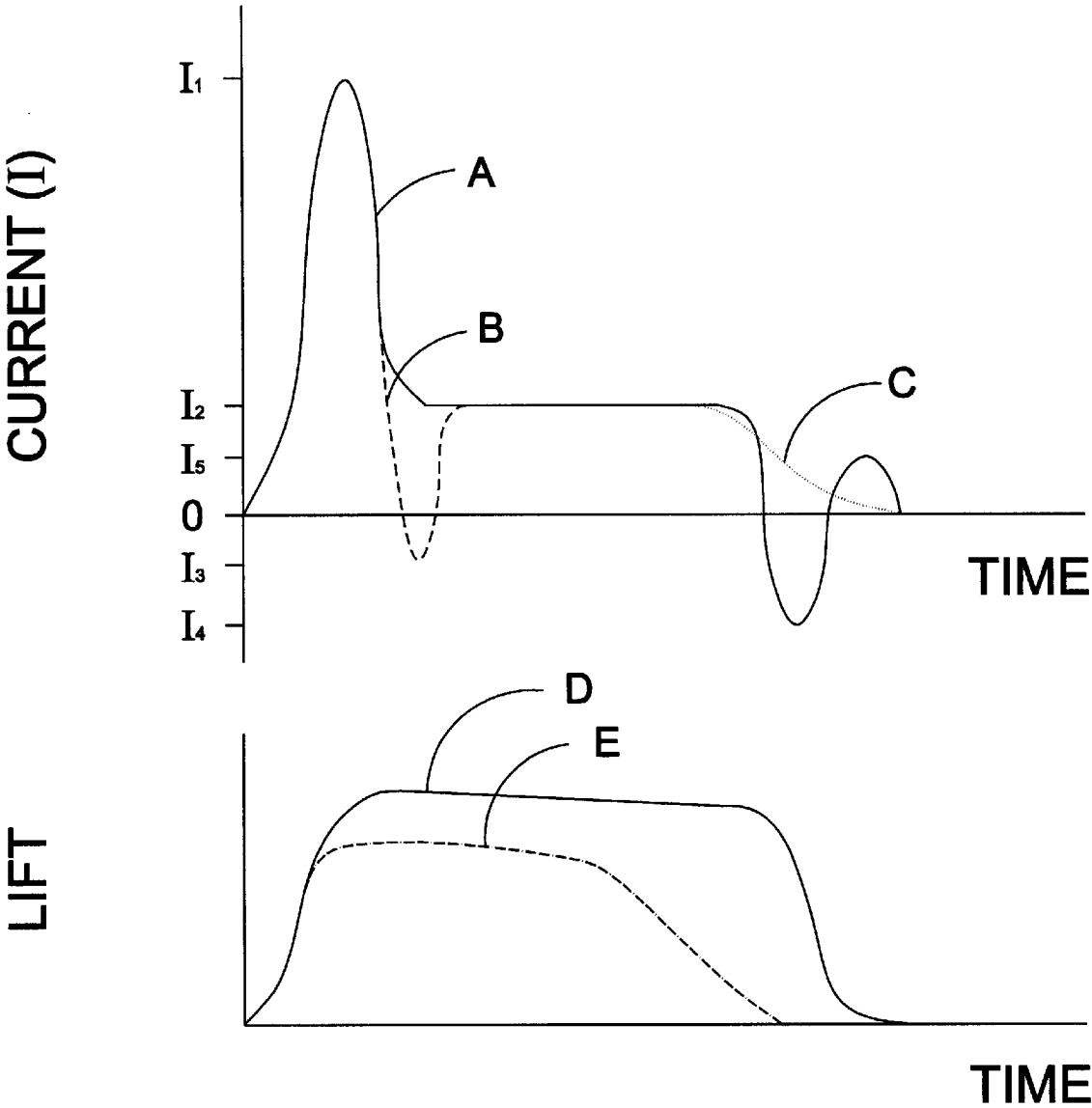


Figure 4

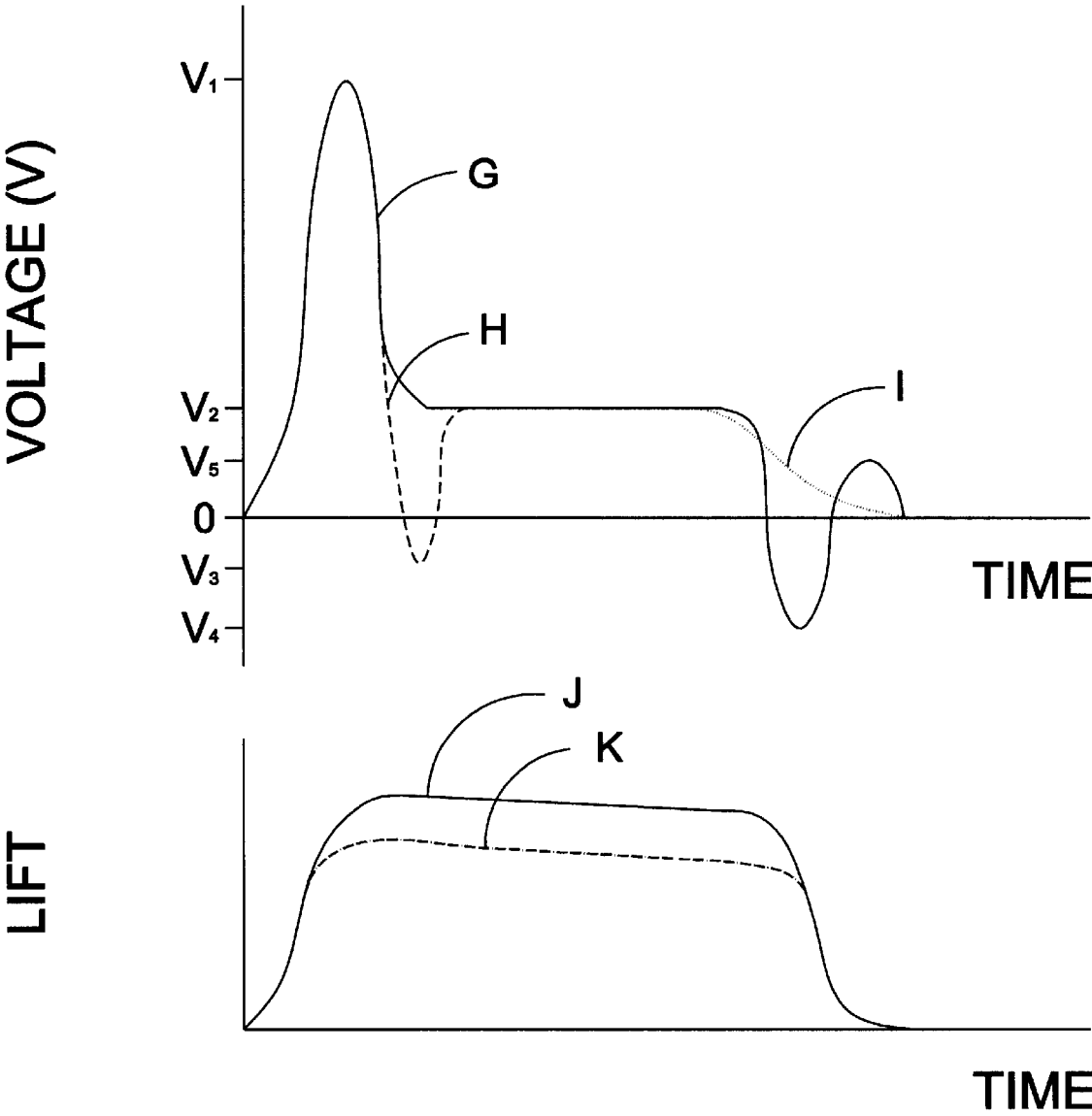


Figure 5

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DIRECTLY ACTUATED INJECTION VALVE**CROSS-REFERENCE TO RELATED APPLICATION(s)**

The present application relates to and claims priority benefits from U.S. Provisional Patent Application Serial No. 60/159,791 filed Oct. 15, 1999, entitled "Directly Actuated Injector", which is incorporated by reference in its entirety.

TECHNICAL FIELD

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.

BACKGROUND

Direct injection of a gaseous fuel into the combustion chamber of an internal combustion engine is desirable for several reasons. For example, direct injection allows charge stratification, eliminating throttling losses associated with homogeneous charge engines. Additionally, with direct injection late in the compression stroke, a high-compression ratio can be maintained, maintaining efficiency. Further, when the fuel that is directly injected comprises natural gas, propane, or hydrogen, the emissions of NO_x and particulate matter (PM) are significantly reduced. The directly injected gaseous fuel can be ignited with a glow plug, with a spark plug or with pilot diesel fuel. The gaseous fuel needs to be injected at high pressure to overcome the combustion chamber pressure, which is high at the end of the compression stroke. Preferably, the injection pressure is high enough to promote good mixing between the injected fuel and the combustion chamber air.

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.

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). An injection valve is typically opened by increasing the hydraulic fluid pressure and closed by reducing the hydraulic fluid pressure, such that the opening force applied to the injection valve is reduced, causing the valve to close. However, in the

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context of a conventional gaseous injector, hydraulic operation presents several drawbacks, including:

the need for additional hydraulic hardware such as a hydraulic pump, valves, and a reservoir for the hydraulic fluid;

the need for a seal to be established between the variable pressure hydraulic fluid and the high pressure gaseous fuel;

increased bulkiness of the injection valve assembly because of the additional hardware requirements; and delayed response of the system due to time delay of the hydraulic fluid between the electrical valve hardware and the needle that controls gas flow from the injector.

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. In this respect, it is difficult to do lift control, with some limited capabilities when using double-spring configuration. Therefore, it is desirable to avoid the use of hydraulics to operate gas injectors, particularly for high-speed engines. "Lift" in the context of needle valves is defined herein as the displacement of the valve needle away from its closed/seated position to its open position.

In response to at least some of the drawbacks with hydraulic activation, solenoid actuators have been considered as an alternative for injection valve actuation because of the simplicity and reliability of solenoids. For example, U.S. Pat. No. 5,035,360 (the '360 patent) discloses a directly actuated gas only injector employing a solenoid actuator. However, the application disclosed for the solenoid actuator is an injection valve for a two-stroke engine with an operating speed of 2100 RPM. The '360 patent discloses introducing fuel into the piston cylinder between the times during the engine cycle when the piston is at approximately bottom dead center and 60 degrees after bottom dead center. The '360 patent further discloses injecting fuel at a pressure of about 300 pounds per square inch (psi) (about 2.1 MPa). Accordingly, the fuel is not introduced at pressures as high as the pressure when the piston is at or near top dead center, for example, at pressures of 3,000 psi (21 MPa) and higher. For a constant needle diameter, higher fuel pressures require higher actuating forces and to increase the actuating force of a solenoid it must be made larger. The '360 patent also discloses that "large solenoids of conventional type are inherently slower than small ones". 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).

It is also known to use piezoelectric or magnetostrictive actuation (devices which can change their dimensions under the effect of an electric or magnetic field) for directly actuated injection valves. For example, U.S. Pat. No. 5,031,841 (the '841 patent) describes a metering valve using an actuating member, which according to the patent could be a

piezoelectric stack or a magnetostrictive actuator. One feature disclosed by the '841 patent is the addition of a diaphragm which has the dual purpose of acting as a spring biasing the valve in its closed position and of providing a seal between the metered fluid and the actuator. The '841 patent discloses an adjusting screw for mechanically setting the position of the actuator within the housing. According to the '841 patent, the valve needle is rigidly connected to the actuator by a pressure pin.

Piezoelectric or magnetostrictive actuation devices have also been used in injection valves to actuate an internal hydraulic control valve. For example, U.S. Pat. No. 5,819,710 (the '710 patent) describes an injection valve within which a servo valve is used. The servo-valve is actuated by an actuating member, which could be a piezoelectric stack or a magnetostrictive material. The actuating member can be controlled to close the servo valve gently to reduce wear and improve service life. According to the '710 patent, the servo valve actuating member can be paired with a insert bolt or stud to compensate for differences in thermal expansion between the actuator and the injector housing. (See column 4, lines 25-48).

U.S. Pat. No. 5,845,852 (the '852 patent) describes another injector that employs a piezoelectric actuator to operate an internal three-way hydraulic control valve to open and close the main injection check valve. The '852 patent describes a piezoelectric actuator acting through the intermediate of a self-locking preload assembly. This self-locking preload assembly has three functions: (i) to compensate for dimensional changes and/or imperfections; (ii) to offset some of the upward force due to fuel pressure; and, (iii) to preload the piezoelectric stack for better performance.

Similarly, U.S. Pat. No. 5,779,149 describes an injector using a piezoelectric actuator acting on a hydraulic control valve through the intermediate of a hydraulic amplifier, which serves to amplify the movement of the actuator. The hydraulic control valve allows the main injection valve to open and close to meter the amount of fuel injected.

A problem with employing a piezoelectric or magnetostrictive actuator to operate a control valve, which in turn controls the flow of a hydraulic fluid to operate an injection valve, is that this arrangement requires the intermediate action of a hydraulic fluid. Any delays caused by the displacement of the hydraulic fluid causes delays in the actuation of the injector. Accordingly, there is a need for an injector that is directly actuated by an actuator without an intermediate active hydraulic operator generating any actuating forces. Another disadvantage of active hydraulically operated systems is that a hydraulic fluid needs to be supplied and drained from a hydraulic cylinder. When diesel fuel is the main fuel used by the engine, the diesel fuel may be used as the hydraulic fluid. However, when a gaseous fuel is the engine's main fuel, a separate hydraulic fluid system would be needed to operate injectors that rely on hydraulic actuation.

SUMMARY

An injection valve injects fuel into a combustion chamber of an internal combustion engine. The injection valve comprises:

- (a) a valve housing comprising:
 - a fuel inlet port;
 - an interior chamber fluidly connected to the fuel inlet port;
 - a nozzle comprising a nozzle orifice providing a fluid passage from the interior chamber to the combustion chamber;

- (b) a valve needle disposed within the valve housing wherein the valve needle is movable between a closed position at which a sealing end of the valve needle contacts a valve seat to fluidly seal the interior chamber from the nozzle orifice, and an open position at which the sealing end of the valve needle is spaced apart from the valve seat whereby the interior chamber is fluidly connected with the nozzle orifice, wherein valve needle lift equals the distance traveled by the sealing end away from the valve seat;
- (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
- (e) a hydraulic link assembly comprising a hydraulic link having a fluid thickness through which the opening and closing forces are transmitted, wherein the thickness of the hydraulic link is 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.

In a preferred embodiment, the thickness of the hydraulic link is auto-adjustable in response to changes in the dimensional relationship caused by differential thermal expansion, and/or wear to components of the injection valve. The hydraulic link assembly preferably comprises a sealed hydraulic cylinder, with a piston and hydraulic fluid disposed within the hydraulic cylinder. The piston may be an integral part of the valve needle.

The actuator assembly preferably comprises a magnetostrictive member or a piezoelectric stack. When the actuator assembly comprises a magnetostrictive member, an electric coil is disposed around the magnetostrictive member and a flux tube is disposed around the electric coil. In preferred arrangements, the actuator assembly may be disposed within the interior chamber of the injection valve. In a particular preferred embodiment, the actuator assembly is tubular and disposed within an annular space around a cylindrical portion of the valve needle. One end of the tubular actuator assembly may be held in a fixed position in relation to the valve housing by a pole that supports the magnetostrictive member. The pole is attached to the valve housing to prevent movement of the supported end of the magnetostrictive member when the actuator assembly is activated.

When the injection valve actuator assembly employs a magnetostrictive member or a piezoelectric stack, the actuator assembly is controllable to control the desired lift between 10 and 100 percent of maximum lift. That is, the control pulse directed to the actuator assembly can be modulated to provide full or partial lift, as desired. When the actuator assembly comprises a magnetostrictive member, the control pulse is a modulated electric current directed to an electric coil that produces a magnetic field. When the actuator assembly comprises a piezoelectric stack, the control pulse is a modulated voltage applied to the piezoelectric stack.

The present injection valve is particularly suited for injecting a gaseous fuel because the ability to modulate the movement of the valve needle may be beneficially used to slow down the closing action of the valve needle to reduce impact upon closing. When a liquid fuel is injected, the closing impact is dampened by the displacement of the thin

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liquid fuel layer, which is considerably denser than gaseous fuels. When the fuel is a gaseous fuel, it can be injected into the combustion chamber at a pressure greater than about 2000 psi (about 13.8 MPa).

A magnetostrictive material that is suitable for use in the present injection valve comprises a material known as ETREMA Terfenol-D® magnetostrictive alloy that is available from Etrema Products Inc. ETREMA Terfenol-D® magnetostrictive alloy is a metal alloy composed of the elements terbium, dysprosium, and iron.

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.

To improve the range of valve lift for a given magnetostrictive or piezoelectric actuator length, a compressive force may be applied to the magnetostrictive member or piezoelectric stack. By pre-loading magnetostrictive members and piezoelectric stacks, net displacement may be increased per respective unit of applied magnetic field or applied voltage. Accordingly, a compression spring member may be employed for applying a compressive force to pre-load the magnetostrictive member or piezoelectric stack. In a preferred embodiment, the compression spring member comprises at least one disc spring (also known as a Belleville spring or Belleville washer).

The injection valve housing may comprise a plurality of parts that are joined with each other to provide a fluidly sealed body. For example, the valve housing may comprise a hollow main housing with a removable valve cap that allows access to the valve components disposed within the main housing. The valve housing may further comprise a separate valve tip so that it is replaceable when worn. In addition, the valve tip may be designed so that it is the only portion of the valve body that is directly exposed to the interior of the combustion chamber. In this case the valve tip may be made from a material that will provide greater durability when directly exposed to the conditions that might be expected within a combustion chamber.

While the hydraulic link is designed to compensate for changes in the dimensional relationships between valve components, including changes caused by differential thermal expansion, the demands placed upon the hydraulic link may be reduced by the selection of materials for the valve components that have similar thermal expansion coefficients.

A preferred fuel injection valve for an internal combustion engine comprises:

- (a) a valve housing comprising:
 - a fuel inlet port;
 - an interior chamber fluidly connected to the fuel inlet port;
 - a nozzle comprising a valve seat and a nozzle orifice providing a fluid passage from the interior chamber to the combustion chamber;
- (b) a valve needle comprising a cylindrical portion having a sealing end and a piston portion having a pre-load end, the valve needle disposed within the valve housing wherein the valve needle is movable between a closed position at which the sealing end contacts the valve seat to fluidly seal the interior chamber from the nozzle orifice, and an open position at which the sealing end is spaced apart from the valve seat whereby the interior chamber is fluidly connected with the nozzle orifice, wherein valve needle lift equals distance traveled by the sealing end away from the valve seat;
- (c) a needle spring associated with the pre-load end of the valve needle, wherein the needle spring is compressed

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to apply a closing force to the valve needle for biasing the valve needle in the closed position;

- (d) an actuator assembly that may be activated to apply an opening force to the valve needle that is stronger than the closing force, for moving the valve needle to the open position, the actuator assembly comprising:
 - a tubular magnetostrictive member disposed around the cylindrical portion of the valve needle;
 - an electrical coil disposed around the magnetostrictive member;
 - a flux tube disposed around the electrical coil; and
 - a support for the actuator assembly that acts as a pole and provides a fixed position for one end of the magnetostrictive member relative to the valve housing; and

- (e) a hydraulic link assembly comprising a sealed hydraulic cylinder disposed about the piston portion of the valve needle, a hydraulic fluid disposed within the hydraulic cylinder, wherein the opening and closing forces applied to the valve needle are transmitted through the thickness of hydraulic fluid whereby the hydraulic fluid acts as a hydraulic link and the thickness 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.

Also provided is a method of using a shaped waveform to control an injection valve that employs a magnetostrictive or piezoelectric actuator assembly. The method comprises, in sequence:

- (a) initiating an injection event by applying a control pulse and accelerating valve opening by raising the value of the control pulse to a spike value that is greater than the value required for the desired lift (the spike value may be up to about an order of magnitude higher than the value required for the desired lift);
- (b) reducing the control pulse from the spike value to a value that is needed to provide the desired lift;
- (c) reducing the control pulse to a negative value to accelerate valve closing;
- (d) increasing the control pulse to a positive value to slow down valve closing to reduce the impact force of the valve needle on the valve seat; and
- (e) reducing the control pulse to zero to close the valve.

The method may further comprise shaping the waveform to modulate the movement of the valve needle, for example, to provide only partial lift when reduced fuel flow is desired. This result could be achieved, for example, by momentarily reducing the control pulse to a value that is lower than the value that is needed for the desired lift to reduce the average value of the control pulse during the injection event. The reduction in the control pulse value is preferably timed immediately after increasing the control pulse to the spike value, so that the reduced control pulse helps to stop the opening action of the valve needle.

When the actuator assembly employs a magnetostrictive member, the control pulse is a modulated electric current directed to an electric coil that produces a magnetic field oriented in the direction of actuation. When the actuator assembly employs a piezoelectric stack, the control pulse is a modulated voltage applied to the piezoelectric stack.

In the preferred method, the time needed to move the valve needle between the closed position and the desired open position may be as short as about 175 microseconds. More typically, however, the time needed to move the valve needle between the closed position and the desired open position may be as short as about 250 microseconds.

An advantage of the present injection valve is that it may be employed for late-cycle high-pressure direct injection of fuels into internal combustion engines. For example, the present injection valve may be used to inject a gaseous fuel into the combustion chamber of an internal combustion engine at pressures of between about 2000 and 5000 psi (about 13.8 and 34.5 MPa). The present injection valve may be employed to introduce liquid fuels into internal combustion engines at even higher pressures.

Still another advantage of the present injection valve is that it provides an injection valve that eliminates the need for an active hydraulic operator and the associated high-pressure hydraulic system for generating the actuation force to actuate the injection valve. Conventional active hydraulic operators are different from the hydraulic link of the present invention, which may be described as a passive hydraulic link because the hydraulic fluid sealed within the hydraulic link assembly merely transmits the actuating forces but is not employed to generate an actuating force for actuating the valve. 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. A benefit of eliminating the need for a conventional active hydraulic operator is the elimination of the associated active hydraulic systems. Conventional active hydraulic actuators, such as those that employ rapidly increasing and decreasing hydraulic fluid pressure to actuate an injection valve need to be connected to a source of high pressure hydraulic fluid and need valves for controlling the flow of hydraulic fluid in and 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.

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.

An advantage of employing a directly actuated injection valve is that a shaped control pulse may be employed to control the acceleration and deceleration of the valve needle as it moves between the open and closed positions. For example, when a magnetostrictive actuator is employed, the current applied to the electromagnetic coil can be controlled, for example, to reduce the current in a manner that will close the valve gently. Similarly, when a piezoelectric actuator is employed, the voltage applied to the piezoelectric stack can be controlled, for example, to accelerate the opening of the valve by initially providing an overvoltage (that is, a voltage that is higher than the voltage that is needed to provide the necessary displacement). Thus, control pulses may be employed to control the expansion and contraction of magnetostrictive or piezoelectric actuators to control the movement of the valve needle. An advantage of controlling the

deceleration of the valve needle is that the impact of the valve needle on the valve seat upon closing can be reduced to reduce the wear on the valve components, thereby improving durability.

Yet another advantage of the present injection valve is that the control pulse may be shaped to provide for partial lifting of the valve needle in a repeatable manner. 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.

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.

These and other advantages are provided by a directly actuated injector as described below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a preferred embodiment of a directly actuated fuel injection valve;

FIG. 2 is an enlarged view of an upper portion of the fuel injection valve of FIG. 1;

FIG. 3 is an enlarged view of a lower portion of the fuel injection valve of FIG. 1;

FIG. 4 is a timing diagram for a preferred method of controlling electric current applied to the actuator assembly of the fuel injection valve of FIG. 1; and

FIG. 5 is a timing diagram for a preferred method of controlling voltage applied to a piezoelectric actuator assembly for a fuel injection valve.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT(S)

FIGS. 1 through 3 show a preferred embodiment of a directly actuated fuel injection valve 100 for internal combustion engines. Injection valve 100 includes elongated valve housing 102 that cooperates with valve cap 104 and valve tip 106 to provide a fluidly sealed valve body. Seals may be employed to ensure that the assembled valve body is fluid-tight. Valve cap 104 comprises inlet port 108 through which fuel enters the valve body, and valve tip 106 comprises at least one nozzle orifice 110 through which fuel exits the valve body. Valve tip 106 further comprises valve seat 112.

In the preferred embodiment, shown more clearly in the enlarged view of FIG. 3, valve seat 112 is angled to maximize fluid flow following the sealing area (where valve needle 114 contacts valve seat 112). The differential angle between the end surface of valve needle 114 and valve seat 112 is chosen so that the flow area does not decrease as gas moves inward toward the central throat of valve tip 106 that feeds nozzle orifice(s) 110.

Valve Needle

Valve needle 114 is disposed within the interior of the valve body and contacts valve seat 112 to close injection valve 100 by preventing fuel from passing beyond valve seat 112 to nozzle orifice 110. In the embodiment of FIG. 1, valve needle 114 comprises valve stem 114a, which moves into the open position by moving inward within the valve body to lift away from valve seat 112. Valve stem 114a is a cylindrical member and since the valve lift is generally small (for example, about 65 micrometers), the diameter of valve stem

114a is selected to ensure sufficient flow capacity through the valve opening since flow area (A) is proportional to valve stem diameter (that is, $A = \pi \times \text{diameter} \times \text{lift}$). Hence, a small lift can be compensated for by a larger diameter. 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.

Spring Assembly

A spring assembly biases valve needle 114 in the closed position. In a preferred arrangement, the spring assembly comprises at least one needle spring 116 for providing a closing force to valve needle 114. With reference to embodiment of FIG. 1, the spring assembly further comprises a needle spring guide 118 for transmitting the closing force from needle spring 116 to valve needle 114. Needle spring 116 is held in compression by needle spring adjuster 120, which cooperates with needle spring housing 122 to provide a load path to valve housing 102. In a preferred arrangement, respective threaded surfaces join needle spring adjuster 120 to needle spring housing 122, and needle housing 122 to valve housing 102. After needle spring adjuster 120 has been rotated to compress needle spring 116 to provide the desired pre-load force to needle spring 116, locking nut 124 may be tightened to prevent needle spring adjuster 120 from loosening. The spring energy set by compressing or preloading needle spring 116 provides the closing force for keeping valve needle 114 in the closed position.

Actuator Assembly

An actuator assembly may be activated to provide an opening force that is opposite and greater than the closing force provided by the spring assembly. In the embodiment illustrated in FIG. 1, the actuator assembly comprises a member that expands or contracts in the direction of the opening force when the member is exposed to a magnetic field or subjected to an electrical voltage, such as, for example, a magnetostrictive material or a piezoelectric stack.

In the embodiment illustrated by FIG. 1, the actuator assembly is a magnetostrictive actuator that comprises magnetostrictive member 130, electric coil 132 disposed around the outer diameter of magnetostrictive member 130, a flux tube 134 disposed around electric coil 132. Flux tube 134 may be made from common carbon steel with a lengthwise slit to break eddy currents. An electric current is supplied to electrical fitting 136. Electric leads (not shown) conduct the electric current from electrical fitting 136 to electric coil 132. When an electric current is applied to electric coil 132 a magnetic flux develops that flows through magnetostrictive member 130, pole 138, 140 and 142, and flux tube 134. Poles 138, 140 and 142 are made from a suitable material such as carbon steel (for example CS1018) or steel that has a low magnetic hysteresis. Pole 138 is a "fixed" pole that provides a structural support for a first end of magnetostrictive member 130, electric coil 132 and flux tube 134. Pole 140 is associated with a second end of magnetostrictive member 130 and pole 142 is associated with a second end of electric coil 132 and flux tube 134. Pole 140 is an "inner" pole and pole 142 is an "outer" pole disposed concentrically around inner pole 140. Pole 142, electric coil 132 and flux tube 134 are held in place by lock nut 144, which preferably

threads into the inner wall of valve housing 102. Poles 140 and 142 cooperate with one another to provide a flux path at the second end of the actuator assembly, but pole 140 may move relative to pole 142 so that magnetostrictive member 130 may expand in the direction of the magnetic field which is oriented so that the actuator assembly provides an opening force in opposition to the closing force of the spring assembly.

A pre-compression force is preferably applied to magnetostrictive member 130 to amplify the magnitude of expansion when a magnetic field is applied. Pre-compression of magnetostrictive member 130 increases the net displacement per unit of applied magnetic field. Similarly, when a piezoelectric member is substituted for magnetostrictive member 130, pre-compression increases the net displacement of the piezoelectric member per unit of applied electric voltage. A spring, such as, for example, disc spring 150 may be employed to provide the pre-compression force. Alternative compression elements may be employed in place of disc spring 150 to provide the pre-compression force, such as, for example, a coil spring or another type of spring with the same spring force, a hydraulic piston, or a combination of compression elements. When a pre-compression force is employed, the actuator's displacement can increase to about 0.13% of the total length of magnetostrictive member 130. However, the amount of displacement may decline as a function of increasing temperature. For example, at typical reciprocating engine cylinder head temperatures the actual displacement may be about 0.065% of the length of pre-compressed magnetostrictive member 130.

The dimensions of magnetostrictive member are dictated by the requirements of injection valve 100. For example, if injection valve 100 is designed to provide a lift of at least about 65 μm , magnetostrictive member 130 is sized to have a length of at least about 100 mm. Additionally, the wall thickness of annular magnetostrictive member 130 is selected to provide sufficient force to overcome all of the opposing forces that hold injection valve 100 in the closed position. If the cross-sectional area of annular magnetostrictive member 130 is not sufficient, the opposing forces can reduce or prevent longitudinal displacement of magnetostrictive member 130, even when electric coil 132 is fully energized. This mode is known as the "blocked force" mode. Accordingly, the magnitude of the closing forces acting on valve needle 114 dictate the cross sectional area of magnetostrictive member 130.

While FIG. 1 shows magnetostrictive member 130, electric coil 132, and flux tube 134 could be replaced with a piezoelectric stack (not shown). Electrical fitting 136 could be employed to direct an electric voltage to the piezoelectric stack. When an electric voltage is applied to a piezoelectric stack, the stack expands and develops a motive force for opening injection valve 100.

As shown in FIG. 1, the actuator assembly may be located within valve housing 102 and disposed concentrically around valve stem 114a where it occupies a portion of the annular space between valve stem 114a and valve housing 102. Accordingly, the actuator assembly may be exposed to fuel that is directed through the hollow valve body on its way from inlet port 108 to nozzle orifice 110.

Hydraulic Link Assembly

The opening force generated by the actuator assembly is transmitted to valve needle 114 through a hydraulic link assembly. The hydraulic link assembly comprises hydraulic cylinder 160, which is disposed in close-fitting relationship around hydraulic piston 114b, which is free to move in the longitudinal direction within cylinder 160. As mentioned

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above, in the embodiment of FIG. 1, hydraulic piston 114b is an integral part of valve needle 114 and the side wall of cylinder 160 helps to guide the movement of valve needle 114 in the actuating direction. A viscous hydraulic fluid is sealed inside hydraulic cylinder 160 by cylinder cap 162 and seals 166, 168 and 169 (see FIG. 2). Seals 166 and 168 permit valve needle 114 to move relative to cylinder cap 162 and cylinder 160, respectively. Known seals may be employed, such as, for example elastomeric O-ring seals, packing, metal seals, or diaphragm/bellow seals.

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). The desired size of the clearance gap is dependent on the viscosity of the chosen hydraulic fluid. The hydraulic flow in the clearance gap is governed by the Hagen-Poiseuille Flow and the hydraulic fluid and clearance gap are preferably selected so that the flow of hydraulic fluid through the gap is insignificant during the time span of fuel injection events when an opening force is transmitted through the hydraulic fluid. Furthermore, the hydraulic fluid preferably has a sufficiently high viscosity and bulk modulus so that it acts as an incompressible solid when activation of the actuator assembly causes a valve opening force to be quickly transmitted through the hydraulic fluid between the bottom of cylinder 160 and hydraulic piston 114b. For consistency of operation, the hydraulic fluid is also preferably an extremely stable fluid that maintains its desired properties over a wide range of temperatures (that is, within the expected operating temperatures inside cylinder 160). Suitable hydraulic fluids are, for example, conventional motor oil, such as grade 15W40, or synthetic lubricants such as Dupont® "Krytox®" grease which is available in a range of viscosities. Krytox® is a PerFluoroPolyEther (PFPE) synthetic lubricant that may be mixed with a thickener to form a grease. These types of hydraulic fluids also help to lubricate seals 166 and 168. Different injection valves may have different sized pistons and clearance gaps, so the hydraulic fluid may be selected with consideration to the characteristics of an individual injection valve design.

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.

Differential thermal expansion or contraction may be caused by differences in thermal expansion coefficients or uneven heat distribution between the components. Even though the components of injection valve 100, such as magnetostrictive member 130, valve needle 114, and valve housing 102, are designed to be reasonably matched to the thermal expansion rates of the other components, because the valve needle lift and the displacement of the components that causes the lift are so small, the effects of thermal expansion or contraction need to be taken into account to

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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° 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.

In summary, the hydraulic link assembly accounts for variations in component dimensions arising from the permitted tolerances in the manufacturing processes and the injection valve assembly methods. Therefore, the hydraulic link assembly reduces manufacturing costs by allowing the injection valve components to be manufactured to less exacting tolerances. In addition, during operation, the hydraulic link assembly auto-adjusts itself between injection events to account for changes in the dimensional relationship between injection valve components that may be caused, for example, by component wear or differential thermal expansion or contraction.

Summary of Operation

When injection valve 100 is at rest in the closed position, the closing force that biases valve needle 114 against valve seat 112 originates from needle spring 116. From needle spring 116, the closing force is transmitted through needle spring guide 118 to valve needle 114. It is preferable for the closing force to be provided by a mechanical spring member, such as the illustrated coil spring, so that the failure mode for injection valve 100 will be in the closed position. That is, if the actuating assembly is not energized or fails, injection valve 100 will remain in the closed position.

To initiate an injection event the actuator assembly is energized by directing an electric current to electric coil 132. A magnetic flux develops that flows through magnetostrictive member 130, poles 138, 140, and 142, and flux tube 134. Under the influence of the magnetic field, magnetostrictive member 130 expands in length (in the direction of the magnetic field). Since pole 138 is in a fixed position, magnetostrictive member 130 expands in the direction of hydraulic cylinder 160. An opening force, originating from expanding magnetostrictive member 130 is transmitted through inner pole 140, the base of cylinder 160, hydraulic fluid 164b (see FIG. 2), which is held between the base of cylinder 160 and a planar surface of hydraulic piston 114b, and finally, through piston 114b, which in the illustrated embodiment is integral with valve needle 114. The opening force is greater than the closing force, which results in compression of needle spring 116. The displacement of hydraulic cylinder 160 also causes further compression of disc spring 150.

As previously discussed, because valve actuation occurs suddenly (on the order of 200 μs), 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.

The movement of valve needle 114 is guided near valve tip 106 by guide 180 (see FIG. 3). FIG. 3 shows annular space 182 disposed around valve stem 114a. Between injection events, fuel remains in annular space 182. When injection valve 100 is open, fuel flows through annular space 182, other gaps between valve components, and openings provided in certain valve components, which all cooperate to permit the free flow of fuel from inlet port 108 through to nozzle orifice 110 (which may be one of a plurality of nozzle orifices radially oriented from the nozzle throat). For example, FIGS. 1 through 3 show openings that provide fluid passages through components such as needle spring housing 122, lock nut 144, and pole 138. FIG. 3 also shows seal 184 between valve housing 102 and valve tip 106, and cylinder head face seal 186, which seals between injection valve 100 and the engine cylinder head (not shown).

As fuel flows through valve housing 102, the fuel cools the actuator assembly. The fuel flow path is preferably arranged to provide the greatest cooling to the internal diameter surface of electric coil 132 and the outer diameter surface of magnetostrictive member 130. In addition, a small percentage of the fuel flow, perhaps up to about 20%, may be directed to flow between the internal diameter of magnetostrictive member 130 and the surface of cylindrical valve stem 114a. When the fuel is used to cool the actuator assembly in this manner, thermal modeling predicts a temperature rise of less than 10° C.

To close injection valve 100, at the end of the injection event, electric coil 132 is de-energized, causing magnetostrictive member 130 to contract. When valve needle 114 is moving from the open position to the closed position, the closing force originates from needle spring 116 and disc spring 150. The closing force from needle spring 116 is again transmitted to valve needle 114 through needle spring guide 118. In the open position, the expanded magnetostrictive member 130 compresses disc spring 150, so upon closing, disc spring 150 de-compresses to push cylinder 160 down and to compress to magnetostrictive member 130. Disc spring 150 may also provide an additional closing force to valve needle 114 by generating a closing force that is transmitted from disc spring 150 through cylinder cap 162, hydraulic fluid 164a and hydraulic piston 114b.

When valve needle 114 moves from the open position to the closed position, the time that elapses is again typically less than 250 microseconds, and preferably less than about 200 microseconds so hydraulic fluid 164 again does not have time to flow through the clearance gap between piston 114b and cylinder 160. Consequently, pressure builds up in hydraulic fluid 164a on the upper planar surface of piston 114b.

Once valve needle 114 contacts valve seat 112, injection valve 100 is closed. When injection valve 100 is closed, the hydraulic link assembly automatically self-adjustments so that the position of hydraulic cylinder 160 relative to hydraulic piston 114b is corrected to account for the effects of temperature, wear, and any small movements of valve needle 114 relative to hydraulic cylinder 160 that may have occurred while valve needle 114 was in the open position. Auto-adjustments are accomplished by the migration of hydraulic fluid 164 from one side of hydraulic piston 114b to the other, while disc spring 150 ensures that hydraulic cylinder 160 and valve needle 114 remain in direct contact at all times.

Control Strategy

Waveforms for controlling a directly actuated injection valve and corresponding actuator displacements are plotted in the graphs shown in FIGS. 4 and 5. The illustrated waveforms show that the control pulse may employ several features to control the movement of a magnetostrictive or piezoelectric member respectively.

In FIG. 4, waveform A represents the electric current that is directed to an electric coil that is used to activate an actuator comprising a magnetostrictive member. The strength of the magnetic field is directly proportional to the amount of electric current that is directed to the electric coil. To promote fast opening, the current is preferably first spiked to current I₁ since higher currents yield stronger magnetic fields that can be employed to accelerate the expansion of the magnetostrictive member. The electric current is lowered to current I₂ during the main injection event.

Initial electric current I₁ corresponds to a current that may be as much as an order of magnitude higher than electric current I₂, which is the current that is actually required to fully open the injection valve. It is also possible to partially open the injection valve, for example, by reducing the current after the initial current spike to a value less than current I₂. As shown by dashed waveform B, which temporarily reverses the current to negative current I₃, the control pulse may be optionally shaped to lower the average current to a level that allows quick attainment of partial lift for better flow control than that which can be obtained purely through pulsewidth modulation. That is, better flow control can be achieved by controlling both the displacement of the valve needle (lift) and the duration of the injection event.

Valve closure may be optionally accelerated by initially reversing the current to negative current I₄. To reduce the impact and consequent wear of the valve needle when it makes contact with the valve seat, as shown by waveform A, the current may be momentarily increased to positive current I₅ to slow down the valve closing action. In an alternative method for controlling the impact of the valve needle on the valve seat, the current can be more gradually reduced without reversing the direction of current, as shown by dotted-line C. Finally, the injection event is completed when injection valve is closed and current is returned to zero.

Line graphs D and E show the displacement of the valve needle through respective fully open and partially open injection events. Graph D corresponds to the injection event controlled by waveform A. Graph D shows the valve needle quickly moving to the fully open position at the beginning of the injection event. In the illustrated example, the injection valve remains in the fully open position for the majority of the injection event, as represented by the essentially flat portion of graph D. However, depending upon the viscosity of the hydraulic fluid and the size of the clearance gap between the hydraulic piston and the hydraulic cylinder, the flat portion of graph D may have a slight slope caused by the flow of hydraulic fluid through the clearance gap during the injection event.

When the injection valve is closed, the closing action is very quick, as shown by the steep downward slope of line D near the end of the injection event. However, in response to the momentary positive current near the end of waveform A, the slope of graph D flattens out just as the valve is returning to the fully closed position, demonstrating how the shape of waveform A can be used to reduce wear caused by the impact of the valve needle on the valve seat. Graph E corresponds to a waveform (not shown) which, after the

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initial current spike reduces the current to a value less than current I_2 , so that the injection valve is only partially opened. Graph E also shows that the duration of the injection event may be varied by changing the length or duration of the waveform. Compared to the injection event represented by graph D, the valve lift is smaller for the injection event represented graph E, so the initial current spike may be lower than the initial current spike of waveform A. The closing action represented by the more gradual slope of graph E (compared to the steeper slope of graph D), corresponds to a waveform having a shape similar to alternate waveform C.

Persons skilled in the art will recognize that the time required to open or close the injection valve may be decreased by increasing the slope of the control waveform, or increased, by decreasing the slope of the waveform. Thus the shape of the control waveform may be manipulated to produce the desired effects on the speed of the valve needle movement and its displacement with respect to the valve seat (to control lift).

In FIG. 5, waveform G represents a voltage control pulse that may be used to activate a piezoelectric actuator. As will become apparent, the preferred control strategy for piezoelectric actuators employs the same principles as the preferred control strategy described above for magnetostrictive actuators. To promote fast opening, the voltage is preferably first spiked to voltage V_1 since higher voltages can be employed to accelerate the expansion of piezoelectric materials. The voltage is lowered to voltage V_2 during the main injection event. Voltage V_1 corresponds to a voltage that may be as much as an order of magnitude higher than voltage V_2 , which is the voltage that is actually required to fully open the injection valve. It is also possible to partially open the injection valve, for example, by reducing the voltage after the initial voltage spike to a value less than voltage V_2 . As shown by dashed waveform H, which temporarily reduces the voltage to negative voltage V_3 , the control pulse may be optionally shaped to lower the average voltage to a level that allows quick attainment of partial lift for better flow control than that which can be obtained purely through pulsewidth modulation. That is, better flow control can be achieved by controlling both the displacement of the valve needle (lift) and the duration of the injection event.

Valve closure may be optionally accelerated by initially reducing the voltage to negative voltage V_4 . To reduce the impact and consequent wear of the valve needle when it makes contact with the valve seat, as shown by waveform G, the voltage may be momentarily increased to positive voltage V_5 to slow down the valve closing action. Similar to the shape of current waveform C, the shape of voltage waveform I represents an alternative method for reducing the impact of the valve needle on the valve seat upon closing. Finally, the injection event is completed when injection valve is closed and voltage is returned to zero.

Line graphs J and K show the displacement of the valve needle through respective injection events. Graph J corresponds to the injection event controlled by waveform G. Graph J shows the valve needle quickly moving to the fully open position at the beginning of the injection event. In the illustrated example, the injection valve remains in the fully open position for the majority of the injection event, as represented by the essentially flat portion of graph J. However, depending upon the viscosity of the hydraulic fluid and the size of the clearance gap between the hydraulic piston and the hydraulic cylinder, the flat portion of graph J may have a slight slope caused by the flow of hydraulic fluid through the clearance gap during the injection event.

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When the injection valve is closed, the closing action is very quick, as shown by the steep downward slope of line J near the end of the injection event. However, in response to the momentary positive voltage near the end of waveform G, the slope of line J flattens out just as the valve is returning to the fully closed position, demonstrating how the shape of waveform G can be used to reduce wear caused by the impact of the valve needle on the valve seat. Graph K is similar to graph J except that it corresponds to a waveform (not shown) which, after the initial voltage spike reduces the voltage to a value less than voltage V_2 , so that the injection valve is only partially opened.

The time span for the waveforms of FIGS. 4 and 5 may be in the range of 100 to 5000 microseconds, and typically between 250 and 2000 microseconds for the majority of injection events.

The combination of the above described directly actuated injection valve and control strategy provides several benefits, including:

- elimination of the hydraulic fluid supply system that is needed by conventional hydraulically actuated injection valves. This simplifies injection valve construction, for example, by eliminating the need for hydraulic fluid supply and return passages and three way valves that are employed by conventional hydraulically actuated injection valves.

- automatic compensation for differential thermal expansion within the injection valve, for wear due to prolonged operation, and for small differences caused by limitations in manufacturing tolerances.

- a compact concentric valve needle/actuator assembly arrangement for accommodating an elongated magnetostrictive or piezoelectric member.

- an apparatus that permits the use of a control strategy that can throttle fuel flow and reduce valve seat wear. The ability to control the lift displacement permits reduced injection at lower loads and reduced pre-mixed burning. For example, using a magnetostrictive or piezoelectric actuator, the valve needle movement can be controlled between about 10% and 100%. For lower load conditions it is important to be able to reduce the flow of fuel into the combustion chamber, since excess fuel may not be combusted, resulting in lower operating efficiency and higher emissions.

- improved manufacturability is made possible by the use of axisymmetric cylindrical parts and few tight tolerances between the injection valve components.

- valve operation is improved since the actuating assembly permits greater control of the valve needle. For example, the injection valve may be used to inject a gaseous or liquid fuel. When the fuel is gaseous, there is a greater need to slow down the valve needle upon closing because there is no liquid fuel to dampen the impact of the valve needle on the valve seat. By shaping the control pulse waveform applied to the actuator it is possible to slow down the closing of the injection valve to reduce impact on the valve needle and the valve seat.

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled in the art without departing from the spirit and scope of the present disclosure, particularly in light of the foregoing teachings.

What is claimed is:

1. 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;
 - (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;
 - (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;
 - (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
 - (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.
2. The injection valve of claim 1 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by differential thermal expansion.
3. The injection valve of claim 2 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by wear to components of said injection valve.
4. The injection valve of claim 1 wherein said hydraulic link assembly comprises a fluidly sealed hydraulic cylinder that is fluidly sealed from said interior chamber, said hydraulic link assembly comprising a piston and said hydraulic fluid is disposed within said hydraulic cylinder.
5. The injection valve of claim 4 wherein said piston is an integral part of said valve needle.
6. The injection valve of claim 1 wherein said actuator assembly comprises a magnetostrictive member or a piezoelectric stack.
7. The injection valve of claim 1 wherein said actuator assembly comprises a magnetostrictive member, an electric coil disposed around said magnetostrictive member and a flux tube disposed around said electric coil.

8. The injection valve of claim 7 wherein said actuator assembly is disposed within said interior chamber.
9. The injection valve of claim 8 wherein said actuator assembly is tubular and disposed within an annular space around a cylindrical portion of said valve needle.
10. The injection valve of claim 9 wherein one end of said tubular actuator assembly is supported by a pole that is attached to said valve housing.
11. The injection valve of claim 6 wherein when said actuator assembly is controllable to control said desired lift to between 10 and 100 percent of maximum lift.
12. The injection valve of claim 11 wherein said lift is controllable by controlling the electric current directed or voltage applied to said respective magnetostrictive or piezoelectric actuator assembly.
13. The injection valve of claim 7 wherein said magnetostrictive member comprises a metal alloy comprising the elements terbium, dysprosium, and iron.
14. The injection valve of claim 6 wherein said valve needle is controllable to move between said open and closed positions in less than about 200 microseconds.
15. The injection valve of claim 6 further comprising a compression spring member for applying a compressive force to said magnetostrictive or piezoelectric member.
16. The injection valve of claim 15 wherein said compression spring member comprises at least one disc spring.
17. The injection valve of claim 1 wherein said fuel is a gaseous fuel.
18. The injection valve of claim 1 wherein said fuel is injected into said combustion chamber at a pressure greater than about 2000 psi (about 13.8 MPa).
19. The injection valve of claim 1 wherein said valve housing comprises a plurality of parts which are joined with each other to provide a fluidly sealed body.
20. The injection valve of claim 1 wherein said valve housing, said valve needle, and said actuator assembly, are selected from materials with similar thermal expansion coefficients to reduce changes in the dimensional relationship between said components caused by changes in temperature.
21. The injection valve of claim 17 wherein said hydraulic fluid is a liquid.
22. The injection valve of claim 17 wherein said hydraulic fluid is a liquid selected from the group consisting of motor oil and grease.
23. 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 valve seat and a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;
 - (b) a valve needle comprising a cylindrical portion having a sealing end and a piston portion having a pre-load end, said valve needle disposed within said valve housing wherein said valve needle is movable between a closed position at which said sealing end contacts said valve seat to fluidly seal said interior chamber from said nozzle orifice, and an open position at which said sealing end is spaced apart from said valve seat whereby said interior chamber is fluidly connected with said nozzle orifice, wherein valve needle lift equals distance traveled by said sealing end away from said valve seat;

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- (c) a needle spring associated with said pre-load end of said valve needle, wherein said needle spring is compressed to apply a closing force to said valve needle for biasing said valve needle in said closed position;
 - (d) an actuator assembly that may be activated to apply an opening force to said valve needle that is stronger than said closing force, for moving said valve needle to said open position, said actuator assembly comprising:
 - a tubular magnetostrictive member disposed around said cylindrical portion of said valve needle;
 - an electrical coil disposed around said magnetostrictive member;
 - a flux tube disposed around said electrical coil; and
 - a support for said actuator assembly that acts as a pole and provides a fixed position for one end of said magnetostrictive member relative to said valve housing; and
 - (e) a hydraulic link assembly comprising a sealed hydraulic cylinder disposed about said piston portion of said valve needle, a hydraulic fluid disposed within said hydraulic cylinder, wherein said opening and closing forces applied to said valve needle are transmitted through a thickness of said hydraulic fluid whereby said hydraulic fluid acts as a hydraulic link and said thickness is automatically adjustable in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift when said actuator assembly is activated.
24. The injection valve of claim 23 further comprising a compression spring member for applying a compressive force to said magnetostrictive member.
25. The injection valve of claim 23 wherein said magnetostrictive member comprises a metal alloy comprising the elements terbium, dysprosium, and iron.
26. A method of using a shaped waveform to control an injection valve that employs a magnetostrictive or piezoelectric actuator assembly, said method comprising, in sequence:

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- (a) initiating an injection event by applying a control pulse and accelerating valve opening by raising the value of said control pulse to a spike value that is greater than the value required for the desired lift;
 - (b) reducing said control pulse from said spike value to a value that is needed to provide said desired lift;
 - (c) reducing said control pulse to a negative value to accelerate valve closing;
 - (d) increasing said control pulse to a positive value to slow down valve closing to reduce the impact force of a valve needle on a valve seat; and
 - (e) reducing said control pulse to zero to close said valve.
27. The method of claim 26 further comprising, after increasing said control pulse to said spike value, momentarily reducing said control pulse to a value that is lower than the value that is needed for the desired lift.
28. The method of claim 26 wherein said spike value is up to about an order of magnitude higher than the value needed for the desired lift.
29. The method of claim 26 wherein said control pulse is a modulated current directed to an electric coil of an actuator assembly that comprises a magnetostrictive member.
30. The method of claim 26 wherein said control pulse is a modulated voltage applied to a piezoelectric stack of an actuator assembly.
31. The method claim 26 wherein the time needed to move said valve needle between a closed position and a desired open position may be as short as about 172 microseconds.
32. The method claim 26 wherein the time needed to move said valve needle between a closed position and a desired open position may be as short as about 250 microseconds.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,298,829 B1
DATED : October 9, 2001
INVENTOR(S) : Alan B. Welch, Irawan Rahardja and Mike Hebbes

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page.

Item [56], **Reference Cited**, FOREIGN PATENT DOCUMENTS, please delete reference "2 321 278 9/1998 (EP)" and insert -- 2 321 501 7/1998 (GB) --. Also please add the following reference -- 0 869 278 10/1998 (EP) --.

Signed and Sealed this

Sixth Day of August, 2002

Attest:



Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office



Bib Data Sheet

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark OfficeAddress: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER 09/522,130	FILING DATE 03/09/2000 RULE -	CLASS 123	GROUP ART UNIT 3747	ATTORNEY DOCKET NO. 12541US02
APPLICANTS Alan B Welch, Vancouver, CANADA; Irawan B Rahardja, Vancouver, CANADA; Mike Hebbes, Vancouver, CANADA;				
** CONTINUING DATA ***** THIS APPLN CLAIMS BENEFIT OF 60/159,791 10/15/1999				
** FOREIGN APPLICATIONS *****				
IF REQUIRED, FOREIGN FILING LICENSE GRANTED ** 05/17/2000				
Foreign Priority claimed ☒ yes ☐ no 35 USC 119 (a-d) conditions met ☒ yes ☐ no ☐ Met after Allowance Verified and Acknowledged ☒ Yes ☐ No Examiner's Signature: _____ Initials: _____		STATE OR COUNTRY CANADA	SHEETS DRAWING 5	TOTAL CLAIMS 30 INDEPENDENT CLAIMS 3
ADDRESS McAndrews Held & Malloy Ltd. 500 West Madison Street 34th Floor Chicago, IL 60661				
TITLE Directly actuated injection valve				
FILING FEE RECEIVED 1000	FEES: Authority has been given in Paper No. _____ to charge/credit DEPOSIT ACCOUNT No. _____ for following:		☐ All Fees ☐ 1.16 Fees (Filing) ☐ 1.17 Fees (Processing Ext. of time) ☐ 1.18 Fees (Issue) ☐ Other _____ ☐ Credit	

PATENT APPLICATION SERIAL NO. 09/522130

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

03/17/2000 BALEXAND 00000032 09522130

01 FC:101
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*U.S. GPO: 1999-459-082/19144

03-10-C

A

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Attorney Docket No. 12541US02

PATENT APPLICATION TRANSMITTAL

Box Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of

Inventor(s): Alan B. Welch, Irawan B. Rahardja and Mike Hebbes

Title: DIRECTLY ACTUATED INJECTION VALVE

1. Type of Application

This new application is for a:

- ☒ utility patent.
☐ design patent.

This application is a:

- ☐ continuation
☐ divisional
☐ continuation-in-part (CIP).

2. Application Papers Enclosed

- Title Page
43 Pages of Specification (excluding Claims, Abstract & Drawings)
9 Page(s) of Claims
2 Page(s) of Abstract
5 Sheet(s) of Drawings (Figs. 1 - 5)
☒ Formal
☐ Informal

CERTIFICATION UNDER 37 CFR 1.10

I hereby certify that this Patent Application Transmittal and the documents referred to as enclosed therewith are being deposited with the United States Postal Service on March 9, 2000, in an envelope addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231 utilizing the "Express Mail Post Office to Addressee" service of the United States Postal Service under Mailing Label No. EL542917239US.

Robert W. Fieseler

0050130-030500
0050130-030500

3. Declaration or Oath

☐ Enclosed

Executed by (check all applicable boxes)

☐ Inventor(s) (copy from prior application)

☐ Legal representative of inventor(s)
(37 CFR 1.42 or 1.43)

☐ Joint inventor or person showing a proprietary interest on behalf of
inventor who refused to sign or cannot be reached

☐ The petition required by 37 CFR 1.47 and the statement required
by 37 CFR 1.47 are enclosed. See Item 5D below for fee.

☒ Not enclosed - the undersigned attorney or agent is authorized to file this
application on behalf of the applicant(s). An executed declaration will follow.

4. Additional Papers Enclosed

☐ Preliminary Amendment

☐ Information Disclosure Statement, including copies of cited references

☐ Declaration of Biological Deposit

☐ Computer readable copy of sequence listing containing nucleotide and/or amino
acid sequence

☐ Verified statement(s) claiming small entity status under 37 CFR 1.9 and 1.27

☐ Associate Power of Attorney

☐ Verified translation of a non-English patent application

☐ An assignment of the invention (copy of recorded assignment(s) from prior
application)

☐ Certified copy(ies) of application(s):

COUNTRY	APPLICATION NO.	FILED

from which priority under 35 USC 119 is claimed ☐ is(are) attached.

☐ will follow.

☐ Other

5. Filing Fee Calculation (37 CFR 1.16)

A. ☒ Utility Application

CLAIMS AS FILED - INCLUDING PRELIMINARY AMENDMENT (IF ANY)						
			SMALL ENTITY		OTHER THAN A SMALL ENTITY	
	NO. FILED	NO. EXTRA	RATE	FEE	RATE	FEE
BASIC FEE				\$ 345.00		\$ 690.00
TOTAL	30 - 20	= 0	X 9 =	\$	X 18 =	\$ 180.00
INDEP.	3 - 3	= 0	X 39 =	\$	X 78 =	\$ 0.00
☐ First Presentation of Multiple Dependent Claim			+ 130 =	\$	+ 260 =	\$ 0.00
Filing Fee:				\$	OR	\$ 870.00

B. ☐ Design Application (\$155.00/\$310.00) Filing Fee: \$ _____

C. ☐ Plant Application (\$240.00/\$480.00) Filing Fee: \$ _____

D. Other Fees

☐ Recording Assignment [Fee -- \$40.00 per assignment] \$ _____

☐ Petition fee for filing by other than all the inventors or person on behalf of the inventor where inventor refused to sign or cannot be reached [Fee -- \$130.00] \$ _____

☐ Other \$ _____

Total Fees \$ 870.00

6. Method of Payment of Fees

☒ Enclosed check in the amount of: \$ 870.00

☐ Charge Deposit Account No. 13-0017 in the amount of: \$ _____
A copy of this Transmittal is enclosed.

☐ Not enclosed

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7. **Deposit Account and Refund Authorization**

The Commissioner is hereby authorized to charge any deficiency in the amount enclosed or any additional fees which may be required during the pendency of this application under 37 CFR 1.16 or 37 CFR 1.17 or under other applicable rules (except payment of issue fees), to Deposit Account No. 13-0017. A copy of this Transmittal is enclosed.

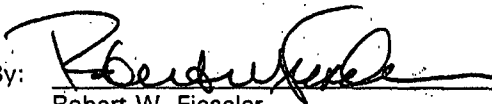
Please refund any overpayment to Deposit Account No. 13-0017.

Please direct all future communications to Robert W. Fieseler at the address below.

McAndrews, Held & Malloy, Ltd.
500 West Madison Street, 34th Floor
Chicago, Illinois 60661

Please direct all telephone calls to Robert W. Fieseler at (312) 707-8889. Please direct all facsimile transmissions to Robert W. Fieseler at (312) 707-9155. Please direct all e-mail transmissions to rfieseler@mhmlaw.com.

Respectfully submitted,

By: 
Robert W. Fieseler
Registration No. 31,826

Date: March 9, 2000

DIRECTLY ACTUATED INJECTION VALVE

Cross-Reference To Related Application(s)

The present application relates to and claims priority benefits from U.S. Provisional Patent Application Serial No. 60/159,791 filed October 15, 1999, entitled "Directly Actuated Injector", which is incorporated by reference in its entirety.

Technical Field

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.

Background

Direct injection of a gaseous fuel into the combustion chamber of an internal combustion engine is desirable for several reasons. For example, direct injection allows charge stratification, eliminating throttling losses associated with homogeneous charge engines. Additionally, with direct injection late in the compression stroke, a high-compression ratio can be maintained, maintaining efficiency. Further, when the fuel that is directly injected comprises

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natural gas, propane, or hydrogen, the emissions of NO_x and particulate matter (PM) are significantly reduced. The directly injected gaseous fuel can be ignited with a glow plug, with
5 a spark plug or with pilot diesel fuel. The gaseous fuel needs to be injected at high pressure to overcome the combustion chamber pressure, which is high at the end of the compression stroke. Preferably, the injection pressure is high enough
10 to promote good mixing between the injected fuel and the combustion chamber air.

Direct injection at high pressures presents several challenges. The use of high pressure fuels for direct injection results in high fuel
15 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
20 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
25 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
30 of time during which the fuel can be injected. For example, at 4500 revolutions per minute (RPM),

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at full load, all of the fuel is preferably injected in less than 2-3 milliseconds.

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). An injection valve is typically opened by increasing the hydraulic fluid pressure and closed by reducing the hydraulic fluid pressure, such that the opening force applied to the injection valve is reduced, causing the valve to close. However, in the context of a conventional gaseous injector, hydraulic operation presents several drawbacks, including:

- the need for additional hydraulic hardware such as a hydraulic pump, valves, and a reservoir for the hydraulic fluid;
- the need for a seal to be established between the variable pressure hydraulic fluid and the high pressure gaseous fuel;
- increased bulkiness of the injection valve assembly because of the additional hardware requirements; and

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- delayed response of the system due to time delay of the hydraulic fluid between the electrical valve hardware and the needle that controls gas flow from the injector.

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. In this respect, it is difficult to do lift control, with some limited capabilities when using double-spring configuration. Therefore, it is desirable to avoid the use of hydraulics to operate gas injectors, particularly for high-speed engines. "Lift" in the context of needle valves is defined herein as the displacement of the valve needle away from its closed/seated position to its open position.

In response to at least some of the drawbacks with hydraulic activation, solenoid actuators have been considered as an alternative for injection valve actuation because of the simplicity and reliability of solenoids. For example, U.S. Patent No. 5,035,360 (the '360 patent) discloses a directly actuated gas only injector employing a solenoid actuator. However, the application disclosed for the solenoid actuator is an injection valve for a two-stroke engine with an operating speed of 2100 RPM. The '360 patent discloses introducing fuel into the piston cylinder between the times during the engine cycle when the piston is at approximately bottom dead

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center and 60 degrees after bottom dead center. The '360 patent further discloses injecting fuel at a pressure of about 300 pounds per square inch (psi) (about 2.1 MPa). Accordingly, the fuel is

5 not introduced at pressures as high as the pressure when the piston is at or near top dead center, for example, at pressures of 3,000 psi (21 MPa) and higher. For a constant needle diameter, higher fuel pressures require higher actuating

10 forces and to increase the actuating force of a solenoid it must be made larger. The '360 patent also discloses that "large solenoids of conventional type are inherently slower than small ones". Thus solenoid actuators are not suitable

15 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

20 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.

25 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

30 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

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valve is open for) and not position control (how much the valve is lifted).

It is also known to use piezoelectric or magnetostrictive actuation (devices which can change their dimensions under the effect of an electric or magnetic field) for directly actuated injection valves. For example, U.S. Patent No. 5,031,841 (the '841 patent) describes a metering valve using an actuating member, which according to the patent could be a piezoelectric stack or a magnetostrictive actuator. One feature disclosed by the '841 patent is the addition of a diaphragm which has the dual purpose of acting as a spring biasing the valve in its closed position and of providing a seal between the metered fluid and the actuator. The '841 patent discloses an adjusting screw for mechanically setting the position of the actuator within the housing. According to the '841 patent, the valve needle is rigidly connected to the actuator by a pressure pin.

Piezoelectric or magnetostrictive actuation devices have also been used in injection valves to actuate an internal hydraulic control valve. For example, U.S. Patent No. 5,819,710 (the '710 patent) describes an injection valve within which a servo valve is used. The servo-valve is actuated by an actuating member, which could be a piezoelectric stack or a magnetostrictive material. The actuating member can be controlled to close the servo valve gently to reduce wear and improve service life. According to the '710 patent, the servo valve actuating member can be



paired with a insert bolt or stud to compensate for differences in thermal expansion between the actuator and the injector housing. (See column 4, lines 25-48).

5 U.S. Patent No. 5,845,852 (the '852 patent) describes another injector that employs a piezoelectric actuator to operate an internal three-way hydraulic control valve to open and close the main injection check valve. The '852
10 patent describes a piezoelectric actuator acting through the intermediate of a self-locking preload assembly. This self-locking preload assembly has three functions: (i) to compensate for
15 dimensional changes and/or imperfections; (ii) to offset some of the upward force due to fuel pressure; and, (iii) to preload the piezoelectric stack for better performance.

Similarly, U.S. Patent No. 5,779,149 describes an injector using a piezoelectric
20 actuator acting on a hydraulic control valve through the intermediate of a hydraulic amplifier, which serves to amplify the movement of the actuator. The hydraulic control valve allows the
25 main injection valve to open and close to meter the amount of fuel injected.

A problem with employing a piezoelectric or magnetostrictive actuator to operate a control valve, which in turn controls the flow of a
30 hydraulic fluid to operate an injection valve, is that this arrangement requires the intermediate action of a hydraulic fluid. Any delays caused by the displacement of the hydraulic fluid causes

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delays in the actuation of the injector.

Accordingly, there is a need for an injector that is directly actuated by an actuator without an intermediate active hydraulic operator generating

5 any actuating forces. Another disadvantage of active hydraulically operated systems is that a hydraulic fluid needs to be supplied and drained from a hydraulic cylinder. When diesel fuel is the main fuel used by the engine, the diesel fuel
10 may be used as the hydraulic fluid. However, when a gaseous fuel is the engine's main fuel, a separate hydraulic fluid system would be needed to operate injectors that rely on hydraulic
15 actuation.

Summary

An injection valve injects fuel into a combustion chamber of an internal combustion engine. The injection valve comprises:

- 20 (a) a valve housing comprising:
a fuel inlet port;
an interior chamber fluidly connected to the fuel inlet port;
a nozzle comprising a nozzle
25 orifice providing a fluid passage from the interior chamber to the combustion chamber;
- (b) a valve needle disposed within the valve housing wherein the valve needle is
30 movable between a closed position at which a sealing end of the valve needle contacts a valve seat to fluidly seal

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the interior chamber from the nozzle orifice, and an open position at which the sealing end of the valve needle is spaced apart from the valve seat whereby the interior chamber is fluidly connected with the nozzle orifice, wherein valve needle lift equals the distance traveled by the sealing end away from the valve seat;

- 5
- 10 (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;
- 15 (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
- 20 moving the valve needle to the open position; and
- 25 (e) a hydraulic link assembly comprising a hydraulic link having a fluid thickness through which the opening and closing forces are transmitted, wherein the thickness of the hydraulic link is adjustable in response to changes in the dimensional relationship between
- 30 components of the injection valve to maintain a desired valve needle lift when the actuator assembly is activated.

In a preferred embodiment, the thickness of the hydraulic link is auto-adjustable in response to changes in the dimensional relationship caused by differential thermal expansion, and/or wear to components of the injection valve. The hydraulic link assembly preferably comprises a sealed hydraulic cylinder, with a piston and hydraulic fluid disposed within the hydraulic cylinder. The piston may be an integral part of the valve needle.

The actuator assembly preferably comprises a magnetostrictive member or a piezoelectric stack. When the actuator assembly comprises a magnetostrictive member, an electric coil is disposed around the magnetostrictive member and a flux tube is disposed around the electric coil. In preferred arrangements, the actuator assembly may be disposed within the interior chamber of the injection valve. In a particular preferred embodiment, the actuator assembly is tubular and disposed within an annular space around a cylindrical portion of the valve needle. One end of the tubular actuator assembly may be held in a fixed position in relation to the valve housing by a pole that supports the magnetostrictive member. The pole is attached to the valve housing to prevent movement of the supported end of the magnetostrictive member when the actuator assembly is activated.

When the injection valve actuator assembly employs a magnetostrictive member or a piezoelectric stack, the actuator assembly is

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controllable to control the desired lift between 10 and 100 percent of maximum lift. That is, the control pulse directed to the actuator assembly can be modulated to provide full or partial lift, as desired. When the actuator assembly comprises a magnetostrictive member, the control pulse is a modulated electric current directed to an electric coil that produces a magnetic field. When the actuator assembly comprises a piezoelectric stack, the control pulse is a modulated voltage applied to the piezoelectric stack.

The present injection valve is particularly suited for injecting a gaseous fuel because the ability to modulate the movement of the valve needle may be beneficially used to slow down the closing action of the valve needle to reduce impact upon closing. When a liquid fuel is injected, the closing impact is dampened by the displacement of the thin liquid fuel layer, which is considerably denser than gaseous fuels. When the fuel is a gaseous fuel, it can be injected into the combustion chamber at a pressure greater than about 2000 psi (about 13.8 MPa).

A magnetostrictive material that is suitable for use in the present injection valve comprises a material known as **ETREMA Terfenol-D**[®] magnetostrictive alloy that is available from Etrema Products Inc. **ETREMA Terfenol-D**[®] magnetostrictive alloy is a metal alloy composed of the elements terbium, dysprosium, and iron.

In a preferred embodiment, the valve needle, actuated by a magnetostrictive or piezoelectric

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actuator assembly is controllable to move between the closed and open positions in less than about 250 microseconds.

To improve the range of valve lift for a given magnetostrictive or piezoelectric actuator length, a compressive force may be applied to the magnetostrictive member or piezoelectric stack. By pre-loading magnetostrictive members and piezoelectric stacks, net displacement may be increased per respective unit of applied magnetic field or applied voltage. Accordingly, a compression spring member may be employed for applying a compressive force to pre-load the magnetostrictive member or piezoelectric stack. In a preferred embodiment, the compression spring member comprises at least one disc spring (also known as a Belleville spring or Belleville washer).

The injection valve housing may comprise a plurality of parts that are joined with each other to provide a fluidly sealed body. For example, the valve housing may comprise a hollow main housing with a removable valve cap that allows access to the valve components disposed within the main housing. The valve housing may further comprise a separate valve tip so that it is replaceable when worn. In addition, the valve tip may be designed so that it is the only portion of the valve body that is directly exposed to the interior of the combustion chamber. In this case the valve tip may be made from a material that will provide greater durability when directly

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exposed to the conditions that might be expected within a combustion chamber.

While the hydraulic link is designed to compensate for changes in the dimensional relationships between valve components, including changes caused by differential thermal expansion, the demands placed upon the hydraulic link may be reduced by the selection of materials for the valve components that have similar thermal expansion coefficients.

A preferred fuel injection valve for an internal combustion engine comprises:

- (a) a valve housing comprising:
 - a fuel inlet port;
 - an interior chamber fluidly connected to the fuel inlet port;
 - a nozzle comprising a valve seat and a nozzle orifice providing a fluid passage from the interior chamber to the combustion chamber;
- (b) a valve needle comprising a cylindrical portion having a sealing end and a piston portion having a pre-load end, the valve needle disposed within the valve housing wherein the valve needle is movable between a closed position at which the sealing end contacts the valve seat to fluidly seal the interior chamber from the nozzle orifice, and an open position at which the sealing end is spaced apart from the valve seat whereby the interior chamber is fluidly

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connected with the nozzle orifice,
wherein valve needle lift equals
distance traveled by the sealing end
away from the valve seat;

- 5 (c) a needle spring associated with the pre-
load end of the valve needle, wherein
the needle spring is compressed to apply
a closing force to the valve needle for
10 biasing the valve needle in the closed
position;
- (d) an actuator assembly that may be
activated to apply an opening force to
the valve needle that is stronger than
the closing force, for moving the valve
15 needle to the open position, the
actuator assembly comprising:
a tubular magnetostrictive member
disposed around the cylindrical portion
of the valve needle;
- 20 an electrical coil disposed around
the magnetostrictive member;
a flux tube disposed around the
electrical coil; and
- 25 a support for the actuator assembly
that acts as a pole and provides a fixed
position for one end of the
magnetostrictive member relative to the
valve housing; and
- 30 (e) a hydraulic link assembly comprising a
sealed hydraulic cylinder disposed about
the piston portion of the valve needle,
a hydraulic fluid disposed within the

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hydraulic cylinder, wherein the opening and closing forces applied to the valve needle are transmitted through the thickness of hydraulic fluid whereby the hydraulic fluid acts as a hydraulic link and the thickness 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.

Also provided is a method of using a shaped waveform to control an injection valve that employs a magnetostrictive or piezoelectric actuator assembly. The method comprises, in sequence:

- (a) initiating an injection event by applying a control pulse and accelerating valve opening by raising the value of the control pulse to a spike value that is greater than the value required for the desired lift (the spike value may be up to about an order of magnitude higher than the value required for the desired lift);
- (b) reducing the control pulse from the spike value to a value that is needed to provide the desired lift;
- (c) reducing the control pulse to a negative value to accelerate valve closing;

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about 175 microseconds. More typically, however, the time needed to move the valve needle between the closed position and the desired open position may be as short as about 250 microseconds.

5 An advantage of the present injection valve is that it may be employed for late-cycle high-pressure direct injection of fuels into internal combustion engines. For example, the present
10 injection valve may be used to inject a gaseous fuel into the combustion chamber of an internal combustion engine at pressures of between about 2000 and 5000 psi (about 13.8 and 34.5 MPa). The
15 present injection valve may be employed to introduce liquid fuels into internal combustion engines at even higher pressures.

Still another advantage of the present injection valve is that it provides an injection valve that eliminates the need for an active hydraulic operator and the associated high-
20 pressure hydraulic system for generating the actuation force to actuate the injection valve. Conventional active hydraulic operators are different from the hydraulic link of the present
25 invention, which may be described as a passive hydraulic link because the hydraulic fluid sealed within the hydraulic link assembly merely transmits the actuating forces but is not employed
30 to generate an actuating force for actuating the valve. 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. A

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benefit of eliminating the need for a conventional active hydraulic operator is the elimination of the associated active hydraulic systems.

Conventional active hydraulic actuators, such as
5 those that employ rapidly increasing and decreasing hydraulic fluid pressure to actuate an injection valve need to be connected to a source of high pressure hydraulic fluid and need valves for controlling the flow of hydraulic fluid in and
10 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
15 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-
20 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
25 hydraulic cylinder.

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
30 manufacturing and assembly tolerances. The disclosed passive hydraulic link accomplishes this by auto-adjusting itself in response to these

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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.

An advantage of employing a directly actuated injection valve is that a shaped control pulse may be employed to control the acceleration and deceleration of the valve needle as it moves between the open and closed positions. For example, when a magnetostrictive actuator is employed, the current applied to the electromagnetic coil can be controlled, for example, to reduce the current in a manner that will close the valve gently. Similarly, when a piezoelectric actuator is employed, the voltage applied to the piezoelectric stack can be controlled, for example, to accelerate the opening of the valve by initially providing an over-voltage (that is, a voltage that is higher than the voltage that is needed to provide the necessary displacement). Thus, control pulses may be employed to control the expansion and contraction of magnetostrictive or piezoelectric actuators to control the movement of the valve needle. An advantage of controlling the deceleration of the valve needle is that the impact of the valve needle on the valve seat upon closing can be reduced to reduce the wear on the valve components, thereby improving durability.

Yet another advantage of the present injection valve is that the control pulse may be

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shaped to provide for partial lifting of the valve
needle in a repeatable manner. The amount of lift
may be controlled by shaping the control pulse to
control the amount of electrical current or
5 voltage directed to the respective
magnetostrictive or piezoelectric actuator
assembly.

Still another advantage of the disclosed
injection valve is that the actual valve needle
10 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.

15 These and other advantages are provided by a
directly actuated injector as described below.

Brief Description Of The Drawings

20 Figure 1 is a cross-sectional view of a
preferred embodiment of a directly actuated fuel
injection valve;

Figure 2 is an enlarged view of an upper
portion of the fuel injection valve of Figure 1;

25 Figure 3 is an enlarged view of a lower
portion of the fuel injection valve of Figure 1;

Figure 4 is a timing diagram for a preferred
method of controlling electric current applied to
the actuator assembly of the fuel injection valve
30 of Figure 1; and

Figure 5 is a timing diagram for a preferred
method of controlling voltage applied to a

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piezoelectric actuator assembly for a fuel injection valve.

Detailed Description Of Preferred Embodiment(S)

5 Figures 1 through 3 show a preferred embodiment of a directly actuated fuel injection valve 100 for internal combustion engines. Injection valve 100 includes elongated valve housing 102 that cooperates with valve cap 104 and
10 valve tip 106 to provide a fluidly sealed valve body. Seals may be employed to ensure that the assembled valve body is fluid-tight. Valve cap 104 comprises inlet port 108 through which fuel enters the valve body, and valve tip 106 comprises
15 at least one nozzle orifice 110 through which fuel exits the valve body. Valve tip 106 further comprises valve seat 112.

 In the preferred embodiment, shown more clearly in the enlarged view of Figure 3, valve
20 seat 112 is angled to maximize fluid flow following the sealing area (where valve needle 114 contacts valve seat 112). The differential angle between the end surface of valve needle 14 and
25 valve seat 112 is chosen so that the flow area does not decrease as gas moves inward toward the central throat of valve tip 106 that feeds nozzle orifice(s) 100.

Valve Needle

30 Valve needle 114 is disposed within the interior of the valve body and contacts valve seat 112 to close injection valve 100 by preventing

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fuel from passing beyond valve seat 112 to nozzle orifice 110. In the embodiment of Figure 1, valve needle 114 comprises valve stem 114a, which moves into the open position by moving inward within the valve body to lift away from valve seat 112. Valve stem 114a is a cylindrical member and since the valve lift is generally small (for example, about 65 micrometers), the diameter of valve stem 114a is selected to ensure sufficient flow capacity through the valve opening since flow area (A) is proportional to valve stem diameter (that is, $A = \pi \times \text{diameter} \times \text{lift}$). Hence, a small lift can be compensated for by a larger diameter. In the preferred embodiment illustrated by Figure 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.

Spring Assembly

A spring assembly biases valve needle 114 in the closed position. In a preferred arrangement, the spring assembly comprises at least one needle spring 116 for providing a closing force to valve needle 114. With reference to embodiment of Figure 1, the spring assembly further comprises a

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needle spring guide 118 for transmitting the closing force from needle spring 116 to valve needle 114. Needle spring 116 is held in compression by needle spring adjuster 120, which
5 cooperates with needle spring housing 122 to provide a load path to valve housing 102. In a preferred arrangement, respective threaded surfaces join needle spring adjuster 120 to needle spring housing 122, and needle housing 122 to
10 valve housing 102. After needle spring adjuster 120 has been rotated to compress needle spring 116 to provide the desired pre-load force to needle spring 116, locking nut 124 may be tightened to prevent needle spring adjuster 120 from loosening.
15 The spring energy set by compressing or pre-loading needle spring 116 provides the closing force for keeping valve needle 114 in the closed position.

20 Actuator Assembly

An actuator assembly may be activated to provide an opening force that is opposite and greater than the closing force provided by the spring assembly. In the embodiment illustrated in
25 Figure 1, the actuator assembly comprises a member that expands or contracts in the direction of the opening force when the member is exposed to a magnetic field or subjected to an electrical voltage, such as, for example, a magnetostrictive
30 material or a piezoelectric stack.

In the embodiment illustrated by Figure 1, the actuator assembly is a magnetostrictive

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actuator that comprises magnetostrictive member 130, electric coil 132 disposed around the outer diameter of magnetostrictive member 130, a flux tube 134 disposed around electric coil 132. Flux tube 134 may be made from common carbon steel with a lengthwise slit to break eddy currents. An electric current is supplied to electrical fitting 136. Electric leads (not shown) conduct the electric current from electrical fitting 136 to electric coil 132. When an electric current is applied to electric coil 132 a magnetic flux develops that flows through magnetostrictive member 130, pole 138, 140 and 142, and flux tube 134. Poles 138, 140 and 142 are made from a suitable material such as carbon steel (for example CS1018) or steel that has a low magnetic hysteresis. Pole 138 is a "fixed" pole that provides a structural support for a first end of magnetostrictive member 130, electric coil 132 and flux tube 134. Pole 140 is associated with a second end of magnetostrictive member 130 and pole 142 is associated with a second end of electric coil 132 and flux tube 134. Pole 140 is an "inner" pole and pole 142 is an "outer" pole disposed concentrically around inner pole 140. Pole 142, electric coil 132 and flux tube 134 are held in place by lock nut 144, which preferably threads into the inner wall of valve housing 102. Poles 140 and 142 cooperate with one another to provide a flux path at the second end of the actuator assembly, but pole 140 may move relative to pole 142 so that magnetostrictive member 130

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may expand in the direction of the magnetic field which is oriented so that the actuator assembly provides an opening force in opposition to the closing force of the spring assembly.

5 A pre-compression force is preferably applied to magnetostrictive member 130 to amplify the magnitude of expansion when a magnetic field is applied. Pre-compression of magnetostrictive member 130 increases the net displacement per unit
10 of applied magnetic field. Similarly, when a piezoelectric member is substituted for magnetostrictive member 130, pre-compression increases the net displacement of the piezoelectric member per unit of applied electric
15 voltage. A spring, such as, for example, disc spring 150 may be employed to provide the pre-compression force. Alternative compression elements may be employed in place of disc spring 150 to provide the pre-compression force, such as,
20 for example, a coil spring or another type of spring with the same spring force, a hydraulic piston, or a combination of compression elements. When a pre-compression force is employed, the actuator's displacement can increase to about
25 0.13% of the total length of magnetostrictive member 130. However, the amount of displacement may decline as a function of increasing temperature. For example, at typical reciprocating engine cylinder head temperatures
30 the actual displacement may be about 0.065% of the length of pre-compressed magnetostrictive member 130.

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The dimensions of magnetostrictive member are dictated by the requirements of injection valve 100. For example, if injection valve 100 is designed to provide a lift of at least about 65

5 μm , magnetostrictive member 130 is sized to have a length of at least about 100 mm. Additionally, the wall thickness of annular magnetostrictive member 130 is selected to provide sufficient force to overcome all of the opposing forces that hold
10 injection valve 100 in the closed position. If the cross-sectional area of annular magnetostrictive member 130 is not sufficient, the opposing forces can reduce or prevent longitudinal displacement of magnetostrictive member 130, even
15 when electric coil 132 is fully energized. This mode is known as the "blocked force" mode. Accordingly, the magnitude of the closing forces acting on valve needle 114 dictate the cross sectional area of magnetostrictive member 130.

20 While Figure 1 shows magnetostrictive member 130, electric coil 132, and flux tube 134 could be replaced with a piezoelectric stack (not shown). Electrical fitting 136 could be employed to direct an electric voltage to the piezoelectric stack.
25 When an electric voltage is applied to a piezoelectric stack, the stack expands and develops a motive force for opening injection valve 100.

As shown in Figure 1, the actuator assembly
30 may be located within valve housing 102 and disposed concentrically around valve stem 114a where it occupies a portion of the annular space

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between valve stem 114a and valve housing 102. Accordingly, the actuator assembly may be exposed to fuel that is directed through the hollow valve body on its way from inlet port 108 to nozzle
5 orifice 110.

Hydraulic Link Assembly

The opening force generated by the actuator assembly is transmitted to valve needle 114
10 through a hydraulic link assembly. The hydraulic link assembly comprises hydraulic cylinder 160, which is disposed in close-fitting relationship around hydraulic piston 114b, which is free to move in the longitudinal direction within cylinder
15 160. As mentioned above, in the embodiment of Figure 1, hydraulic piston 114b is an integral part of valve needle 114 and the side wall of cylinder 160 helps to guide the movement of valve needle 114 in the actuating direction. A viscous
20 hydraulic fluid is sealed inside hydraulic cylinder 160 by cylinder cap 162 and seals 166, 168 and 169 (see Figure 2). Seals 166 and 168 permit valve needle 114 to move relative to cylinder cap 162 and cylinder 160, respectively.
25 Known seals may be employed, such as, for example elastomeric O-ring seals, packing, metal seals, or diaphragm/bellow seals.

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

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is dependent on the viscosity of the chosen hydraulic fluid. The hydraulic flow in the clearance gap is governed by the Hagen-Poiseuille Flow and the hydraulic fluid and clearance gap are preferably selected so that the flow of hydraulic fluid through the gap is insignificant during the time span of fuel injection events when an opening force is transmitted through the hydraulic fluid. Furthermore, the hydraulic fluid preferably has a sufficiently high viscosity and bulk modulus so that it acts as an incompressible solid when activation of the actuator assembly causes a valve opening force to be quickly transmitted through the hydraulic fluid between the bottom of cylinder 160 and hydraulic piston 114b. For consistency of operation, the hydraulic fluid is also preferably an extremely stable fluid that maintains its desired properties over a wide range of temperatures (that is, within the expected operating temperatures inside cylinder 160). Suitable hydraulic fluids are, for example, conventional motor oil, such as grade 15W40, or synthetic lubricants such as DuPont® "Krytox®" grease which is available in a range of viscosities. Krytox® is a PerFluoroPolyEther (PFPE) synthetic lubricant that may be mixed with a thickener to form a grease. These types of hydraulic fluids also help to lubricate seals 166 and 168. Different injection valves may have different sized pistons and clearance gaps, so the hydraulic fluid may be selected with consideration

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to the characteristics of an individual injection valve design.

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.

Differential thermal expansion or contraction may be caused by differences in thermal expansion coefficients or uneven heat distribution between the components. Even though the components of injection valve 100, such as magnetostrictive member 130, valve needle 114, and valve housing 102, are designed to be reasonably matched to the thermal expansion rates of the other components, because the valve needle lift and the displacement

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of the components that causes the lift are so small, the effects of thermal expansion or contraction need to be taken into account to ensure the desired valve needle lift is achieved.

5 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
10 cold climates) and +125°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
15 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
20 greater than the targeted lift.

In summary, the hydraulic link assembly accounts for variations in component dimensions arising from the permitted tolerances in the manufacturing processes and the injection valve
25 assembly methods. Therefore, the hydraulic link assembly reduces manufacturing costs by allowing the injection valve components to be manufactured to less exacting tolerances. In addition, during operation, the hydraulic link assembly auto-
30 adjusts itself between injection events to account for changes in the dimensional relationship between injection valve components that may be

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caused, for example, by component wear or differential thermal expansion or contraction.

Summary of Operation

5 When injection valve 100 is at rest in the closed position, the closing force that biases valve needle 114 against valve seat 112 originates from needle spring 116. From needle spring 116, the closing force is transmitted through needle
10 spring guide 118 to valve needle 114. It is preferable for the closing force to be provided by a mechanical spring member, such as the illustrated coil spring, so that the failure mode for injection valve 100 will be in the closed
15 position. That is, if the actuating assembly is not energized or fails, injection valve 100 will remain in the closed position.

 To initiate an injection event the actuator assembly is energized by directing an electric
20 current to electric coil 132. A magnetic flux develops that flows through magnetostrictive member 130, poles 138, 140, and 142, and flux tube 134. Under the influence of the magnetic field, magnetostrictive member 130 expands in length (in
25 the direction of the magnetic field). Since pole 138 is in a fixed position, magnetostrictive member 130 expands in the direction of hydraulic cylinder 160. An opening force, originating from expanding magnetostrictive member 130 is
30 transmitted through inner pole 140, the base of cylinder 160, hydraulic fluid 164b (see Figure 2), which is held between the base of cylinder 160 and

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a planar surface of hydraulic piston 114b, and finally, through piston 114b, which in the illustrated embodiment is integral with valve needle 114. The opening force is greater than the closing force, which results in compression of needle spring 116. The displacement of hydraulic cylinder 160 also causes further compression of disc spring 150.

As previously discussed, because valve actuation occurs suddenly (on the order of 200 μ 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.

The movement of valve needle 114 is guided near valve tip 106 by guide 180 (see Figure 3). Figure 3 shows annular space 182 disposed around valve stem 114a. Between injection events, fuel remains in annular space 182. When injection valve 100 is open, fuel flows through annular

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space 182, other gaps between valve components, and openings provided in certain valve components, which all cooperate to permit the free flow of fuel from inlet port 108 through to nozzle orifice 110 (which may be one of a plurality of nozzle orifices radially oriented from the nozzle throat). For example, Figures 1 through 3 show openings that provide fluid passages through components such as needle spring housing 122, lock nut 144, and pole 138. Figure 3 also shows seal 184 between valve housing 102 and valve tip 106, and cylinder head face seal 186, which seals between injection valve 100 and the engine cylinder head (not shown).

As fuel flows through valve housing 102, the fuel cools the actuator assembly. The fuel flow path is preferably arranged to provide the greatest cooling to the internal diameter surface of electric coil 132 and the outer diameter surface of magnetostrictive member 130. In addition, a small percentage of the fuel flow, perhaps up to about 20%, may be directed to flow between the internal diameter of magnetostrictive member 130 and the surface of cylindrical valve stem 114a. When the fuel is used to cool the actuator assembly in this manner, thermal modeling predicts a temperature rise of less than 10°C.

To close injection valve 100, at the end of the injection event, electric coil 132 is de-energized, causing magnetostrictive member 130 to contract. When valve needle 114 is moving from the open position to the closed position, the

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closing force originates from needle spring 116 and disc spring 150. The closing force from needle spring 116 is again transmitted to valve needle 114 through needle spring guide 118. In the open position, the expanded magnetostrictive member 130 compressed disc spring 150, so upon closing, disc spring 150 de-compresses to push cylinder 160 down and to compress to magnetostrictive member 130. Disc spring 150 may also provide an additional closing force to valve needle 114 by generating a closing force that is transmitted from disc spring 150 through cylinder cap 162, hydraulic fluid 164a and hydraulic piston 114b.

When valve needle 114 moves from the open position to the closed position, the time that elapses is again typically less than 250 microseconds, and preferably less than about 200 microseconds so hydraulic fluid 164 again does not have time to flow through the clearance gap between piston 114b and cylinder 160. Consequently, pressure builds up in hydraulic fluid 164a on the upper planar surface of piston 114b.

Once valve needle 114 contacts valve seat 112, injection valve 100 is closed. When injection valve 100 is closed, the hydraulic link assembly automatically self-adjustments so that the position of hydraulic cylinder 160 relative to hydraulic piston 114b is corrected to account for the effects of temperature, wear, and any small movements of valve needle 114 relative to

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hydraulic cylinder 160 that may have occurred while valve needle 114 was in the open position. Auto-adjustments are accomplished by the migration of hydraulic fluid 164 from one side of hydraulic piston 114b to the other, while disc spring 150 ensures that hydraulic cylinder 160 and valve needle 114 remain in direct contact at all times.

Control Strategy

10 Waveforms for controlling a directly actuated injection valve and corresponding actuator displacements are plotted in the graphs shown in Figures 4 and 5. The illustrated waveforms show that the control pulse may employ several features to control the movement of a magnetostrictive or piezoelectric member respectively.

15 In Figure 4, waveform A represents the electric current that is directed to an electric coil that is used to activate an actuator comprising a magnetostrictive member. The strength of the magnetic field is directly proportional to the amount of electric current that is directed to the electric coil. To promote fast opening, the current is preferably first spiked to current I_1 since higher currents yield stronger magnetic fields that can be employed to accelerate the expansion of the magnetostrictive member. The electric current is lowered to current I_2 during the main injection event.

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30 Initial electric current I_1 corresponds to a current that may be as much as an order of magnitude higher than electric current I_2 , which

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is the current that is actually required to fully open the injection valve. It is also possible to partially open the injection valve, for example, by reducing the current after the initial current spike to a value less than current I_2 . As shown by dashed waveform B, which temporarily reverses the current to negative current I_3 , the control pulse may be optionally shaped to lower the average current to a level that allows quick attainment of partial lift for better flow control than that which can be obtained purely through pulsewidth modulation. That is, better flow control can be achieved by controlling both the displacement of the valve needle (lift) and the duration of the injection event.

Valve closure may be optionally accelerated by initially reversing the current to negative current I_4 . To reduce the impact and consequent wear of the valve needle when it makes contact with the valve seat, as shown by waveform A, the current may be momentarily increased to positive current I_5 to slow down the valve closing action. In an alternative method for controlling the impact of the valve needle on the valve seat, the current can be more gradually reduced without reversing the direction of current, as shown by dotted-line C. Finally, the injection event is completed when injection valve is closed and current is returned to zero.

Line graphs D and E show the displacement of the valve needle through respective fully open and partially open injection events. Graph D

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corresponds to the injection event controlled by waveform A. Graph D shows the valve needle quickly moving to the fully open position at the beginning of the injection event. In the

5 illustrated example, the injection valve remains in the fully open position for the majority of the injection event, as represented by the essentially flat portion of graph D. However, depending upon the viscosity of the hydraulic fluid and the size
10 of the clearance gap between the hydraulic piston and the hydraulic cylinder, the flat portion of graph D may have a slight slope caused by the flow of hydraulic fluid through the clearance gap during the injection event.

15 When the injection valve is closed, the closing action is very quick, as shown by the steep downward slope of line D near the end of the injection event. However, in response to the momentary positive current near the end of
20 waveform A, the slope of graph D flattens out just as the valve is returning to the fully closed position, demonstrating how the shape of waveform A can be used to reduce wear caused by the impact of the valve needle on the valve seat. Graph E
25 corresponds to a waveform (not shown) which, after the initial current spike reduces the current to a value less than current I_2 , so that the injection valve is only partially opened. Graph E also shows that the duration of the injection event may
30 be varied by changing the length or duration of the waveform. Compared to the injection event represented by graph D, the valve lift is smaller.

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for the injection event represented graph E, so the initial current spike may be lower than the initial current spike of waveform A. The closing action represented by the more gradual slope of graph E (compared to the steeper slope of graph D), corresponds to a waveform having a shape similar to alternate waveform C.

Persons skilled in the art will recognize that the time required to open or close the injection valve may be decreased by increasing the slope of the control waveform, or increased, by decreasing the slope of the waveform. Thus the shape of the control waveform may be manipulated to produce the desired effects on the speed of the valve needle movement and its displacement with respect to the valve seat (to control lift).

In Figure 5, waveform G represents a voltage control pulse that may be used to activate a piezoelectric actuator. As will become apparent, the preferred control strategy for piezoelectric actuators employs the same principles as the preferred control strategy described above for magnetostrictive actuators. To promote fast opening, the voltage is preferably first spiked to voltage V_1 since higher voltages can be employed to accelerate the expansion of piezoelectric materials. The voltage is lowered to voltage V_2 during the main injection event. Voltage V_1 corresponds to a voltage that may be as much as an order of magnitude higher than voltage V_2 , which is the voltage that is actually required to fully open the injection valve. It is also possible to

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partially open the injection valve, for example, by reducing the voltage after the initial voltage spike to a value less than voltage V_2 . As shown by dashed waveform H, which temporarily reduces the voltage to negative voltage V_3 , the control pulse may be optionally shaped to lower the average voltage to a level that allows quick attainment of partial lift for better flow control than that which can be obtained purely through pulsewidth modulation. That is, better flow control can be achieved by controlling both the displacement of the valve needle (lift) and the duration of the injection event.

Valve closure may be optionally accelerated by initially reducing the voltage to negative voltage V_4 . To reduce the impact and consequent wear of the valve needle when it makes contact with the valve seat, as shown by waveform G, the voltage may be momentarily increased to positive voltage V_5 to slow down the valve closing action. Similar to the shape of current waveform C, the shape of voltage waveform I represents an alternative method for reducing the impact of the valve needle on the valve seat upon closing. Finally, the injection event is completed when injection valve is closed and voltage is returned to zero.

Line graphs J and K show the displacement of the valve needle through respective injection events. Graph J corresponds to the injection event controlled by waveform G. Graph J shows the valve needle quickly moving to the fully open

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position at the beginning of the injection event. In the illustrated example, the injection valve remains in the fully open position for the majority of the injection event, as represented by the essentially flat portion of graph J. However, depending upon the viscosity of the hydraulic fluid and the size of the clearance gap between the hydraulic piston and the hydraulic cylinder, the flat portion of graph J may have a slight slope caused by the flow of hydraulic fluid through the clearance gap during the injection event.

When the injection valve is closed, the closing action is very quick, as shown by the steep downward slope of line J near the end of the injection event. However, in response to the momentary positive voltage near the end of waveform G, the slope of line J flattens out just as the valve is returning to the fully closed position, demonstrating how the shape of waveform G can be used to reduce wear caused by the impact of the valve needle on the valve seat. Graph K is similar to graph J except that it corresponds to a waveform (not shown) which, after the initial voltage spike reduces the voltage to a value less than voltage V_2 , so that the injection valve is only partially opened.

The time span for the waveforms of Figures 4 and 5 may be in the range of 100 to 5000 microseconds, and typically between 250 and 2000 microseconds for the majority of injection events.

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The combination of the above described directly actuated injection valve and control strategy provides several benefits, including:

- 5 • elimination of the hydraulic fluid supply system that is needed by conventional hydraulically actuated injection valves. This simplifies injection valve construction, for example, by eliminating the need for
10 hydraulic fluid supply and return passages and three way valves that are employed by conventional hydraulically actuated injection valves.
- 15 • automatic compensation for differential thermal expansion within the injection valve, for wear due to prolonged operation, and for small differences caused by limitations in manufacturing tolerances.
- 20 • a compact concentric valve needle/actuator assembly arrangement for accommodating an elongated magnetostrictive or piezoelectric member.
- 25 • an apparatus that permits the use of a control strategy that can throttle fuel flow and reduce valve seat wear. The ability to control the lift displacement permits reduced injection at lower loads
30 and reduced pre-mixed burning. For example, using a magnetostrictive or piezoelectric actuator, the valve needle

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movement can be controlled between about 10% and 100%. For lower load conditions it is important to be able to reduce the flow of fuel into the combustion chamber, since excess fuel may not be combusted, resulting in lower operating efficiency and higher emissions.

- improved manufacturability is made possible by the use of axisymmetric cylindrical parts and few tight tolerances between the injection valve components.
- valve operation is improved since the actuating assembly permits greater control of the valve needle. For example, the injection valve may be used to inject a gaseous or liquid fuel. When the fuel is gaseous, there is a greater need to slow down the valve needle upon closing because there is no liquid fuel to dampen the impact of the valve needle on the valve seat. By shaping the control pulse waveform applied to the actuator it is possible to slow down the closing of the injection valve to reduce impact on the valve needle and the valve seat.

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled

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in the art without departing from the spirit and scope of the present disclosure, particularly in light of the foregoing teachings.

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What is claimed is:

- Suba's
1. An injection valve for injecting fuel into a combustion chamber of an internal combustion engine, said injection valve comprising:
- 5
- (a) a valve housing comprising:
- 10 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;
- 15 (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;
- 20 wherein valve needle lift equals the distance traveled by said sealing end away from said valve seat;
- 25 (c) a needle spring associated with said valve needle, wherein said needle spring applies a closing force to said valve
- 30

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Suba' >

needle for biasing said valve needle 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

(e) a hydraulic link assembly comprising a hydraulic link having a fluid thickness through which said opening and closing forces are transmitted, wherein said thickness of said hydraulic link is adjustable in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift when said actuator assembly is activated.

2. The injection valve of claim 1 wherein said thickness of said hydraulic link is auto-adjustable in response to changes in said dimensional relationship caused by differential thermal expansion.

3. The injection valve of claim 2 wherein said thickness of said hydraulic link is auto-adjustable in response to changes in said dimensional relationship caused by wear to components of said injection valve.

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4. The injection valve of claim 1 wherein
said hydraulic link assembly comprises a sealed
hydraulic cylinder, with a piston and hydraulic
5 fluid disposed within said hydraulic cylinder.

5. The injection valve of claim 4 wherein
said piston is an integral part of said valve
needle.

10

6. The injection valve of claim 1 wherein
said actuator assembly comprises a
magnetostrictive member or a piezoelectric stack.

15

7. The injection valve of claim 1 wherein
said actuator assembly comprises a
magnetostrictive member, an electric coil disposed
around said magnetostrictive member and a flux
tube disposed around said electric coil.

20

8. The injection valve of claim 7 wherein
said actuator assembly is disposed within said
interior chamber.

25

9. The injection valve of claim 8 wherein
said actuator assembly is tubular and disposed
within an annular space around a cylindrical
portion of said valve needle.

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10. The injection valve of claim 9 wherein
one end of said tubular actuator assembly is

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supported by a pole that is attached to said valve housing.

11. The injection valve of claim 6 wherein
5 when said actuator assembly is controllable to control said desired lift to between 10 and 100 percent of maximum lift.

12. The injection valve of claim 11 wherein
10 said lift is controllable by controlling the electric current directed or voltage applied to said respective magnetostrictive or piezoelectric actuator assembly.

13. The injection valve of claim 7 wherein
15 said magnetostrictive member comprises a metal alloy comprising the elements terbium, dysprosium, and iron.

14. The injection valve of claim 6 wherein
20 said valve needle is controllable to move between said open and closed positions in less than about 200 microseconds.

15. The injection valve of claim 6 further
25 comprising a compression spring member for applying a compressive force to said magnetostrictive or piezoelectric member.

16. The injection valve of claim 15 wherein
30 said compression spring member comprises at least one disc spring.

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17. The injection valve of claim 1 wherein said fuel is a gaseous fuel.

5 18. The injection valve of claim 1 wherein said fuel is injected into said combustion chamber at a pressure greater than about 2000 psi (about 13.8 MPa).

10 19. The injection valve of claim 1 wherein said valve housing comprises a plurality of parts which are joined with each other to provide a fluidly sealed body.

15 20. The injection valve of claim 1 wherein said valve housing, said valve needle, and said actuator assembly, are selected from materials with similar thermal expansion coefficients to reduce changes in the dimensional relationship
20 between said components caused by changes in temperature.

23

21. An injection valve for injecting fuel into a combustion chamber of an internal
25 combustion engine, said injection valve comprising:

(a) a valve housing comprising:
a fuel inlet port;
an interior chamber fluidly
30 connected to said fuel inlet port;
a nozzle comprising a valve seat
and a nozzle orifice providing a fluid

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passage from said interior chamber to said combustion chamber;

(b) a valve needle comprising a cylindrical portion having a sealing end and a piston portion having a pre-load end, said valve needle disposed within said valve housing wherein said valve needle is movable between a closed position at which said sealing end contacts said valve seat to fluidly seal said interior chamber from said nozzle orifice, and an open position at which said sealing end is spaced apart from said valve seat whereby said interior chamber is fluidly connected with said nozzle orifice, wherein valve needle lift equals distance traveled by said sealing end away from said valve seat;

(c) a needle spring associated with said pre-load end of said valve needle, wherein said needle spring is compressed to apply a closing force to said valve needle for biasing said valve needle in said closed position;

(d) an actuator assembly that may be activated to apply an opening force to said valve needle that is stronger than said closing force, for moving said valve needle to said open position, said actuator assembly comprising:

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a tubular magnetostrictive member disposed around said cylindrical portion of said valve needle;

an electrical coil disposed around said magnetostrictive member;

a flux tube disposed around said electrical coil; and

a support for said actuator assembly that acts as a pole and provides a fixed position for one end of said magnetostrictive member relative to said valve housing; and

(e) a hydraulic link assembly comprising a sealed hydraulic cylinder disposed about said piston portion of said valve needle, a hydraulic fluid disposed within said hydraulic cylinder, wherein said opening and closing forces applied to said valve needle are transmitted through a thickness of said hydraulic fluid whereby said hydraulic fluid acts as a hydraulic link and said thickness is automatically adjustable in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift when said actuator assembly is activated.

²⁴
~~22~~. The injection valve of claim ²³~~21~~ further comprising a compression spring member for

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applying a compressive force to said
magnetostrictive member.

25
~~23~~ The injection valve of claim ²³~~21~~ wherein
5 said magnetostrictive member comprises a metal
alloy comprising the elements terbium, dysprosium,
and iron.

26
~~24~~. A method of using a shaped waveform to
10 control an injection valve that employs a
magnetostrictive or piezoelectric actuator
assembly, said method comprising, in sequence:
(a) initiating an injection event by
15 applying a control pulse and
accelerating valve opening by raising
the value of said control pulse to a
spike value that is greater than the
value required for the desired lift;
(b) reducing said control pulse from said
20 spike value to a value that is needed to
provide said desired lift;
(c) reducing said control pulse to a
negative value to accelerate valve
closing;
25 (d) increasing said control pulse to a
positive value to slow down valve
closing to reduce the impact force of a
valve needle on a valve seat; and
(e) reducing said control pulse to zero to
30 close said valve.

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²⁷
~~25~~. The method of claim ²⁶~~24~~ further
comprising, after increasing said control pulse to
said spike value, momentarily reducing said
control pulse to a value that is lower than the
5 value that is needed for the desired lift.

²⁸
~~26~~. The method of claim ²⁶~~24~~ wherein said
spike value is up to about an order of magnitude
higher than the value needed for the desired lift.

10 ²⁹
~~27~~. The method of claim ²⁶~~24~~ wherein said
control pulse is a modulated current directed to
an electric coil of an actuator assembly that
comprises a magnetostrictive member.

15 ³⁰
~~28~~. The method of claim ²⁶~~24~~ wherein said
control pulse is a modulated voltage applied to a
piezoelectric stack of an actuator assembly.

20 ³¹
~~29~~. The method claim ²⁶~~24~~ wherein the time
needed to move said valve needle between a closed
position and a desired open position may be as
short as about 172 microseconds.

25 ³²
~~30~~. The method claim ²⁶~~24~~ wherein the time
needed to move said valve needle between a closed
position and a desired open position may be as
short as about 250 microseconds.

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DIRECTLY ACTUATED INJECTION VALVE

Abstract

5 A directly actuated injection valve comprises a hollow valve housing, a valve needle disposed within the hollow interior, a needle spring, an actuator assembly, and a hydraulic link assembly. The valve needle is movable between a closed position and an open position for governing the flow of fuel into the combustion chamber of an internal combustion engine. The displacement of the valve needle from the closed position is defined as the lift. The a needle spring biases the valve needle in the closed position. The actuator assembly generates an opening force that acts against the needle spring to open the valve. The hydraulic link assembly is interposed between the valve needle and the needle spring and the actuator assembly. The hydraulic link assembly transmits respective closing and opening forces to the valve needle.

10 20 The hydraulic link preferably comprises a piston disposed within a cylinder that is filled with a hydraulic fluid. The opening and closing forces are transmitted through a thickness of the hydraulic fluid that is trapped between the planar surfaces of the piston and the head and base of the hydraulic cylinder. 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

25 30

components of the injection valve to maintain a
desired valve needle lift when the actuator
assembly is activated. When the actuator
35 assembly comprises a magnetostrictive or
piezoelectric member, the movements of the
valve needle can be controlled by the
application of a shaped control pulse or
waveform to improve the speed of the opening
40 and closing motion of the valve needle, and to
reduce the impact of the valve needle on the
valve seat upon closing.

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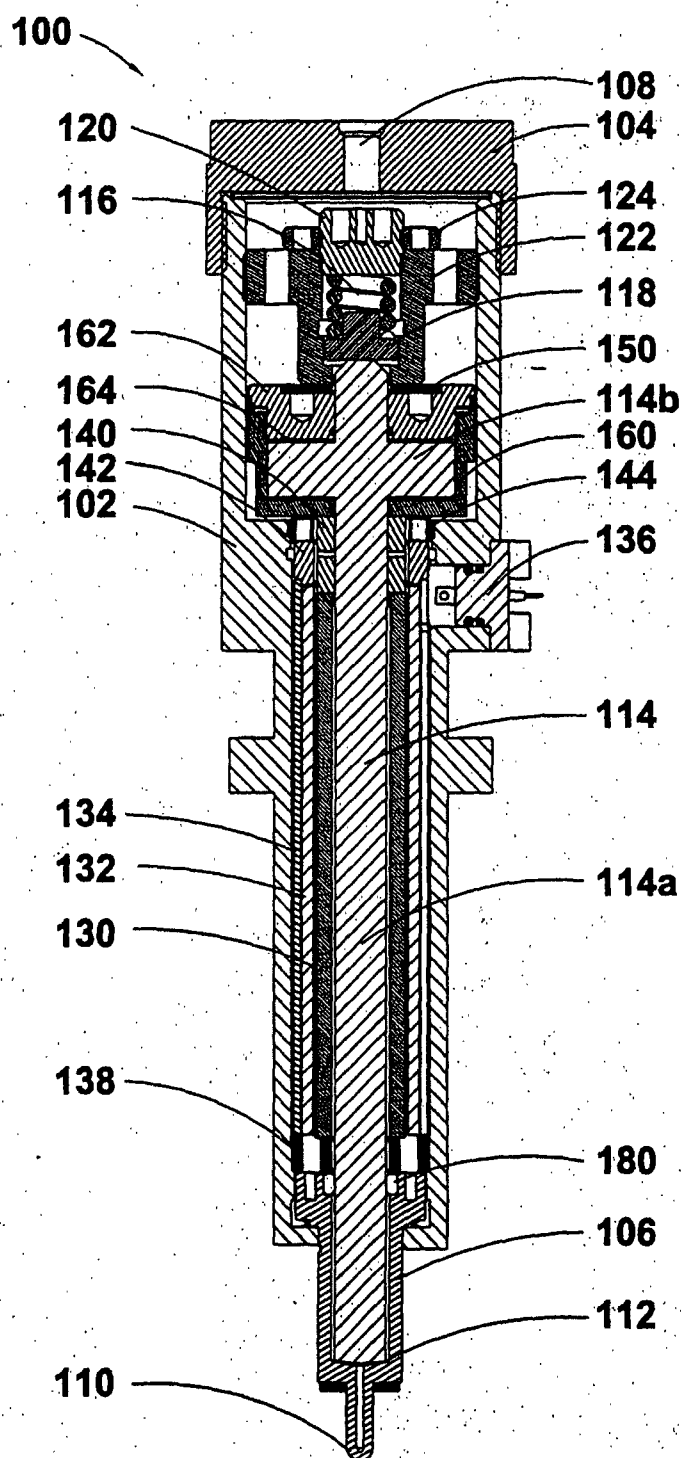


Figure 1

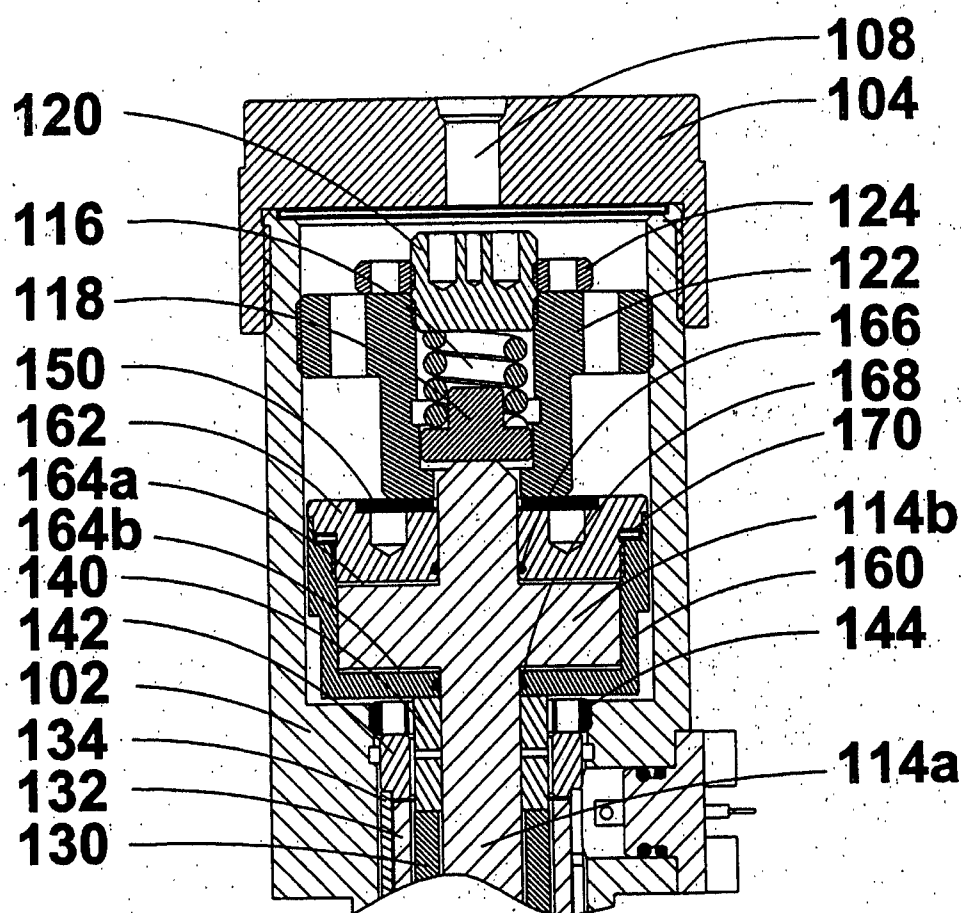


Figure 2

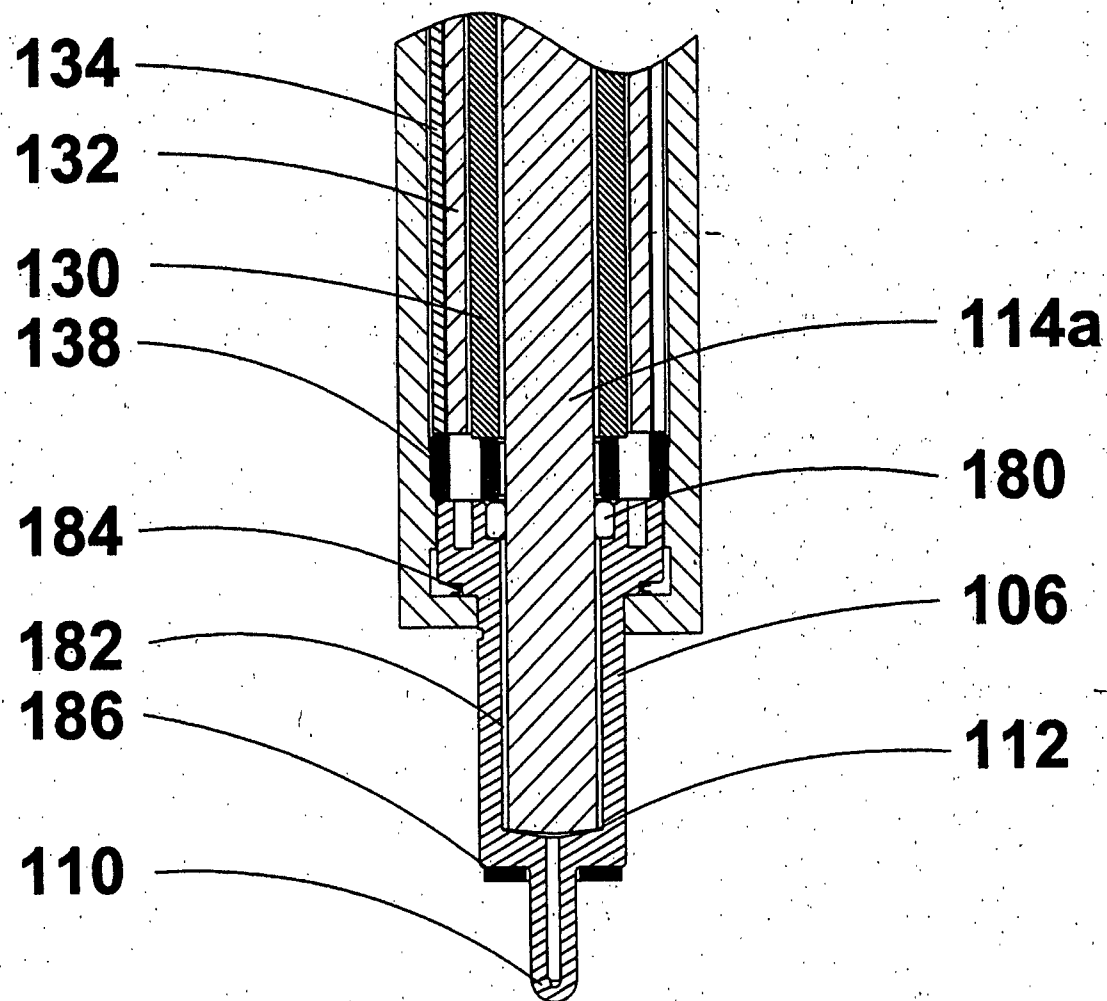


Figure 3

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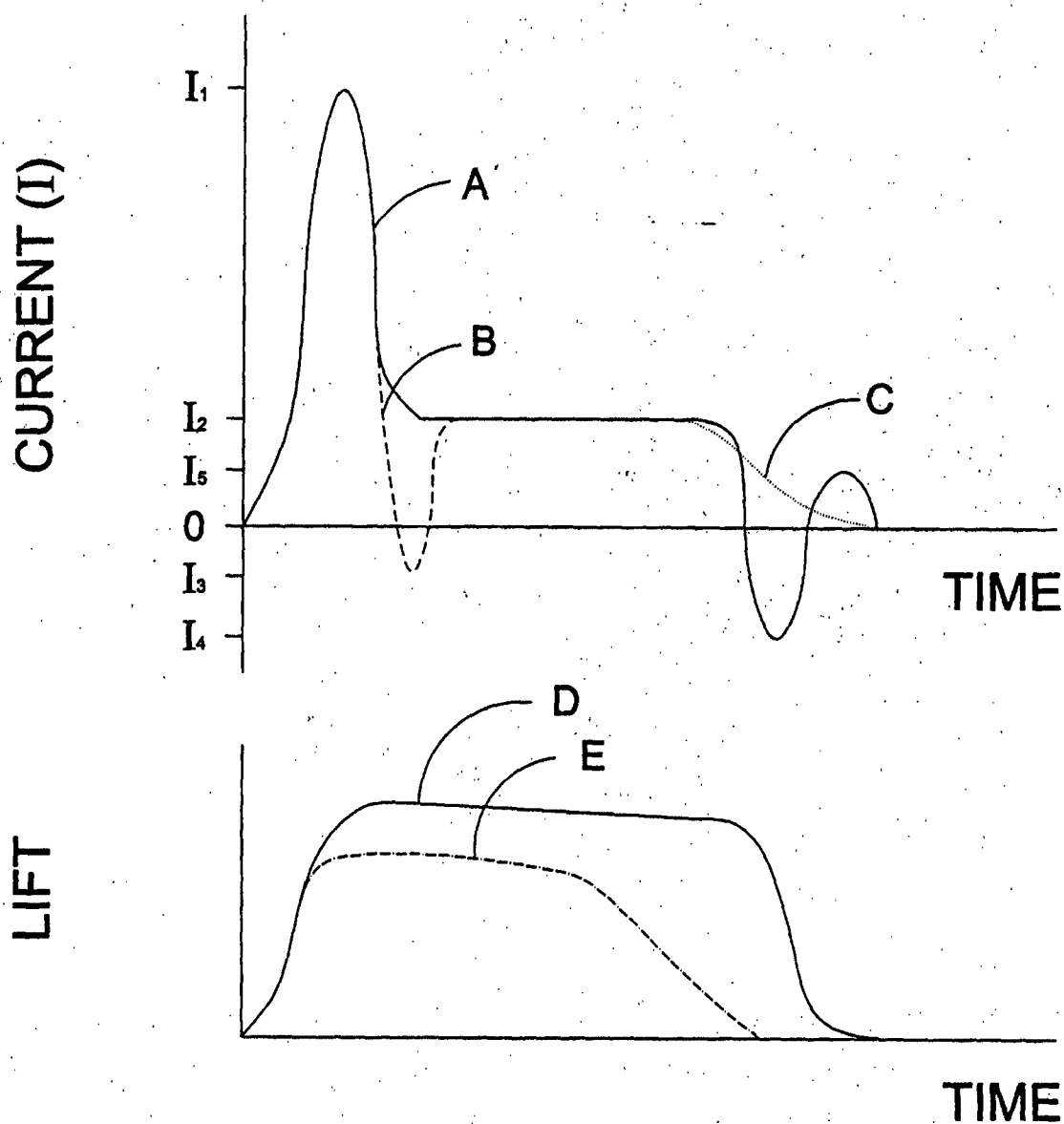


Figure 4

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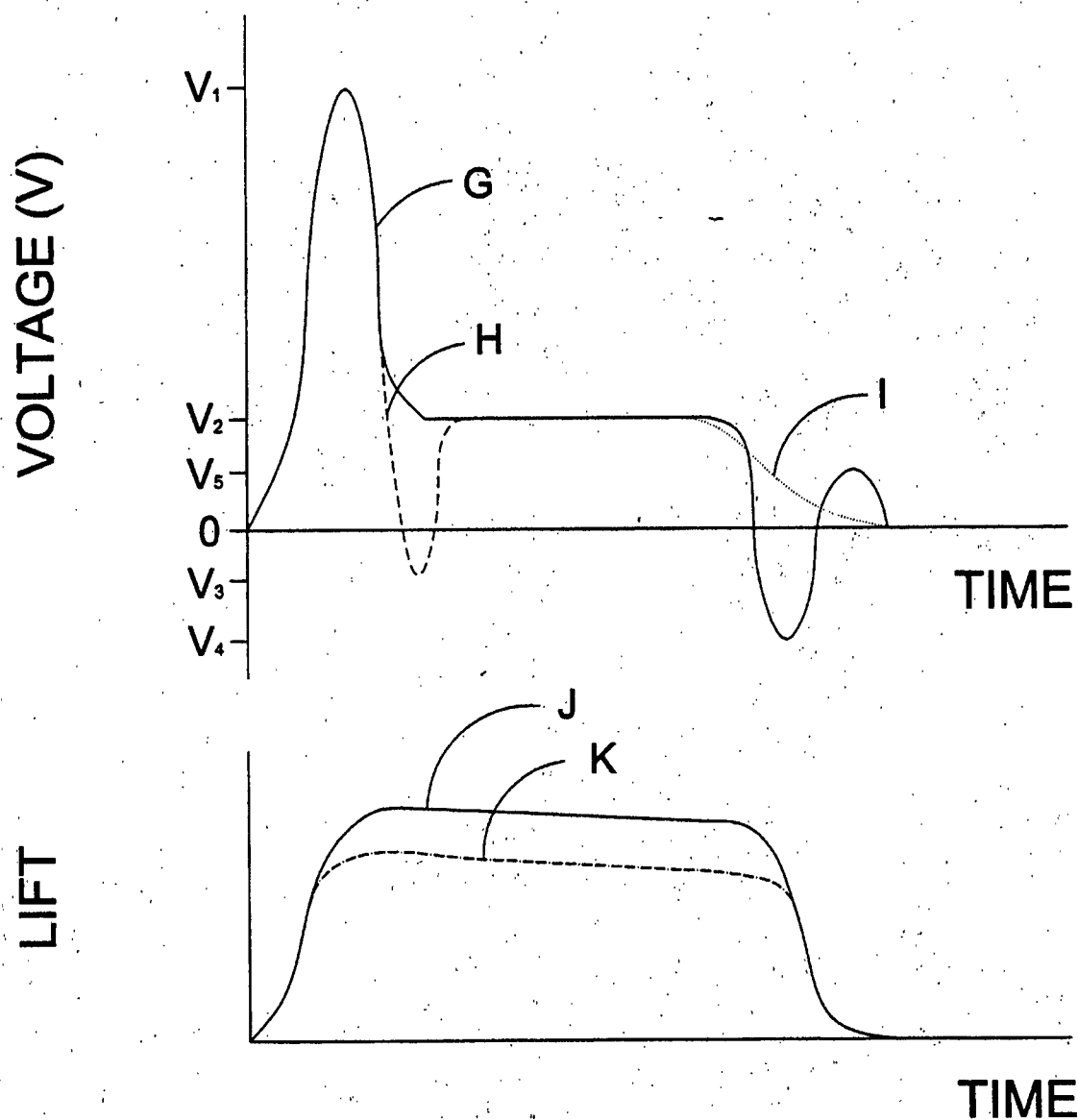


Figure 5

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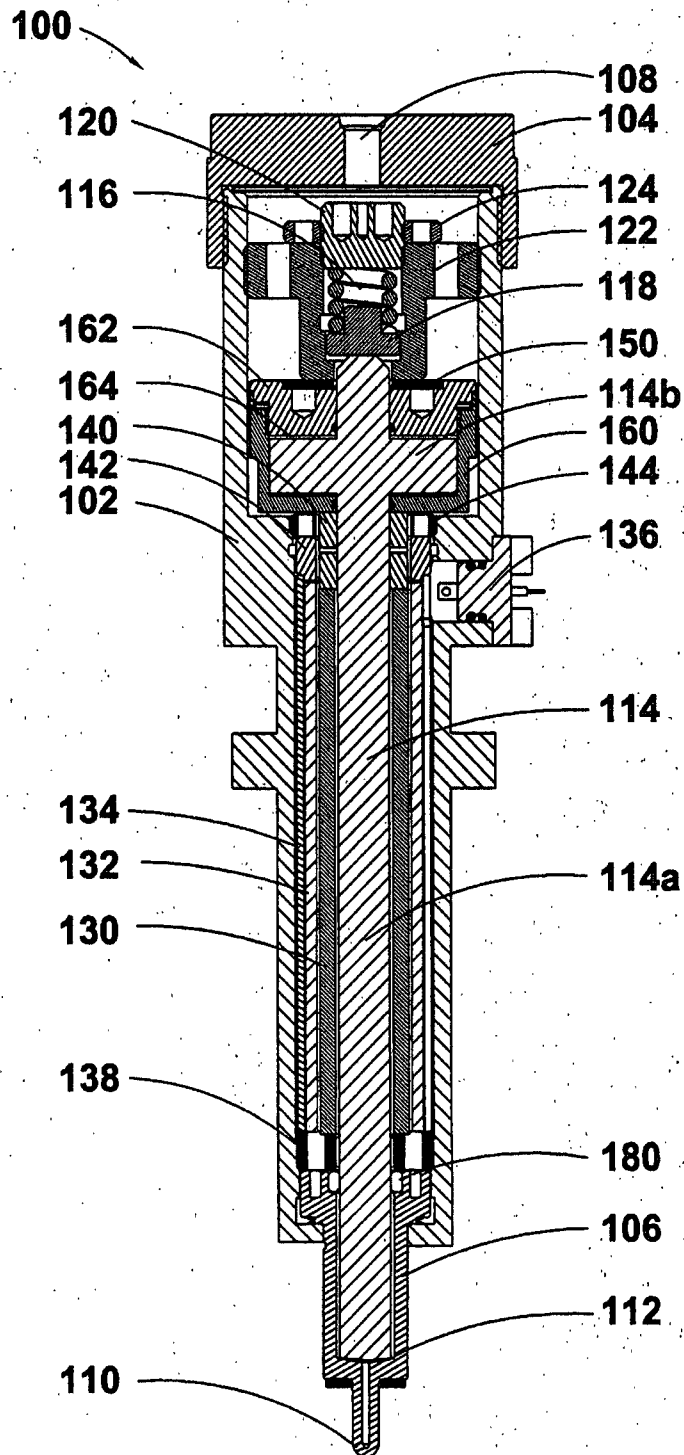


Figure 1

5

09522130.030900

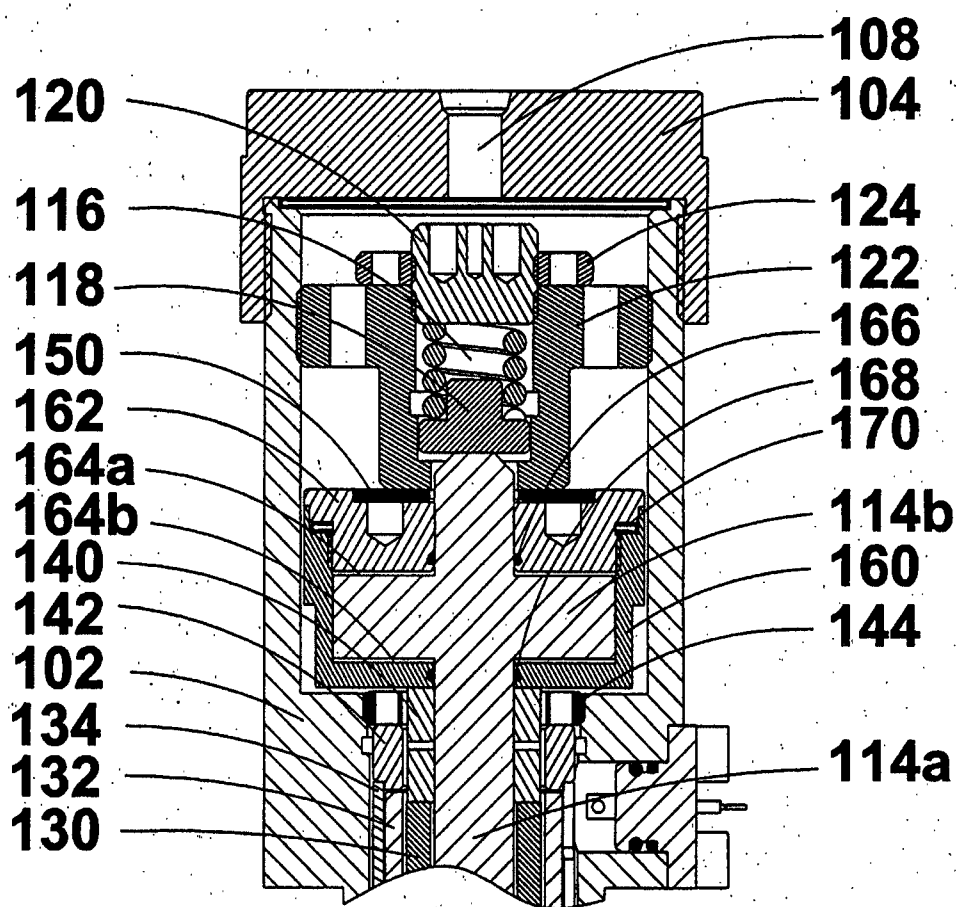


Figure 2

09522130-030900

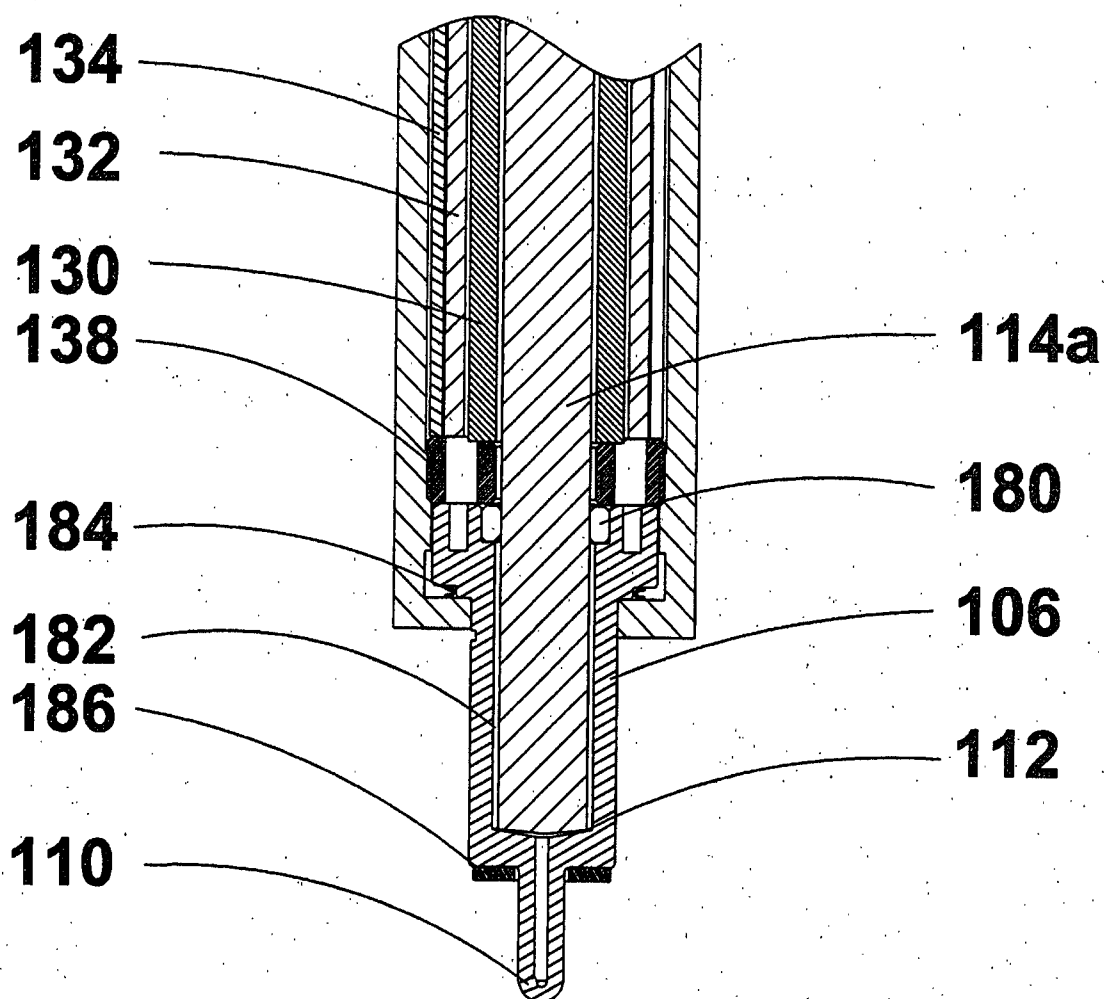


Figure 3

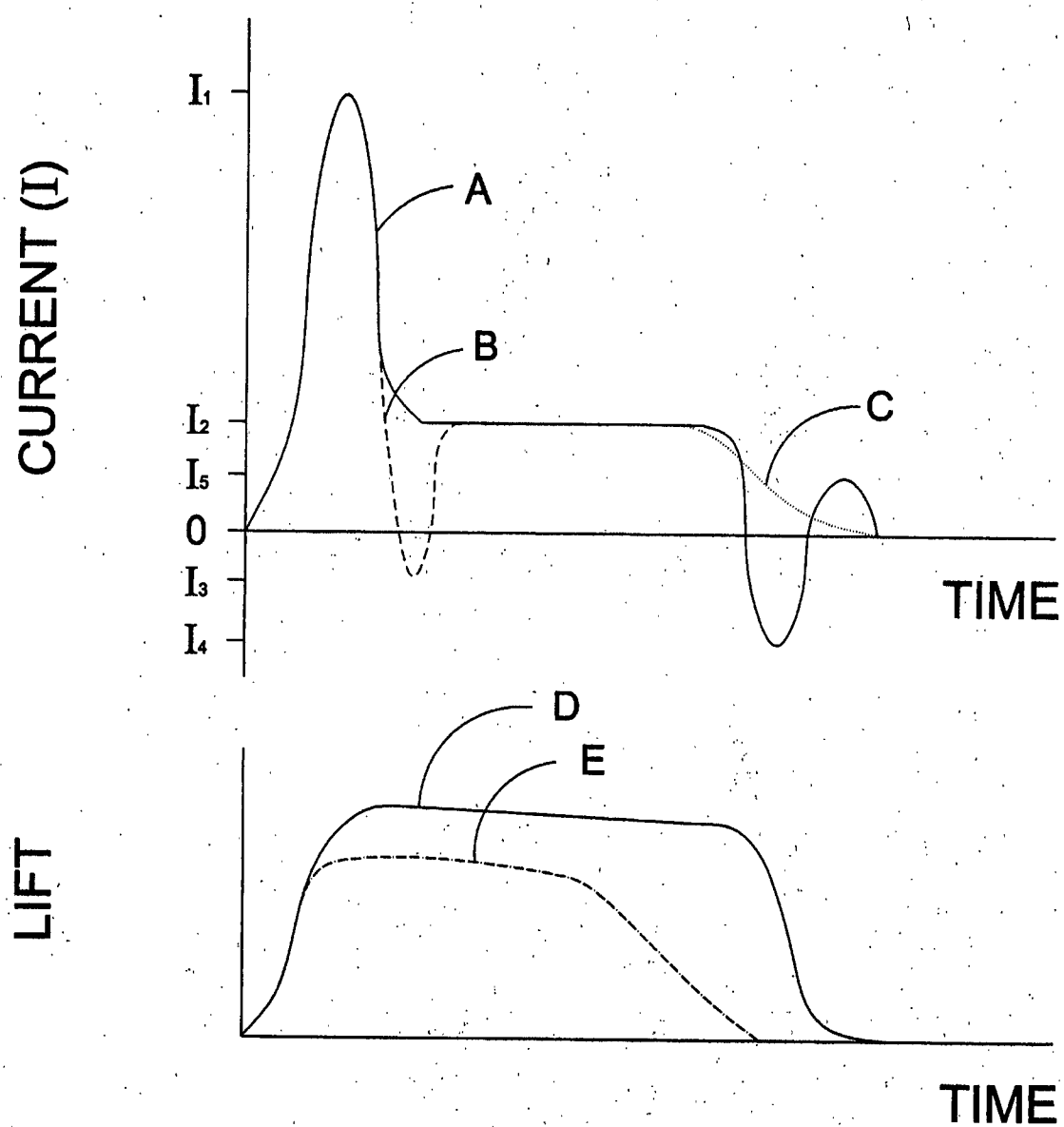


Figure 4

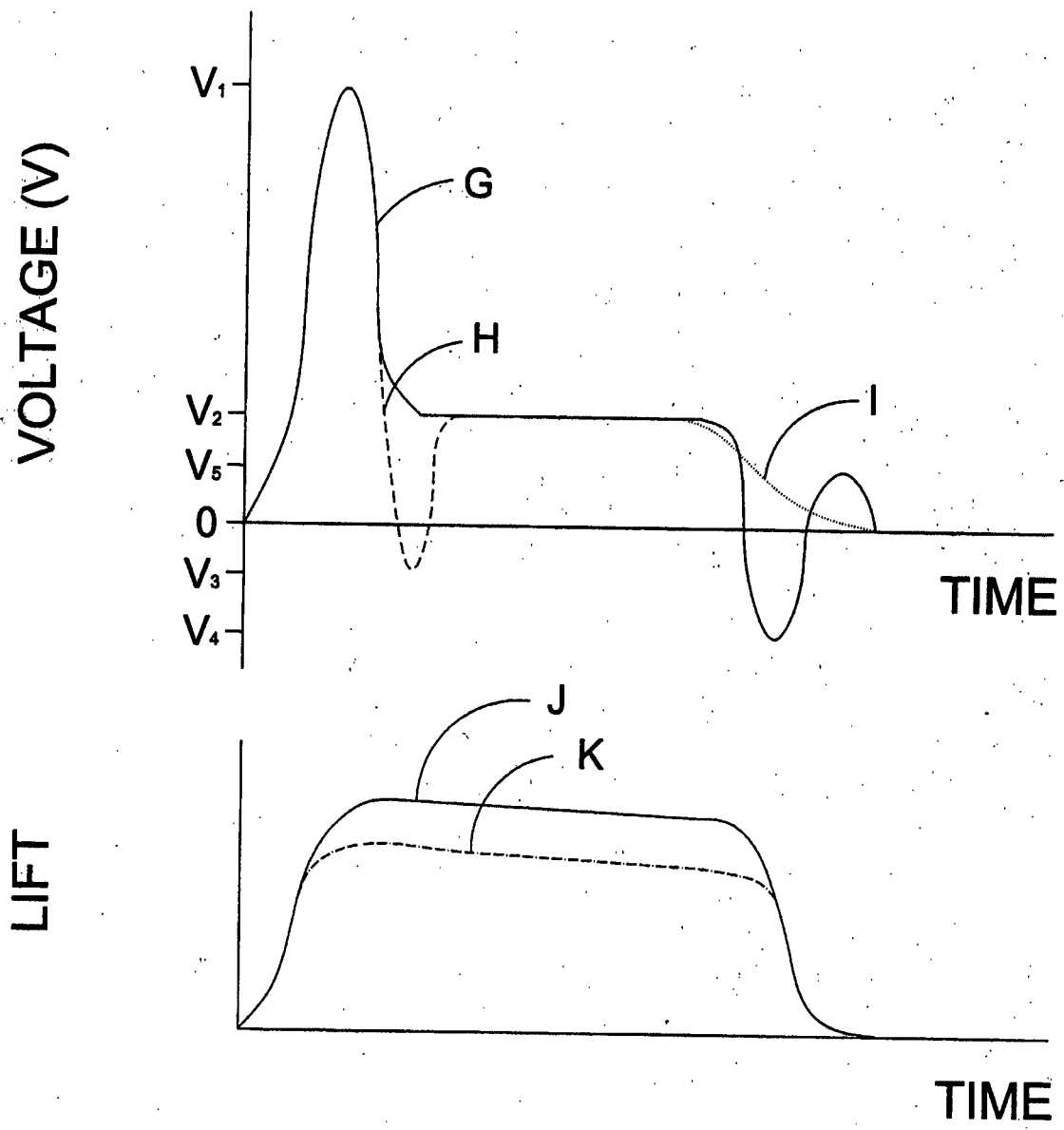


Figure 5

42

FORMALITIES LETTER



OC000000005123383

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark OfficeAddress: COMMISSIONER OF PATENT AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
09/522,130	03/09/2000	Alan B Welch	12541US02

McAndrews Held & Malloy LTd
500 West Madison Street 34th Floor
Chicago, IL 60661

Date Mailed: 05/17/2000

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given TWO MONTHS from the date of this Notice within which to file all required items and pay any fees required below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- The oath or declaration is missing.
A properly signed oath or declaration in compliance with 37 CFR 1.63, identifying the application by the above Application Number and Filing Date, is required.
- To avoid abandonment, a late filing fee or oath or declaration surcharge as set forth in 37 CFR 1.16(e) of \$130 for a non-small entity, must be submitted with the missing items identified in this letter.
- The balance due by applicant is \$ 130.

*A copy of this notice **MUST** be returned with the reply.*

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PART 3 - OFFICE COPY

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2001-05-17

Document Title - USPTO Communication Re: Change of Address



PATENT
Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH, IRAWAN
RAHARDJA and MIKE HEBBES

SERIAL NO. 09/522,130

FILED: March 9, 2000

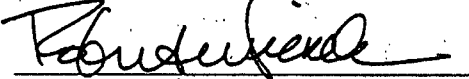
FOR: DIRECTLY ACTUATED
INJECTION VALVE

GROUP ART UNIT: _____

EXAMINER: B. Hines

CERTIFICATE OF MAILING

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this date: June 14, 2000.


Robert W. Fieseler
Registration No. 31,826
Attorney for Applicant(s)

RESPONSE TO NOTICE TO FILE MISSING PARTS

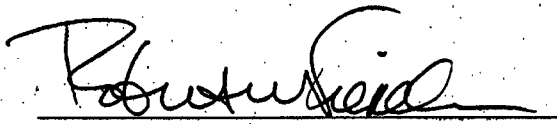
Box Missing Parts
Assistant Commissioner For Patents
Washington, D.C. 20231

Sir:

In response to the Notice To File Missing Parts Of
Application dated May 17, 2000 (return copy enclosed), enclosed
is the executed Declaration and Power Of Attorney for the above
application. Also enclosed is a check in the amount of \$130.00
to cover the surcharge due for a large entity.

Please charge any additional fees, or credit any
overpayment, incurred in connection with this submission to
Deposit Account No. 13-0017.

Respectfully submitted,



Robert W. Fieseler
Registration No. 31,826
Attorney For Applicants

McANDREWS, HELD & MALLOY, LTD.
500 West Madison Street, 34th Floor
Chicago, Illinois 60661

Telephone (312) 775-8000
Facsimile (312) 775-8100

Date: June 14, 2000

FORMALITIES LETTER



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Patent and Trademark OfficeAddress: COMMISSIONER OF PATENT AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
09/522,130	03/09/2000	Alan B Welch	12541US02

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500 West Madison Street 34th Floor
Chicago, IL 60661

Date Mailed: 05/17/2000

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

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- The balance due by applicant is \$ 130.

A copy of this notice **MUST** be returned with the reply.

Customer Service Center

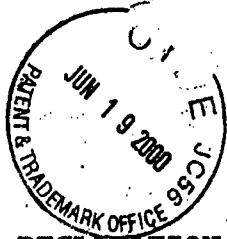
Initial Patent Examination Division (703) 308-1202

PART 2 - COPY TO BE RETURNED WITH RESPONSE

06/21/2000 WKOROMA 00000096 09522130

01 FC:105

130.00 OP



Attorney Docket No. 12541US02

DECLARATION AND POWER OF ATTORNEY

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

DIRECTLY ACTUATED INJECTION VALVE

the specification of which was filed as U.S. Patent Application Serial No. 09/522,130 on March 9, 2000.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims. I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, section 119(a)-(d) or section 365(b) of any foreign application(s) for patent or inventor's certificate, or section 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application on which priority is claimed:

NONE.

I hereby claim the benefit under Title 35, United States Code, section 119(e) of any United States provisional application(s) listed below:

U.S. Provisional Patent Application

Serial No. 60/159,791 filed October 15, 1999.

I hereby claim the benefit under Title 35, United States Code, section 120 of any United States application(s), or section 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, section 1.56(a) which became available between the filing date of the prior application(s) and the national or PCT international filing date of this application:

I hereby appoint:

George P. McAndrews	Reg. No. 22,760
John J. Held	Reg. No. 21,061
Timothy J. Malloy	Reg. No. 25,600
William M. Wesley	Reg. No. 26,521
Lawrence M. Jarvis	Reg. No. 27,341
Gregory J. Vogler	Reg. No. 31,313
Jean Dudek Kuelper	Reg. No. 30,171
Herbert D. Hart III	Reg. No. 30,063
Robert W. Fieseler	Reg. No. 31,826
D. David Hill	Reg. No. 35,543
Thomas J. Wimbiscus	Reg. No. 36,059
Steven J. Hampton	Reg. No. 33,707
Priscilla F. Gallagher	Reg. No. 32,223
Stephen F. Sherry	Reg. No. 30,590
Patrick J. Arnold Jr.	Reg. No. 37,769
George Wheeler	Reg. No. 28,766
Janet M. McNicholas	Reg. No. 32,918
Ronald E. Larson	Reg. No. 24,478
Christopher C. Winslade	Reg. No. 36,308
Edward A. Mas II	Reg. No. 37,179
Gregory C. Schodde	Reg. No. 36,668
Edward W. Remus	Reg. No. 25,703
Donald J. Pochopien	Reg. No. 32,167
Sharon A. Hwang	Reg. No. 39,717
David D. Headrick	Reg. No. 40,642
Dean D. Small	Reg. No. 34,730
Alejandro Menchaca	Reg. No. 34,389
Kirk A. Vander Leest	Reg. No. 34,036
Richard T. McCaulley, Jr.	Reg. No. 41,977

Anthony E. Dowell	Reg. No. 39,661
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Michael B. Harlin	Reg. No. 43,658
Jonathan R. Sick	Reg. No. 43,920
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John F. Nethery	Reg. No. 42,928
Alison L. Pollock	Reg. No. 43,863
James Nuttall	Reg. No. 44,978
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Dean A. Pelletier	Reg. No. 45,007
Joseph M. Barich	Reg. No. 42,291
Scott P. McBride	Reg. No. 42,853
Patricia J. McGrath	Reg. No. 44,919
Andrew M. Everest	Reg. No. 44,674

the address and telephone number of each of whom is McAndrews, Held & Malloy, Ltd., 500 West Madison Street, 34th Floor, Chicago, Illinois 60661, (312) 775-8000, as our attorneys with full power of substitution and revocation to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Please direct telephone calls to Robert W. Fieseler at (312) 775-8000. Please direct facsimiles to Robert W. Fieseler at (312) 707-9155 or (312) 775-8100.

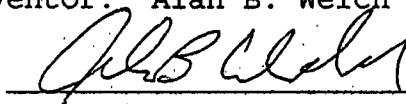
Please address correspondence to:

Robert W. Fieseler
McAndrews, Held & Malloy, Ltd.
500 West Madison Street, Suite 3400
Chicago, Illinois 60661

I hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of first inventor: Alan B. Welch

Inventor's signature



Date: 2000-may-01

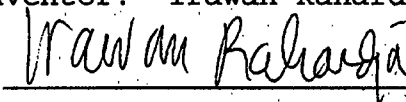
Residence Address: 2828 West 34th Avenue
Vancouver, British Columbia, Canada V6N 2J6

Citizenship: Canadian

Post Office Address: Westport Research Inc.
1691 West 75th Avenue
Vancouver, British Columbia, Canada V6P 6P2

Full name of second inventor: Irawan Rahardja

Inventor's signature



Date: March 20, 2000

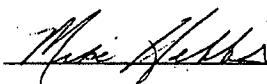
Residence Address: Suite 401 - 1945 Barclay Street
Vancouver, British Columbia, Canada V6G 1L2

Citizenship: Canadian

Post Office Address: Westport Research Inc.
1691 West 75th Avenue
Vancouver, British Columbia, Canada V6P 6P2

Full name of third inventor: Mike Hebbes

Inventor's signature



Date: 00 03 20

Residence Address: Apt. #415, 600 Drake Street
Vancouver, British Columbia, Canada V6B 5W7

Citizenship: Canadian

Post Office Address: Westport Research Inc.
1691 West 75th Avenue
Vancouver, British Columbia, Canada V6P 6P2



3747
#4

PATENT

Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH,
IRAWAN RAHARDJA and
MIKE HEBBES

SERIAL NO. 09/522,130

FILED: MARCH 9, 2000

FOR: DIRECTLY ACTUATED
INJECTION VALVE

GROUP ART UNIT: 3747

EXAMINER: Not yet assigned

CERTIFICATE OF MAILING

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Commissioner for Patents,
Washington, D.C. 20231, on
this date:

July 17, 2000

Robert W. Fieseler

Robert W. Fieseler
Registration No. 31,826
Attorney for Applicant(s)

INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Applicants submit herewith a copy of each of the
following references for consideration by the U.S. Patent and
Trademark Office in connection with the above application.

RECEIVED
JUL 24 2000
TC 3700 MAIL ROOM

<u>U.S. Patent No.</u>	<u>Inventor(s)</u>	<u>Issue Date</u>
4,158,368	Clark	06/79
4,725,002	Trachte	02/88
5,031,841	Schafer	07/91
5,035,360	Green et al.	07/91
5,779,149	Hayes, Jr.	07/98
5,819,710	Huber	10/98
5,845,852	Waldman et al.	12/98

The above references are listed on the enclosed Form PTO-1449 entitled "Information Disclosure Citation."

Concise Explanation of The
Relevance of the Cited Reference

Clark U.S. Patent No. 4,158,368 discloses a magnetostrictive valve for controlling the flow of fluids which includes a cylindrical housing, a tapered plunger, and a magnetizing means.

Trachte U.S. Patent No. 4,725,002 discloses a measuring valve for dosing liquids or gases in which the metering valve employs a piezoelectric control member and in which electrical excitation transfers changes in length of the control member to the valve element. The disclosed valve is described as neutralizing slow changes due to temperature, wear and manufacturing tolerances.

Schafer U.S. Patent No. 5,031,841 discloses a metering valve, particularly a fuel injection valve, which includes a nozzle opening, a spring diaphragm, an inlet in the housing for introducing pressurized fluid solely in the second chamber, and a valve needle.

Green et al. U.S. Patent No. 5,035,360 discloses an electrically actuated gaseous fuel timing and metering device that includes a cylindrical solenoid cavity, an injector tip, an elongate pintle, an electrically actuated multipole solenoid and an armature of ferromagnetic material for the solenoid.

Hayes, Jr. U.S. Patent No. 5,779,149 discloses a piezoelectric controlled common rail injector with hydraulic amplification of the piezoelectric stroke in which a hydraulic amplifier increases the stroke of the piezoelectric actuator and compensates for tolerance and shifts due to temperature and wear.

Huber U.S. Patent No. 5,819,710 discloses a servo valve for an injection nozzle that includes a housing having a valve chamber, a high-pressure opening, a connecting and return

opening, a first and second seat, a valve member and an actuating means.

Waldman et al. U.S. Patent No. 5,845,852 discloses a direct operated check injector that includes an injector body assembly, a three-way control valve, a check disposed in the injector body assembly, an actuator and an injector which includes a clearance fit located in the control valve.

This Information Disclosure Statement is being submitted before the receipt of a first office action on the merits of the above application. Please charge any fees incurred in connection with this submission to Deposit Account No. 13-0017.

Respectfully submitted,



Robert W. Fieseler
Registration No. 31,826
Attorney for Applicants

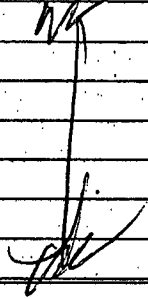
McANDREWS, HELD & MALLOY, LTD.
500 West Madison Street, 34th Floor
Chicago, Illinois 60661

Telephone: (312) 775-8000
Facsimile: (312) 775-8100

Dated: July 17, 2000

Form PTO-1449 (Rev. 8-83) (modified)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTY. DOCKET NO. 12541US02	SERIAL NO. 09/522,130
			APPLICANT(s): Welch	
	INFORMATION DISCLOSURE CITATIONS (Use several sheets if necessary)		FILING DATE March 9, 2000	GROUP ART UNIT: 3747

U.S. PATENT DOCUMENTS

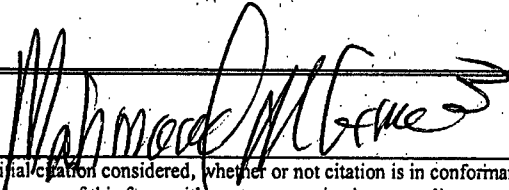
EXAMINER INITIAL	DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
	4,158,368	06/79	Clark	137	487.5	
	4,725,002	02/88	Trachte	239	102.2	
	5,031,841	07/91	Schafer	239	585	
	5,035,360	07/91	Green et al.	239	585	
	5,779,149	07/98	Hayes, Jr.	239	124	
	5,819,710	10/98	Huber	123	498	
	5,845,852	12/98	Waldman et al.	239	533.8	

FOREIGN PATENT DOCUMENTS

EXAMINER INITIAL	DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
						YES	NO

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

RECEIVED
 JUL 24 2000
 TC 8700 MAIL ROOM

EXAMINER 	DATE CONSIDERED: 3/19/01
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*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.



GAD 3747
#6

PATENT
Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH,
IRAWAN RAHARDJA and
MIKE HEBBES

SERIAL NO. 09/522,130

FILED: MARCH 9, 2000

FOR: DIRECTLY ACTUATED
INJECTION VALVE

GROUP ART UNIT: 3747

EXAMINER: Not yet assigned

CERTIFICATE OF MAILING

I hereby certify that this
correspondence is being
deposited with the United
States Postal Service as
first class mail, postage
prepaid, in an envelope
addressed to: Assistant
Commissioner for Patents,
Washington, D.C. 20231, on
this date:

March 12, 2001

Robert W. Fieseler
Robert W. Fieseler
Registration No. 31,826
Attorney for Applicant(s)

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicants submit herewith a copy of each of the
following references for consideration by the U.S. Patent and
Trademark Office in connection with the above application.

RECEIVED
MAR 15 2001
TC 3700 MAIL ROOM

<u>U.S. Patent No.</u>	<u>Inventor(s)</u>	<u>Issue Date</u>
4,813,601	Schwerdt et al.	03/89
5,697,554	Auwaerter et al.	12/97
5,875,764	Kappel et al.	03/99
6,062,533	Kappel et al.	05/00

<u>Foreign Patent No.</u>	<u>Country</u>	<u>Publication Date</u>
WO 85/02445	PCT	06/85
09-324723	Japan	12/97
10-009084	Japan	01/98
2 321 501	Great Britain	07/98
0 869 278	EPO	08/98
197 27 992	Germany	01/99

The above references are listed on the enclosed Form PTO-1449 entitled "Information Disclosure Citation."

Concise Explanation of the
Relevance of the Cited Reference(s)

Schwerdt et al. U.S. Patent No. 4,813,601 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Auwaerter et al. U.S. Patent No. 5,697,554 was cited in the International Search Report issued in connection with the

PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Kappel et al. U.S. Patent No. 5,875,764 discloses an apparatus and method for valve control. The valve has a piezo actuator or a magnetostrictive actuator. The fluid is contained in an unsealed hydraulic chamber and transmits actuation forces from the actuator to the valve needle.

Kappel et al. U.S. Patent No. 6,062,764 discloses an apparatus and method for valve control. The primary drive, a piezo actuator, guided in a first bore, transfers its stroke motion onto a secondary-side lifter element in a secondary bore which then transmits its stroke by means of a hydraulic transmission.

PCT/International Publication No. WO 85/02445 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the

reference in the view of the International Searching Authority.

Japanese Patent Publication No. 09-324723 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Japanese Patent Publication No. 10-009084 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

British Patent No. 2 321 501 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

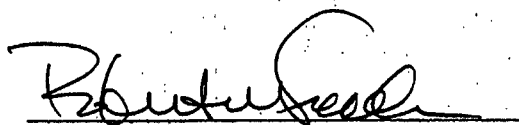
European Patent Publication No. 0 869 278 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

German Patent Publication No. 197 27 992 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority. Applicants have not obtained a full-text translation of the German language document, but are willing to obtain and provide such a translation upon request.

This Supplemental Information Disclosure Statement is being submitted before the receipt of a first office action on the merits of the above application.

Please charge any fees incurred in connection with this submission to Deposit Account No. 13-0017 in the name of McAndrews, Held & Malloy, Ltd.

Respectfully submitted,



Robert W. Fieseler
Registration No. 31,826
Attorney for Applicants

Russell A. Garrison
McANDREWS, HELD & MALLOY, LTD.
500 West Madison Street, 34th Floor
Chicago, Illinois 60661

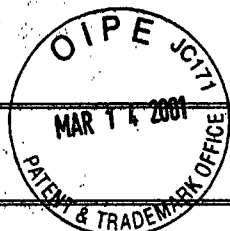
Telephone: (312) 775-8000
Facsimile: (312) 775-8100

Dated: March 12, 2001

#8 252
Sheet 1 of 1

Form PTO-1449 (Rev. 8-83) (modified)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTY. DOCKET NO. 12541US02	SERIAL NO. 09/522,130
		APPLICANT(s): Welch et al.	
		FILING DATE March 9, 2000	GROUP ART UNIT: 3747

INFORMATION DISCLOSURE CITATION
(Use several sheets if necessary)



U.S. PATENT DOCUMENTS							
EXAMINER INITIAL		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
<i>my</i>		4,813,601	03/89	Schwerdt et al.	239	91	
		5,697,554	12/97	Auwaerter et al.	239	88	
<i>de</i>		5,875,764	03/99	Kappel et al.	123	467	
		6,062,533	05/00	Kappel et al.	251	57	

FOREIGN PATENT DOCUMENTS								
EXAMINER INITIAL		DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
							YES	NO
ck		WO 85/02445	06/85	PCT				
	✓ 1	09-324723	12/97	Japan			X (abstract)	
	✓ 2	10-009084	01/98	Japan			X (abstract)	
		2 321 501	07/98	Great Britain				
		0 869 278	08/98	EPO				
dr		197 27 992	01/99	Germany				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)		

RECEIVED
MAR 15 2001
3700 MAIL ROOM

EXAMINER <i>Wm. G. Smith</i>	DATE CONSIDERED: 8/6/01
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*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.



**UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office**

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
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09/522,130 03/09/00 WELCH

A 12541US02

EXAMINER

GM02/0321

MCANDREWS HELD & MALLOY LTD
500 WEST MADISON STREET 34TH FLOOR
CHICAGO IL 60661

GIMIE, M

ART UNIT

PAPER NUMBER

3747

DATE MAILED:

03/21/01

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks

Office Action Summary	Application No.	Applicant(s)	
	09/522,130	WELCH ET AL.	
	Examiner	Art Unit	
	Mahmoud M Gimie	3747	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136 (a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If the period for reply specified above is less than thirty (30) days, a reply within the statutory minimum of thirty (30) days will be considered timely.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133).
- Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1) ☐ Responsive to communication(s) filed on ____.

2a) ☐ This action is FINAL. 2b) ☒ This action is non-final.

3) ☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4) ☒ Claim(s) 1-30 is/are pending in the application.

4a) Of the above claim(s) ____ is/are withdrawn from consideration.

5) ☒ Claim(s) 21-30 is/are allowed.

6) ☒ Claim(s) 1-20 is/are rejected.

7) ☐ Claim(s) ____ is/are objected to.

8) ☐ Claims ____ are subject to restriction and/or election requirement.

Application Papers

9) ☐ The specification is objected to by the Examiner.

10) ☐ The drawing(s) filed on ____ is/are objected to by the Examiner.

11) ☐ The proposed drawing correction filed on ____ is: a) ☐ approved b) ☐ disapproved.

12) ☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119

13) ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a) ☐ All b) ☐ Some * c) ☐ None of:

1. ☐ Certified copies of the priority documents have been received.

2. ☐ Certified copies of the priority documents have been received in Application No. ____.

3. ☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

14) ☒ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

Attachment(s)

15) ☒ Notice of References Cited (PTO-892)

16) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

17) ☒ Information Disclosure Statement(s) (PTO-1449) Paper No(s) 5

18) ☐ Interview Summary (PTO-413) Paper No(s) ____

19) ☐ Notice of Informal Patent Application (PTO-152)

20) ☐ Other: ____

DETAILED ACTION

Claim Rejections - 35 USC § 102

1. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –

(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of application for patent in the United States.

2. Claims 1-6, 12, 15, 17 and 19 are rejected under 35 U.S.C. 102(b) as being anticipated by O'Neill (3,598,506).

O'Neill discloses an injection valve (55) 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 (57); an interior chamber fluidly connected to said fuel inlet port (not numbered); a nozzle comprising a nozzle orifice (56) providing a fluid passage from said interior chamber to said combustion chamber (not shown);

(b) a valve needle (51) 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 (56), 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 (51) lift equals the distance traveled by said sealing end away from said valve seat;

(c) a needle spring (58) associated with said valve needle, wherein said needle spring

applies a closing force to said valve needle (51) for biasing said valve needle 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

(e) a hydraulic link assembly comprising a hydraulic link (42,43) having a fluid thickness through which said opening and closing forces are transmitted, wherein said thickness of said hydraulic link is adjustable in response to changes in the dimensional relationship between components of said injection valve to maintain a desired valve needle lift when said actuator assembly is activated, see figure 4.

Regarding claim 2, the thickness of said hydraulic link is auto-adjustable in response to changes in said dimensional relationship caused by differential thermal expansion.

Regarding claim 3, said thickness of said hydraulic link is auto-adjustable in response to changes in said dimensional relationship caused by wear to components of said injection valve.

Regarding claim 4, said hydraulic link assembly comprises a sealed hydraulic cylinder, with a piston and hydraulic fluid disposed within said hydraulic cylinder.

Regarding claim 5, said piston is an integral part of said valve needle.

Regarding claim 6, said actuator assembly comprises a magnetostrictive member or a piezoelectric stack.

Claim Rejections - 35 USC § 103

3. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

4. Claims 7-11, 13, 14, 16, 18 and 20 are rejected under 35 U.S.C. 103(a) as being unpatentable over O'Neill (3,598,506).

O'Neill discloses all the limitations as applied to claims 1-6, 12, 15, 17 and 19 except for components of specific design of an electrostrictive actuator.

It would have been an obvious choice of design for one of ordinary skill in the art at the time of the invention was made to modify the invention of O'Neill by using an electrostrictive actuator comprised of magnetostrictive member, an electric coil disposed around said magnetostrictive member and a flux tube disposed around said electric coil.

The motivation to do so would have been to lower manufacturing cost.

Allowable Subject Matter

5. Claims 21-30 are allowed over prior art of record.

Conclusion

6. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure. The cited references show fuel injection actuators.

7. This application currently names joint inventors. In considering patentability of the claims under 35 U.S.C. 103(a), the examiner presumes that the subject matter of the various claims was commonly owned at the time any inventions covered therein

Application/Control Number: 09/522,130
Art Unit: 3747

Page 5

were made absent any evidence to the contrary. Applicant is advised of the obligation under 37 CFR 1.56 to point out the inventor and invention dates of each claim that was not commonly owned at the time a later invention was made in order for the examiner to consider the applicability of 35 U.S.C. 103(c) and potential 35 U.S.C. 102(e), (f) or (g) prior art under 35 U.S.C. 103(a).

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Mahmoud M Gimie whose telephone number is 703-305-1037. The examiner can normally be reached on 7:00-3:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Henry Yuen can be reached on 703-308-1946. The fax phone numbers for the organization where this application or proceeding is assigned are 703-308-7766 for regular communications and 703-308-7766 for After Final communications.

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is 703-308-0861.

M Gimie, Examiner
March 20, 2001


Henry Yuen
Supervisory Patent Examiner
Group 3700

Notice of References Cited	Application/Control No. 09/522,130	Applicant(s)/Patent Under Reexamination WELCH ET AL	
	Examiner Mahmoud M Gimie	Art Unit 3747	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification	
	A	US-3598506-A	08-1971	O'Neill	417	383
	B	US-4803393-A	02-1989	Takahashi	310	328
	C	US-4022166-A	05-1997	Bart	123	32
	D	US-4101076-A	07-1978	Bart	239	584
	E	US-5821671-A	10-1998	Trzmjel	310	328
	F	US- -				
	G	US- -				
	H	US- -				
	I	US- -				
	J	US- -				
	K	US- -				
	L	US- -				
	M	US- -				

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification	
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	O	- -					
	P	- -					
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	R	- -					
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	T	- -					

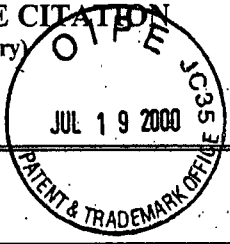
NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Page #4
Sheet 1 of 1

Form PTO-1449 (Rev. 8-83) (modified)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTY. DOCKET NO. 12541US02	SERIAL NO. 09/522,130
		APPLICANT(s): Welch	
		FILING DATE March 9, 2000	GROUP ART UNIT: 3747



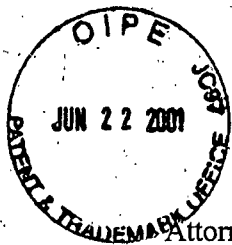
U.S. PATENT DOCUMENTS							
EXAMINER INITIAL		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
J		4,158,368	06/79	Clark	137	487.5	
		4,725,002	02/88	Trachte	239	102.2	
		5,031,841	07/91	Schafer	239	585	
		5,035,360	07/91	Green et al.	239	585	
		5,779,149	07/98	Hayes, Jr.	239	124	
AC		5,819,710	10/98	Huber	123	498	
		5,845,852	12/98	Waldman et al.	239	533.8	

FOREIGN PATENT DOCUMENTS								
EXAMINER INITIAL		DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
							YES	NO

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)		

RECEIVED
JUL 24 2001
TC 3700 MAIL ROOM

EXAMINER <i>Waldman</i>	DATE CONSIDERED: 3/19/01
*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.	



U/P-3747

#7

Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH,
IRAWAN RAHARDJA and
MIKE HEBBES

SERIAL NO.: 09/522,130

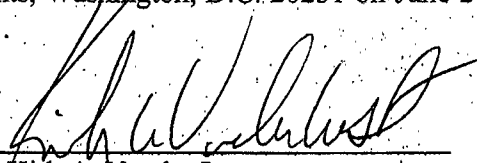
FILED: March 9, 2000

FOR: DIRECTLY ACTUATED INJECTION
VALVE

GROUP ART UNIT: 3747

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231 on June 20, 2001.

By 
Kirk A. Vander Leest
Reg. No. 34,036

TRANSMITTAL LETTER

Assistant Commissioner for Patents
Washington, D.C. 20231

RECEIVED

JUN 27 2001

TECHNOLOGY CENTER R3700

We are transmitting herewith the following:

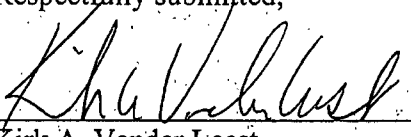
1. AMENDMENT AND REQUEST FOR RECONSIDERATION; and
2. SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT AND FORM PTO-1449

Please charge any additional fees or credit overpayment to the deposit account of McAndrews, Held & Malloy, Ltd. Account No. 13-0017.

Date: June 20, 2001

McANDREWS, HELD & MALLOY, LTD.
500 West Madison Street
Suite 3400
Chicago, Illinois 60661
(312) 775-8000

Respectfully submitted,


Kirk A. Vander Leest
Reg. No. 34,036



Amendment for Serial No. 09/522,130

Page 2 of 8

June 20, 2001

a nozzle comprising a nozzle orifice providing a fluid passage from said interior chamber to said combustion chamber;

- a1
- (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;
 - (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;
 - (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
 - (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
- 55
- A

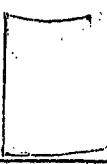
Amendment for Serial No. 09/522,130
Page 3 of 8
June 20, 2001

injection valve to maintain a desired valve needle lift upon activation of said actuator assembly.

a' 2. The injection valve of claim 1 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by differential thermal expansion.

3. The injection valve of claim 2 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by wear to components of said injection valve.

4. The injection valve of claim 1 wherein said hydraulic link assembly comprises a fluidly sealed hydraulic cylinder that is fluidly sealed from said interior chamber, said hydraulic link assembly comprising a piston and said hydraulic fluid is disposed within said hydraulic cylinder.

 Please add new claims 31 and 32 as follows:

aa 21
31 The injection valve of claim 17 wherein said hydraulic fluid is a liquid.

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Amendment for Serial No. 09/522,130

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June 20, 2001

aa ²²
~~32~~ The injection valve of claim 17 wherein said hydraulic fluid is a liquid selected from the group consisting of motor oil and grease.

REMARKS

Claims 1-32 remain in the application, claims 31 and 32 having been added by amendment. Claims 1-4 have been amended as set forth in the attached Appendix. Claims 1-20 stand rejected under 35 U.S.C. § 102 and 103, and claims 21-30 have been indicated as being allowable over the references of record. Reconsideration of the rejected claims is respectfully requested.

Claims 1-19 stand rejected as being unpatentable over O'Neill under 35 U.S.C. §102(b) and 103. Claim 1 has been amended to specify that the hydraulic link is a "passive" hydraulic link. None of the cited references, including O'Neill, disclose or suggest a "passive" hydraulic link, as defined in the present specification (see page 17, lines 22 through 32). Claim 1 has also been amended to clarify that the hydraulic fluid in the hydraulic link assembly "acts substantially as a solid . . . while said actuator assembly is activated," a feature which is neither disclosed nor suggested by the cited references, including O'Neill. Conversely, between injections, while the actuator assembly is not activated, the hydraulic fluid may flow within the sealed cylinder from one side of the piston to the other, to auto-adjust for changes, for example, caused by temperature, wear, etc. (See also claims 2 and 3).

The cited references, including O'Neill, all disclose assemblies that rely on the dynamic flow of a hydraulic fluid to actuate/open the valve. That is, a change in the volume of the actuator causes a displacement of a fluid, which actuates the valve. A disadvantage of this

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arrangement is that there are time delays associated with the dynamic flow of the fluid, compared to the present invention where the actuating force of the actuator is immediately transmitted through the thickness of the hydraulic fluid, which behaves as a solid during valve actuation. In this respect, O'Neill discloses an arrangement where an electroexpansive material 44 is activated to displace fluid from chamber 41 through passage 42 in piston cylinder 43 to lift piston 50 and open the valve. (See Figures 4 and 6). Accordingly, to open the valve, the actuating fluid is displaced and flows dynamically (that is, behaves as a liquid and not a solid). By contrast, claim 1 specifies that the hydraulic fluid acts "substantially as solid while said actuator assembly is activated." In view of the above, claim 1 and its dependent claims, are believed to be allowable over the reference of record.

New claims 31 and 32 have been added to reflect another advantage the present invention has over the prior art. These claims ultimately depend from claim 1 and are believed allowable for the reasons given above.

Support for the claim amendments can be found in the specification as follows:

Claim 1:

- "passive" - support can be found in the specification, for example, on page 17, lines 22 through 32.
- "whereby said hydraulic fluid acts substantially as a solid with said thickness being substantially constant while said actuator assembly is activated" - support can be found in the specification, for example, on page 28, lines 9 through 15.



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- “while said actuator is not activated” - support can be found in the specification, for example, on page 30, lines 28 through 32, and on page 34, lines 25 through 32.

Claims 2 and 3:

- “while said actuator assembly is not activated” - support can be found in the specification, for example, on page 30, lines 28 through 32, and on page 34, lines 25 through 32.

Claim 4

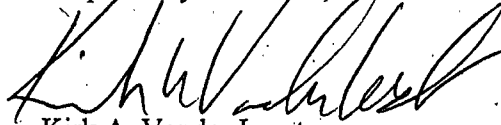
- Support can be found in the specification on page 27, lines 19 through 27.

New claims 31-32:

- Support can be found in the specification on page 28, lines 15 through 29.

In view of the foregoing, applicants submit that claims 1-32 are allowable. The examiner is invited to telephone the applicants' undersigned attorney at (312) 775-8000 if any unresolved matters remain. No fees are believed to be due in connection with this submission. The Commissioner is hereby authorized to charge any deficiency to Deposit Account No. 13-0017.

Respectfully submitted,

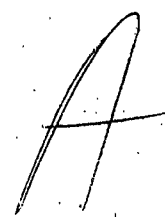


Kirk A. Vander Leest

Reg. No. 34,036

Date: June 20, 2001

McAndrews, Held & Malloy, Ltd.
500 West Madison St., 34th Flr.
Chicago, Illinois 60661
Telephone: (312) 775-8000



APPENDIX
AMENDMENTS TO THE CLAIMS

1. 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;
- (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;
- (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;
- (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
- (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



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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 [when] said actuator assembly-[is activated].

2. The injection valve of claim 1 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by differential thermal expansion.

3. The injection valve of claim 2 wherein said thickness of said hydraulic link is auto-adjustable while said actuator assembly is not activated in response to changes in said dimensional relationship caused by wear to components of said injection valve.

4. The injection valve of claim 1 wherein said hydraulic link assembly comprises a fluidly sealed hydraulic cylinder that is fluidly sealed from said interior chamber, said hydraulic link assembly comprising [with] a piston and said hydraulic fluid is disposed within said hydraulic cylinder.



Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH,
IRAWAN RAHARDJA and
MIKE HEBBES

SERIAL NO.: 09/522,130

FILED: March 9, 2000

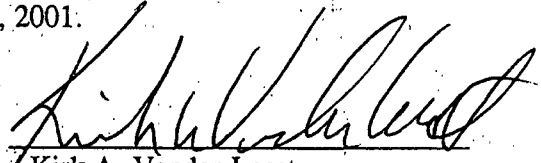
FOR: DIRECTLY ACTUATED INJECTION
VALVE

GROUP ART UNIT: 3747

CERTIFICATE OF MAILING

I hereby certify that this correspondence is
being deposited with the United States Postal
Service as first class mail in an envelope
addressed to: Assistant Commissioner for
Patents, Washington, D.C. 20231 on June
20, 2001.

By


Kirk A. Vander Leest
Reg. No. 34,036

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicants submit herewith a copy of each of the following references for consideration
by the U.S. Patent and Trademark Office in connection with the above application.

<u>U.S. Patent No.</u>	<u>Inventor(s)</u>	<u>Issue Date</u>
4,726,389	Minoura et al.	02/88
5,917,692	Schmitz et al.	06/99
<u>Foreign Patent No.</u>	<u>Country</u>	<u>Publication Date</u>
0 376 493	EPO	07/90

The above reference are listed on the enclosed Form PTO-1449 entitled "Information Disclosure Citation."

Concise Explanation of the Relevance of the Cited Reference(s)

Minoura et al. U.S. Patent No. 4,726,389 was cited in the International Search Report issued on May 3, 2001 in connection with the PCT/International application No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

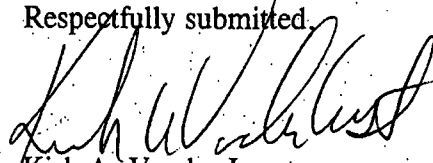
Schmitz et al. U.S. Patent No. 5,917,692 was cited in the International Search Report issued on May 3, 2001 in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

European Patent Publication No. 0 376 493 was cited in the International Search Report issued on May 3, 2001 in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in view of the International Searching Authority.

No fee is believed to be due because this statement and enclosures are being filed within three months of the issuance of the May 3, 2001 International Search Report issued in connection with the corresponding PCT/International application. Please charge any fees

incurred in connection with this submission to Deposit Account No. 13-0017 in the name of
McAndrews, Held & Malloy, Ltd.

Respectfully submitted,

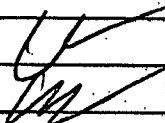


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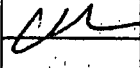
Form PTO-1449 (Rev. 8-83)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE				ATTORNEY DOCKET NO. 12541US02	SERIAL NO. 09/522,130
INFORMATION DISCLOSURE CITATION. (Use several sheets if necessary)							
						APPLICANT: Welch et al.	
						#8	
GROUP ART UNIT:							
U.S. PATENT DOCUMENTS							
*EXAMINER INITIAL		DOCUMENT NUMBER	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
	A	4,726,389	02/88	Minoura et al.			
	B	5,917,692	06/99	Schmitz et al.			
	C						
	D						
	E						
	F						
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	H						
	I						

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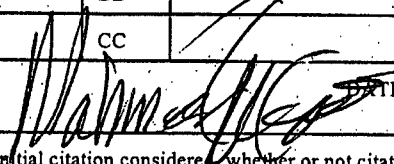
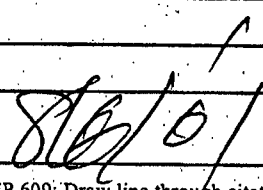
JUN 27 2001

TECHNOLOGY CENTER R3700

FOREIGN PATENT DOCUMENTS

		DOCUMENT NUMBER	DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
							YES	NO
	K	0 376 493	07/90	EPO				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

	AA	
	BB	
	CC	
EXAMINER		
	DATE CONSIDERED	
		
*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.		

Notice of Allowability	Application No.	Applicant(s)	
	09/522,130	WELCH ET AL.	
	Examiner Mahmoud M Gimie	Art Unit 3747	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to amendment filed on June 22, 2001.

2. ☒ The allowed claim(s) is/are 1-32.

3. ☒ The drawings filed on 09 March 2000 are accepted by the Examiner.

4. ☒ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a) ☐ All b) ☐ Some* c) ☐ None of the:

1. ☐ Certified copies of the priority documents have been received.

2. ☐ Certified copies of the priority documents have been received in Application No. _____

3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

* Certified copies not received: _____

5. ☒ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. § 119(e) (to a provisional application).

(a) ☐ The translation of the foreign language provisional application has been received.

6. ☐ Acknowledgment is made of a claim for domestic priority under 35 U.S.C. §§ 120 and/or 121.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application. **THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.**

7. ☐ A SUBSTITUTE OATH OR DECLARATION must be submitted. Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL PATENT APPLICATION (PTO-152) which gives reason(s) why the oath or declaration is deficient.

8. ☐ CORRECTED DRAWINGS must be submitted.

(a) ☐ including changes required by the Notice of Draftsperson's Patent Drawing Review (PTO-948) attached

1) ☐ hereto or 2) ☐ to Paper No. _____

(b) ☐ including changes required by the proposed drawing correction filed _____, which has been approved by the Examiner.

(c) ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No. _____

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the top margin (not the back) of each sheet. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftsperson.

9. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1 ☐ Notice of References Cited (PTO-892)	2 ☐ Notice of Informal Patent Application (PTO-152)
3 ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)	4 ☐ Interview Summary (PTO-413), Paper No. _____
5 ☒ Information Disclosure Statements (PTO-1449), Paper No. <u>8.</u>	6 ☐ Examiner's Amendment/Comment
7 ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material	8 ☐ Examiner's Statement of Reasons for Allowance
	9 ☐ Other

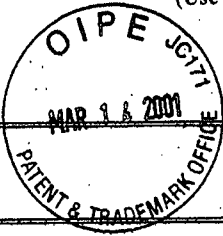
Henry C. Yuen
Supervisory Patent Examiner
Group 3700

EXTRA COPY

Dup # 6

Sheet 1 of 1

Form PTO-1449 (Rev. 8-83) (modified)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTY. DOCKET NO. 12541US02	SERIAL NO. 09/522,130
INFORMATION DISCLOSURE CITATION (Use several sheets if necessary)		APPLICANT(s): Welch et al.	
		FILING DATE March 9, 2000	GROUP ART UNIT: 3747



U.S. PATENT DOCUMENTS							
EXAMINER INITIAL		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
J		4,813,601	03/89	Schwerdt et al.	239	91	
		5,697,554	12/97	Auwaerter et al.	239	88	
		5,875,764	03/99	Kappel et al.	123	467	
		6,062,533	05/00	Kappel et al.	251	57	

FOREIGN PATENT DOCUMENTS								
EXAMINER INITIAL		DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
							YES	NO
J		WO 85/02445	06/85	PCT				
		09-324723	12/97	Japan			X (abstract)	
		10-009084	01/98	Japan			X (abstract)	
		2 321 501	07/98	Great Britain				
		0 869 278	08/98	EPO				
S		197 27 992	01/99	Germany				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)							

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EXAMINER 	DATE CONSIDERED: 8/6/01
*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.	

Attachment for PTO-948 (Rev. 03/01, or earlier)
6/18/01

The below text replaces the pre-printed text under the heading, "Information on How to Effect Drawing Changes," on the back of the PTO-948 (Rev. 03/01, or earlier) form.

INFORMATION ON HOW TO EFFECT DRAWING CHANGES

1. Correction of Informalities -- 37 CFR 1.85

New corrected drawings must be filed with the changes incorporated therein. Identifying indicia, if provided, should include the title of the invention; inventor's name, and application number, or docket number (if any) if an application number has not been assigned to the application. If this information is provided, it must be placed on the front of each sheet and centered within the top margin. If corrected drawings are required in a Notice of Allowability (PTOL-37), the new drawings **MUST** be filed within the **THREE MONTH** shortened statutory period set for reply in the Notice of Allowability. Extensions of time may **NOT** be obtained under the provisions of 37 CFR 1.136(a) or (b) for filing the corrected drawings after the mailing of a Notice of Allowability. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftsperson.

2. Corrections other than Informalities Noted by Draftsperson on form PTO-948.

All changes to the drawings, other than informalities noted by the Draftsperson, **MUST** be made in the same manner as above except that, normally, a highlighted (preferably red ink) sketch of the changes to be incorporated into the new drawings **MUST** be approved by the examiner before the application will be allowed. No changes will be permitted to be made, other than correction of informalities, unless the examiner has approved the proposed changes.

Timing of Corrections

Applicant is required to submit the drawing corrections within the time period set in the attached Office communication. See 37 CFR 1.85(a)

Failure to take corrective action within the set period will result in **ABANDONMENT** of the application.

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UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

NOTICE OF ALLOWANCE AND ISSUE FEE DUE

QM02/0807

MCANDREWS HELD & MALLOY LTD
500 WEST MADISON STREET 34TH FLOOR
CHICAGO IL 60661

APPLICATION NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP/ART.UNIT	DATE MAILED
09/522,130	03/09/00	032	GIMIE, M	3747 08/07/01
First Named Applicant	WELCH,	35 USC 154(b) term ext. =		

TITLE OF INVENTION DIRECTLY ACTUATED INJECTION VALVE

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN TYPE	SMALL ENTITY	FEE DUE	DATE DUE
2	12541US02	123-467.000	K21 UTILITY	NO	\$1240.00	11/07/01

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED.

THE ISSUE FEE MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED.

HOW TO RESPOND TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

A. If the status is changed, pay twice the amount of the FEE DUE shown above and notify the Patent and Trademark Office of the change in status, or

B. If the status is the same, pay the FEE DUE shown above.

If the SMALL ENTITY is shown as NO:

A. Pay FEE DUE shown above; or

B. File verified statement of Small Entity Status before, or with, payment of 1/2 the FEE DUE shown above.

II. Part B-Issue Fee Transmittal should be completed and returned to the Patent and Trademark Office (PTO) with your ISSUE FEE. Even if the ISSUE FEE has already been paid by charge to deposit account, Part B Issue Fee Transmittal should be completed and returned. If you are charging the ISSUE FEE to your deposit account, section "4b" of Part B-Issue Fee Transmittal should be completed and an extra copy of the form should be submitted.

III. All communications regarding this application must give application number and batch number. Please direct all communications prior to issuance to Box ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PATENT AND TRADEMARK OFFICE COPY

PTOL-85 (REV. 10-95) Approved for use through 06/30/99. (0651-0033)

ISSUE FEE TRANSMITTAL

Complete and mail this form, together with applicable fees, to:

Box ISSUE FEE
Assistant Commissioner for Patents
Washington, D.C. 20231

MAILING INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE. Blocks 1 through 4 should be completed as appropriate. All further correspondence including the Issue Fee Receipt, the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Legibly mark-up with any corrections or use Block 1)

QM02/0807

MCANDREWS HELD & MALLOY LTD
500 WEST MADISON STREET 34TH FLOOR
CHICAGO IL 60661

Note: The certificate of mailing below can only be used for domestic mailings of the Issue Fee Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing.

Certificate of Mailing

I hereby certify that this Issue Fee Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Box Issue Fee address above on the date indicated below.

Robert W. Fieseler (Depositor's name)

(Signature)

August 21, 2001 (Date)

APPLICATION NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT	DATE MAILED
09/522,130	03/09/00	032	GIMIE, M	3747 08/07/01
First Named Applicant	WELCH, 35 USC 154(b) term ext. = 0 Days.			

TITLE OF INVENTION DIRECTLY ACTUATED INJECTION VALVE

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
2	12541US02	123-467.000	K21 UTILITY	NO	\$1240.00	11/07/01

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363). Use of PTO form(s) and Customer Number are recommended, but not required.

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☒ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47) attached.

2. For printing on the patent front page, list (1) the names of up to 3 registered patent attorneys or agents OR, alternatively, (2) the name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

McAndrews, Held & Malloy, Ltd.

2

3

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE COMPLETED

PLEASE NOTE: Unless an assignee

Inclusion of assignee data is only appropriate when an assignment has been previously submitted to the PTO or is being submitted under separate cover. Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE Westport Research Inc.

(B) RESIDENCE: (CITY & STATE OR COUNTRY) Vancouver, BC, Canada

Please check the appropriate assignee category indicated below (will not be printed on the patent)

☐ individual ☒ corporation or other private group entity ☐ government

☒ Issue Fee

☐ Advance Order - # of Copies

4b. The following fees or deficiency fees should be charged to:

DEPOSIT ACCOUNT NUMBER 13-0017

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☐ Issue Fee

☒ Advance Order - # of Copies 15

The COMMISSIONER OF PATENTS AND TRADEMARKS IS requested to apply the Issue Fee to the application identified above.

(Authorized Signature)

(Date)

NOTE: The Issue Fee will not be accepted from anyone other than the applicant; a registered attorney or agent; or the assignee or other party in interest as shown by the records of the Patent and Trademark Office.

Burden Hour Statement: This form is estimated to take 0.2 hours to complete. Time will vary depending on the needs of the individual case. Any comments on the amount of time required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington, D.C. 20231: DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND FEES AND THIS FORM TO: Box Issue Fee, Assistant Commissioner for Patents, Washington D.C. 20231

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08/24/2001 MFAME11 00000097 130017 09522130

01 FC:142

02 FC:561

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Approved for use through 06/30/99. OMB 0651-0033

Patent and Trademark Office; U.S. DEPARTMENT OF COMM

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2001-10-09

Document Title - USPTO Grant



P. C. of C
#10

PATENT
Attorney Docket No.: 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application of:	)	CERTIFICATE OF MAILING
	)	
ALAN B. WELCH,	)	I hereby certify that this
IRAWAN RAHARDJA and	)	paper is being deposited with
MIKE HEBBES	)	the United States Postal
	)	Service as first class mail,
Patent No: 6,298,829	)	postage prepaid, in an
	)	envelope addressed to:
Issued: OCTOBER 9, 2001	)	Assistant Commissioner for
	)	Patents, Washington, DC 20231
Serial No: 09/522,130	)	on this date:
	)	
Filed: MARCH 9, 2000	)	<u>January 4, 2002</u>
	)	
For: DIRECTLY ACTUATED	)	<u>Robert W. Fieseler</u>
INJECTION VALVE	)	Robert W. Fieseler
	)	Registration No. 31,826
	)	Attorney for Applicants

REQUEST FOR CERTIFICATE OF CORRECTION UNDER §1.322(a)

Assistant Commissioner for Patents
Washington, D.C. 20231

CERTIFICATE

FEB 08 2002

OF CORRECTION

Sir:

Pursuant to 37 CFR §1.322(a), Applicants hereby request a Certificate of Correction to be issued for the above-identified U.S. Patent correcting the patent as noted in the attached "Certificate of Correction" form PTO 1050 (Rev. 2-93).

The errors listed below in the patent can be verified by reviewing the Information Disclosure Statement mailed on March 12, 2001. Both of the incorrect and missing references were submitted on the Information Disclosure Statement filed on that date (copy attached). The references were acknowledged and considered by the Examiner, as indicated by his signature on the return copy of the IDS, dated August 6, 2001 (copy attached). Specifically, the errors that need to be corrected are as follows:

In the References Cited section, under Foreign Patent Documents, please delete reference "2 321 278 9/1998 (EP)" and insert --2 321 501 7/1998 (GB)--. Also, please add the following reference --0 869 278 10/1998 (EP)--.

In accordance with Applicants' request, Applicants' attach hereto the corresponding form PTO 1050 bearing the requested corrections. Duplicate copies of the form are attached hereto.



In the event that any additional fees are required for the filing of this response, the Commissioner is authorized to charge our Deposit Account No. 13-0017 in the name of McAndrews, Held & Malloy, Ltd., or to refund any overpayment thereto. A duplicate copy of this form is enclosed.

Respectfully submitted,

Robert W. Fieseler
Registration No. 31,826
Attorney for Applicants

McANDREWS, HELD & MALLOY, LTD.
500 West Madison Street, 34th Floor
Chicago, Illinois 60661

Telephone: (312) 775-8000
Facsimile: (312) 775-8100

Dated: January 4, 2002

Staple
Here
Only!

PRINTER'S TRIM LINE

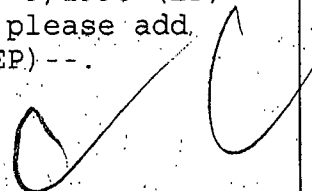
UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,298,829 *B1*
DATED : October 9, 2001
INVENTOR(S) : Alan B. Welch, Irawan Rahardja, and Mike Hebbes

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page, Item (5b)

~~In the~~ References Cited ~~section~~ under Foreign Patent Documents, please delete reference "2 321 278 9/1998 (EP)" and insert -- 2 321 501 7/1998 (GB) --. Also, please add the following reference -- 0 869 278 10/1998 (EP) --.



MAILING ADDRESS OF SENDER:

McAndrews, Held & Malloy, Ltd.
500 West Madison Street, Floor 34
Chicago, Illinois 60661

Patent No: 6,289,637
No. of add'l. copies
@ 50¢ per page



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PRINTER'S TRIM LINE

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,298,829
DATED : October 9, 2001
INVENTOR(S) : Alan B. Welch, Irawan Rahardja, and Mike Hebbes

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the References Cited section, under Foreign Patent Documents, please delete reference "2 321 278 9/1998 (EP)" and insert -- 2 321 501 7/1998 (GB)--. Also, please add the following reference --0 869 278 10/1998 (EP)--.

MAILING ADDRESS OF SENDER:

McAndrews, Held & Malloy, Ltd.
500 West Madison Street, Floor 34
Chicago, Illinois 60661

Patent No: 6,289,637
No. of add'l. copies
@ 50¢ per page





PATENT
Attorney Docket No. 12541US02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT APPLICATION OF:

ALAN B. WELCH,
IRAWAN RAHARDJA and
MIKE HEBBES

SERIAL NO. 09/522,130

FILED: MARCH 9, 2000

FOR: DIRECTLY ACTUATED
INJECTION VALVE

GROUP ART UNIT: 3747

EXAMINER: Not yet assigned

CERTIFICATE OF MAILING

I hereby certify that this
correspondence is being
deposited with the United
States Postal Service as
first class mail, postage
prepaid, in an envelope
addressed to: Assistant
Commissioner for Patents,
Washington, D.C. 20231, on
this date:

March 12, 2001

Robert W. Fieseler
Robert W. Fieseler
Registration No. 31,826
Attorney for Applicant(s)

SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicants submit herewith a copy of each of the
following references for consideration by the U.S. Patent and
Trademark Office in connection with the above application.

<u>U.S. Patent No.</u>	<u>Inventor(s)</u>	<u>Issue Date</u>
4,813,601	Schwerdt et al.	03/89
5,697,554	Auwaerter et al.	12/97
5,875,764	Kappel et al.	03/99
6,062,533	Kappel et al.	05/00

<u>Foreign Patent No.</u>	<u>Country</u>	<u>Publication Date</u>
WO 85/02445	PCT	06/85
09-324723	Japan	12/97
10-009084	Japan	01/98
2 321 501	Great Britain	07/98
0 869 278	EPO	08/98
197 27 992	Germany	01/99

The above references are listed on the enclosed Form PTO-1449 entitled "Information Disclosure Citation."

Concise Explanation of the
Relevance of the Cited Reference(s)

Schwerdt et al. U.S. Patent No. 4,813,601 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Auwaerter et al. U.S. Patent No. 5,697,554 was cited in the International Search Report issued in connection with the

PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Kappel et al. U.S. Patent No. 5,875,764 discloses an apparatus and method for valve control. The valve has a piezo actuator or a magnetostrictive actuator. The fluid is contained in an unsealed hydraulic chamber and transmits actuation forces from the actuator to the valve needle.

Kappel et al. U.S. Patent No. 6,062,764 discloses an apparatus and method for valve control. The primary drive, a piezo actuator, guided in a first bore, transfers its stroke motion onto a secondary-side lifter element in a secondary bore which then transmits its stroke by means of a hydraulic transmission.

PCT/International Publication No. WO 85/02445 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the

reference in the view of the International Searching Authority.

Japanese Patent Publication No. 09-324723 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

Japanese Patent Publication No. 10-009084 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

British Patent No. 2 321 501 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

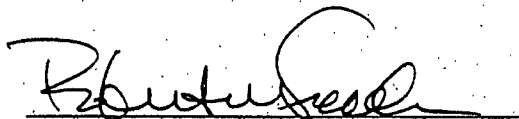
European Patent Publication No. 0 869 278 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority.

German Patent Publication No. 197 27 992 was cited in the International Search Report issued in connection with the PCT/International application, No. PCT/CA00/01156 (copy enclosed herewith), which corresponds to the present application. The International Search Report sets forth the relevance of the reference in the view of the International Searching Authority. Applicants have not obtained a full-text translation of the German language document, but are willing to obtain and provide such a translation upon request.

This Supplemental Information Disclosure Statement is being submitted before the receipt of a first office action on the merits of the above application.

Please charge any fees incurred in connection with this submission to Deposit Account No. 13-0017 in the name of McAndrews, Held & Malloy, Ltd.

Respectfully submitted,



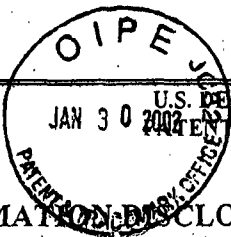
Robert W. Fieseler
Registration No. 31,826
Attorney for Applicants

Russell A. Garrison
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500 West Madison Street, 34th Floor
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Telephone: (312) 775-8000
Facsimile: (312) 775-8100

Dated: March 12, 2001

Form PTO-1449
(Rev. 8-83)
(modified)



U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE

ATTY. DOCKET NO.
12541US02

SERIAL NO.
09/522,130

Sheet 1 of 1

INFORMATION DISCLOSURE CITATION
(Use several sheets if necessary)

APPLICANT(s):
Welch et al.

FILING DATE
March 9, 2000

GROUP ART. UNIT:
3747

U.S. PATENT DOCUMENTS

EXAMINER INITIAL	DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
	4,813,601	03/89	Schwerdt et al.	239	91	
	5,697,554	12/97	Auwaerter et al.	239	88	
	5,875,764	03/99	Kappel et al.	123	467	
	6,062,533	05/00	Kappel et al.	251	57	

FOREIGN PATENT DOCUMENTS

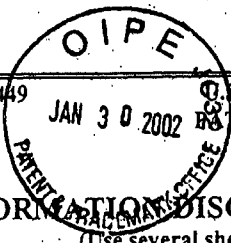
EXAMINER INITIAL	DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
						YES	NO
	WO 85/02445	06/85	PCT				
	09-324723	12/97	Japan			X (abstract)	
	10-009084	01/98	Japan			X (abstract)	
	2 321 501	07/98	Great Britain				
	0 869 278	08/98	EPO				
	197 27 992	01/99	Germany				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

EXAMINER

DATE CONSIDERED:

*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.



Form PTO-1449 (Rev. 8-83) (modified)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTY. DOCKET NO. 12541US02	SERIAL NO. 09/522,130
		APPLICANT(s): Welch et al.	
		FILING DATE March 9, 2000	GROUP ART UNIT: 3747

INFORMATION DISCLOSURE CITATION
(Use several sheets if necessary)

U.S. PATENT DOCUMENTS							
EXAMINER INITIAL		DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
		4,813,601	03/89	Schwerdt et al.	239	91	
		5,697,554	12/97	Auwaerter et al.	239	88	
		5,875,764	03/99	Kappel et al.	123	467	
		6,062,533	05/00	Kappel et al.	251	57	

FOREIGN PATENT DOCUMENTS								
EXAMINER INITIAL		DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
							YES	NO
		WO 85/02445	06/85	PCT				
		09-324723	12/97	Japan			X (abstract)	
		10-009084	01/98	Japan			X (abstract)	
		2 321 501	07/98	Great Britain				
		0 869 278	08/98	EPO				
		197 27 992	01/99	Germany				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)		

EXAMINER	DATE CONSIDERED:
*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.	

Form PTO-1449
(Rev. 8-83)
(modified)

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE

ATTY. DOCKET NO.
12541US02

SERIAL NO.
09/522,130

INFORMATION DISCLOSURE CITATION
(Use several sheets if necessary)

APPLICANT(s):
Welch et al.

FILING DATE
March 9, 2000

GROUP ART UNIT:
3747

U.S. PATENT DOCUMENTS

EXAMINER INITIAL	DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS	FILING DATE IF APPROPRIATE
<i>mk</i>	4,813,601	03/89	Schwerdt et al.	239	91	
	5,697,554	12/97	Auwaerter et al.	239	88	
<i>ck</i>	5,875,764	03/99	Kappel et al.	123	467	
	6,062,533	05/00	Kappel et al.	251	57	

FOREIGN PATENT DOCUMENTS

EXAMINER INITIAL	DOCUMENT NO.	PUBLICATION DATE	COUNTRY	CLASS	SUBCLASS	TRANSLATION	
						YES	NO
<i>ck</i>	WO 85/02445	06/85	PCT				
	09-324723	12/97	Japan			X (abstract)	
	10-009084	01/98	Japan			X (abstract)	
	2 321 501	07/98	Great Britain				
<i>ck</i>	0 869 278	08/98	EPO				
	197 27 992	01/99	Germany				

OTHER DOCUMENTS (Including Author, Title, Date, Pertinent Pages, Etc.)

EXAMINER

DATE CONSIDERED:

*EXAMINER: Initial citation considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2002-07-22

Document Title - Certificate of Correction - Post Issue Communication

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,298,829 B1
DATED : October 9, 2001
INVENTOR(S) : Alan B. Welch, Irawan Rahardja and Mike Hebbes

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

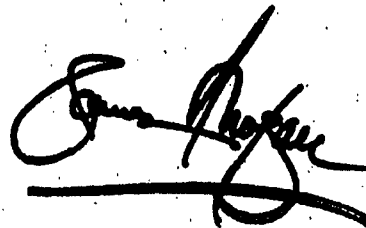
Title page.

Item [56], **Reference Cited**, FOREIGN PATENT DOCUMENTS, please delete reference "2 321 278 9/1998 (EP)" and insert -- 2 321 501 7/1998 (GB) --. Also please add the following reference -- 0 869 278 10/1998 (EP) --.

Signed and Sealed this

Sixth Day of August, 2002

Attest:



Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2003-03-26

Document Title - USPTO Communication Re: Change of Address

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2012-07-23

Document Title - USPTO Communication Re: Change of Address

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2012-07-24

Document Title - USPTO Communication Re: Power of Attorney

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2015-01-27

Document Title - USPTO Communication Re: Change of Address

File History Content Report

The following content is missing from the original file history record obtained from the United States Patent and Trademark Office. No additional information is available.

Document Date - 2017-03-31

Document Title - USPTO Communication Re: Change of Address

111

PATENT APPLICATION FEE DETERMINATION RECORD Effective December 29, 1999				Application or Docket Number	
CLAIMS AS FILED - PART I					
(Column 1)		(Column 2)			
FOR	NUMBER FILED	NUMBER EXTRA			
BASIC FEE					
TOTAL CLAIMS	30 minus 20 =	*	10		
INDEPENDENT CLAIMS	3 minus 3 =	*			
MULTIPLE DEPENDENT CLAIM PRESENT					
* If the difference in column 1 is less than zero, enter "0" in column 2					
CLAIMS AS AMENDED - PART II					
(Column 1)		(Column 2)	(Column 3)		
AMENDMENT A	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	
	Total	* 32	Minus	** 30	= 2
	Independent	* 3	Minus	*** 3	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				
(Column 1)		(Column 2)	(Column 3)		
AMENDMENT B	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				
(Column 1)		(Column 2)	(Column 3)		
AMENDMENT C	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	
	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				
* If the entry in column 1 is less than the entry in column 2, write "0" in column 3. ** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20." *** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3." The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.					

SMALL ENTITY TYPE ☐		OR	OTHER THAN SMALL ENTITY	
RATE	FEE		RATE	FEE
	345.00	OR		690.00
X\$ 9=		OR	X\$18=	180.00
X39=		OR	X78=	
+130=		OR	+260=	
TOTAL		OR	TOTAL	870.00

SMALL ENTITY TYPE ☐		OR	OTHER THAN SMALL ENTITY	
RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
		OR		
X\$ 9=		OR	X\$18=	36
X39=		OR	X78=	
+130=		OR	+260=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

SMALL ENTITY TYPE ☐		OR	OTHER THAN SMALL ENTITY	
RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
		OR		
X\$ 9=		OR	X\$18=	
X39=		OR	X78=	
+130=		OR	+260=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

SMALL ENTITY TYPE ☐		OR	OTHER THAN SMALL ENTITY	
RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
		OR		
X\$ 9=		OR	X\$18=	
X39=		OR	X78=	
+130=		OR	+260=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

Derwent Innovation Patent Export, 2022-01-13 01:27:11 +0000

Search results for: PNS=(US6298829);

Collections searched: DWPI; ARIPO grant; Argentina UM; Argentina app; Armenia grant; Australia UM; Australia app; Australia grant; Austria UM; Austria app; Austria grant; Belarus UM; Belarus grant; Belgium app; Belgium grant; Brazil UM; Brazil app; Brazil grant; Bulgaria UM; Bulgaria app; Bulgaria grant; Canada app; Canada grant; China, Mainland UM; China, Mainland app; China, Mainland grant; Colombia app; Costa Rica UM; Costa Rica app; Croatia UM; Croatia app; Croatia grant; Cuba app; Cuba grant; Czech Republic UM; Czech Republic app; Czech Republic grant; Czechoslovakia grant; Denmark UM; Denmark app; Denmark grant; Estonia UM; Estonia app; Estonia grant; Eurasian (EAPO) grant; Europe (EP) app; Europe (EP) grant; Finland app; Finland grant; France app; France grant; Georgia grant; German Democratic Republic app; German Democratic Republic grant; Germany UM; Germany app; Germany grant; Greece app; Greece grant; Gulf Cooperation Council grant; Hong Kong UM; Hong Kong app; Hong Kong grant; Hungary grant; Iceland grant; India app; India grant; Indonesia UM; Indonesia app; Ireland UM; Ireland app; Ireland grant; Israel grant; Italy grant; Italy grant; Italy grant; Italy grant; Japan UM; Japan app; Japan grant; Korea UM; Korea app; Korea grant; Latvia grant; Lithuania grant; Luxembourg app; Luxembourg grant; Malaysia app; Malaysia grant; Mexico app; Mexico grant; Moldova UM; Moldova grant; Monaco grant; Mongolia UM; Mongolia grant; Morocco app; Morocco grant; Netherlands app; Netherlands grant; New Zealand grant; Norway app; Norway grant; OAPI grant; PCT (WO) app; Philippines UM; Philippines app; Philippines grant; Poland UM; Poland grant; Portugal UM; Portugal app; Portugal grant; Romania UM; Romania app; Romania granted; Russia UM; Russia app; Russia grant; Serbia UM; Serbia app; Serbia grant; Singapore app; Singapore grant; Slovakia UM; Slovakia app; Slovakia grant; Slovenia UM; Slovenia grant; South Africa app; Spain UM; Spain app; Spain grant; Sweden app; Sweden grant; Switzerland app; Switzerland grant; Taiwan UM; Taiwan appl; Taiwan grant; Thailand UM; Thailand app; Thailand grant; Tunisia app; Turkey UM; Turkey app; Turkey grant; UK app; UK grant; USSR grant; Ukraine UM; Ukraine grant; United States app; United States grant; Uruguay app; Vietnam UM; Vietnam app; Vietnam grant; Other

Table of Contents

- 1. US6298829B1 Directly actuated injection valve
-

Family 1/1

1 record(s) per family

Record 1/1 US6298829B1 Directly actuated injection valve

Title: Directly actuated injection valve

Title - DWPI: Injection valve for gaseous fuel in combustion chamber of internal combustion engine, has thickness adjustable hydraulic link connecting actuator and needle valve

Priority Number: US1999159791P

Priority Date: 1999-10-15

Application Number: US2000522130A

Application Date: 2000-03-09

Publication Date: 2001-10-09

IPC Class Table:

IPC	Section	Class	Subclass	Class Group	Subgroup
F02D004120	F	F02	F02D	F02D0041	F02D004120
F02M002102	F	F02	F02M	F02M0021	F02M002102
F02M004700	F	F02	F02M	F02M0047	F02M004700
F02M004704	F	F02	F02M	F02M0047	F02M004704
F02M005100	F	F02	F02M	F02M0051	F02M005100
F02M005106	F	F02	F02M	F02M0051	F02M005106
F02M006108	F	F02	F02M	F02M0061	F02M006108
F02M006110	F	F02	F02M	F02M0061	F02M006110
F02M006116	F	F02	F02M	F02M0061	F02M006116
F02M006300	F	F02	F02M	F02M0063	F02M006300

IPC Class Table - DWPI:

IPC - DWPI	Section - DWPI	Class - DWPI	Subclass - DWPI	Class Group - DWPI	Subgroup - DWPI
F02M005106 (IPC 1-7)	F	F02	F02M	F02M0051	F02M005106 (IPC 1-7)
F01L000904 (IPC	F	F01	F01L	F01L0009	F01L000904 (IPC

1-7)					1-7)
F02D004120 (IPC 1-7)	F	F02	F02D	F02D0041	F02D004120 (IPC 1-7)
F02M002102 (IPC 1-7)	F	F02	F02M	F02M0021	F02M002102 (IPC 1-7)
F02M004120 (IPC 1-7)	F	F02	F02M	F02M0041	F02M004120 (IPC 1-7)
F02M004700 (IPC 1-7)	F	F02	F02M	F02M0047	F02M004700 (IPC 1-7)
F02M004704 (IPC 1-7)	F	F02	F02M	F02M0047	F02M004704 (IPC 1-7)
F02M006110 (IPC 1-7)	F	F02	F02M	F02M0061	F02M006110 (IPC 1-7)
F02M006116 (IPC 1-7)	F	F02	F02M	F02M0061	F02M006116 (IPC 1-7)
F02M006300 (IPC 1-7)	F	F02	F02M	F02M0063	F02M006300 (IPC 1-7)
F01L000904	F	F01	F01L	F01L0009	F01L000904
F02D004120	F	F02	F02D	F02D0041	F02D004120
F02M002102	F	F02	F02M	F02M0021	F02M002102
F02M004700	F	F02	F02M	F02M0047	F02M004700
F02M004704	F	F02	F02M	F02M0047	F02M004704
F02M005100	F	F02	F02M	F02M0051	F02M005100
F02M005106	F	F02	F02M	F02M0051	F02M005106
F02M006108	F	F02	F02M	F02M0061	F02M006108
F02M006110	F	F02	F02M	F02M0061	F02M006110
F02M006116	F	F02	F02M	F02M0061	F02M006116
F02M006300	F	F02	F02M	F02M0063	F02M006300

Assignee/Applicant: Westport Research Inc.,Vancouver,CA

JP F Terms:

JP FI Codes:

Assignee - Original: Westport Research Inc.

Any CPC Table:

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Type	Invention	Additional	Version	Office
Current	F02M 61/167	F02B 2275/14	20130101	EP; US
Current	F02D 19/024	F02D 41/2096	20130101	EP; US
Current	F02D 41/20	F02D 2041/2037	20130101	EP; US
Current	F02M 21/0254	F02M 2200/30	20130101	EP; US
Current	F02M 21/0263	F02M 2200/304	20130101	EP; US
Current	F02M 51/005	F02M 2200/507	20130101	EP; US
Current	F02M 51/0607	Y02T 10/12	20130101	EP; US
Current	F02M 61/08	Y02T 10/30	20130101	EP; US
Current	F02M 61/10		20130101	EP; US
Current	F02M 61/166		20130101	EP; US
Original	F02M 61/167	F02B 2275/14	20130101	US
Original	F02D 19/024	F02D 41/2096	20130101	US
Original	F02D 41/20	F02D 2041/2037	20130101	US
Original	F02M 21/0254	F02M 2200/30	20130101	US
Original	F02M 21/0263	F02M 2200/304	20130101	US
Original	F02M 51/005	F02M 2200/507	20130101	US
Original	F02M 51/0607	Y02T 10/12	20130101	US
Original	F02M 61/08	Y02T 10/30	20130101	US
Original	F02M 61/10		20130101	US
Original	F02M 61/166		20130101	US

ECLA: F02M006116G | F02D004120 | F02M002102S10 | F02M005100C | F02M005106A2 | F02M006108 | F02M006110 | F02M006116F | R02B027514 | R02D004120C6 | R02D004120P | R02M020030 | R02M020030H | R02M020050C

Abstract:

A directly actuated injection valve comprises a hollow valve housing, a valve needle disposed within the hollow interior, a needle spring, an actuator assembly, and a hydraulic link assembly. The valve needle is movable between a closed position and an open position for governing the flow of fuel into the combustion chamber of an internal combustion engine. The displacement of the valve needle from the closed position is defined as the lift. The a needle spring biases the valve needle in the closed position. The actuator assembly generates an opening force that acts against the needle spring to open the valve. The hydraulic link assembly is interposed between the valve needle and the needle spring and the actuator assembly. The hydraulic link assembly transmits respective closing and opening forces to the valve needle. The hydraulic link preferably comprises a piston disposed within a cylinder that is filled with a hydraulic fluid. The opening and closing forces are transmitted through a thickness of the hydraulic fluid that is trapped between the planar surfaces of the piston and the head and base of the hydraulic cylinder. 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. When the actuator assembly comprises a magnetostrictive or piezoelectric member, the movements of the valve needle can be controlled by the application of a shaped control pulse or waveform to improve the speed of the opening and closing motion of the valve needle, and to reduce the impact of the valve needle on the valve seat upon closing.

Language of Publication: EN

INPADOC Legal Status Table:

Gazette Date	Code	INPADOC Legal Status Impact
2021-07-16	AS	-
Description: ASSIGNMENT WESTPORT FUEL SYSTEMS CANADA INC., BRITISH COLUMBIA CHANGE OF NAME; ASSIGNOR:WESTPORT POWER INC.; REEL/FRAME:056898/0199 2021-03-31		
2021-06-09	AS	-
Description: ASSIGNMENT WESTPORT POWER INC., BRITISH COLUMBIA RELEASE BY SECURED PARTY; ASSIGNOR:CANADIAN IMPERIAL BANK OF COMMERCE; REEL/FRAME:056887/0499 2010-06-15		
2016-01-14	AS	-
Description: ASSIGNMENT PANGEA TWO MANAGEMENT, LP, NEW YORK SECURITY INTEREST; ASSIGNOR:WESTPORT POWER INC.; REEL/FRAME:037529/0579 2016-01-11		
2013-03-14	FPAY	+
Description: FEE PAYMENT FEE PAYMENT YEAR 12		
2009-03-11	FPAY	+
Description: FEE PAYMENT FEE PAYMENT YEAR 8		
2007-08-01	AS	-
Description: ASSIGNMENT WESTPORT POWER INC., CANADA RELEASE BY SECURED PARTY; ASSIGNOR:PERSEUS, L.L.C.; REEL/FRAME:019617/0680 2007-07-26		
2006-09-21	AS	-
Description: ASSIGNMENT PERSEUS, L.L.C., DISTRICT OF COLUMBIA SECURITY AGREEMENT; ASSIGNOR:WESTPORT POWER INC; REEL/FRAME:018279/0449 2006-07-24		
2006-09-18	AS	-
Description: ASSIGNMENT CANADIAN IMPERIAL BANK OF COMMERCE, CANADA SECURITY AGREEMENT; ASSIGNOR:WESTPORT POWER INC; REEL/FRAME:018260/0357 2006-07-24		

2006-08-31	AS	-
Description: ASSIGNMENT WESTPORT POWER INC., CANADA ASSIGNMENT OF ASSIGNORS INTEREST; ASSIGNOR:WESTPORT RESEARCH INC.; REEL/FRAME:018184/0812 2006-08-16		
2005-03-15	FPAY	+
Description: FEE PAYMENT FEE PAYMENT YEAR 4		
2002-08-06	CC	-
Description: CERTIFICATE OF CORRECTION		
2001-09-21	STCF	-
Description: INFORMATION ON STATUS: PATENT GRANT PATENTED CASE		
2000-06-19	AS	-
Description: ASSIGNMENT WESTPORT RESEARCH INC., CANADA ASSIGNMENT OF ASSIGNORS INTEREST; ASSIGNORS:WELCH ALAN B.; RAHARDJA, IRAWAN; HEBBES, MIKE; REEL/FRAME:010907/0609; SIGNING DATES FROM 20000320 TO 20000501		

Post-Issuance (US): CORR-CERT Certificate of Correction 2002-08-06 2002 2002-08-27 2002 a Certificate of Correction was issued for this patent

Reassignment (US) Table:

Assignee	Assignor	Date Signed	Reel/Frame	Date
WESTPORT FUEL SYSTEMS CANADA INC.,VANCOUVER,CA	WESTPORT POWER INC.	2021-03-31	056898/0199	2021-07-16
Conveyance: CHANGE OF NAME (SEE DOCUMENT FOR DETAILS).				
Corresponent: CAMERON KYLE 1750 75TH AVE W SUITE 101 VANCOUVER, BCC V6P 6G2				
PANGEA TWO MANAGEMENT LP,NEW YORK,NY,US	WESTPORT POWER INC.	2016-01-11	037529/0579	2016-01-14
Conveyance: SECURITY INTEREST (SEE DOCUMENT FOR DETAILS).				
Corresponent: ROSEANN B. CALDWELL, BENNETT JONES LLP 4500 BANKERS HALL EAST, 855 - 2ND STREET SW CALGARY, T2P 4K7 CANADA				
WESTPORT POWER INC.,VANCOUVER,CA	CANADIAN IMPERIAL BANK OF COMMERCE	2010-06-15	056887/0499	2021-06-09

Conveyance: RELEASE BY SECURED PARTY (SEE DOCUMENT FOR DETAILS).				
Corresponent: CAMERON KYLE 1750 75TH AVE W SUITE 101 VANCOUVER, V6P 6G2 CANADA				
WESTPORT POWER INC.,VANCOUVER,CA	PERSEUS, L.L.C.	2007-07-26	019617/0680	2007-08-01
Conveyance: RELEASE BY SECURED PARTY (SEE DOCUMENT FOR DETAILS).				
Corresponent: COLLEEN HOLCOMB MCDUFFIE 1600 TYSONS BOULEVARD SUITE 900 MCLEAN, VA 22102				
WESTPORT POWER INC.,VANCOUVER, BRITISH COLUMBIA,CA	WESTPORT RESEARCH INC.	2006-08-16	018184/0812	2006-08-31
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).				
Corresponent: MCANDREWS, HELD & MALLOY, LTD. 500 WEST MADISON STREET 34TH FLOOR CHICAGO, IL 60661				
PERSEUS L.L.C.,WASHINGTON,DC,US	WESTPORT POWER INC	2006-07-24	018279/0449	2006-09-21
Conveyance: SECURITY AGREEMENT				
Corresponent: STUART BARKOFF 555 TWELFTH STREET, N.W. IP DOCKETING, ARNOLD & PORTER LLP WASHINGTON, DC 20004				
CANADIAN IMPERIAL BANK OF COMMERCE,TORONTO,CA	WESTPORT POWER INC	2006-07-24	018260/0357	2006-09-18
Conveyance: SECURITY AGREEMENT				
Corresponent: STUART BARKOFF 555 TWELFTH STREET, N.W. IP DOCKETING, ARNOLD & PORTER LLP WASHINGTON, DC 20004				
WESTPORT RESEARCH INC.,VANCOUVER, BC,CA	WELCH ALAN B.	2000-05-01	010907/0609	2000-06-19
	RAHARDJA, IRAWAN	2000-03-20	-	-
	HEBBES, MIKE	2000-03-20	-	-
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).				
Corresponent: MCANDREWS, HELD & MALLOY, LTD. ROBERT W. FIESELER 500 WEST MADISON STREET 34TH FLOOR CHICAGO, IL 60661				

Maintenance Status (US): CC

Litigation (US): 2021-12-15 2021 Westport Fuel Systems Canada Inc. Nissan North America, Inc. E.D. Texas 2:21cv00455 | 2021-12-15 2021 Westport Fuel Systems Canada Inc. Mercedes-

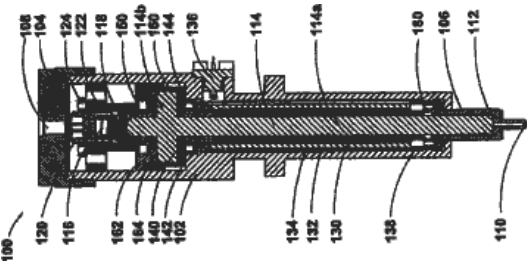
Benz USA, LLC E.D. Texas 2:21cv00454 | 2021-12-15 2021 Westport Fuel Systems Canada Inc.
General Motors, LLC E.D. Texas 2:21cv00456 | 2021-12-15 2021 Westport Fuel Systems
Canada Inc. Ford Motor Company E.D. Texas 2:21cv00453 | 2021-12-15 2021 Westport Fuel
Systems Canada Inc. FCA US LLC d/b/a FCA Group US LLC E.D. Texas 2:21cv00457

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EPO Procedural Status:

Front Page Drawing:



Priority Number - DWPI: US1999159791P | US2000522130A

Priority Date - DWPI: 1999-10-15 | 2000-03-09

Assignee - Current US: WESTPORT FUEL SYSTEMS CANADA INC.



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Directly actuated injection valve

PATENT #

6298829

APPLICATION #

09522130

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ISSUE DATE

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WINDOW		STATUS		FEES	
11.5 Year		Closed		Paid	
Window	First Day to Pay	Surcharge Starts	Last Day to Pay	Status	Fees
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7.5 Year	10/09/2008	04/10/2009	10/09/2009	Closed	Paid
11.5 Year	10/09/2012	04/10/2013	10/09/2013	Closed	Paid

No maintenance fees are due.

Patent Holder Information

Customer #

133599

Entity Status

UNDISCOUNTED

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