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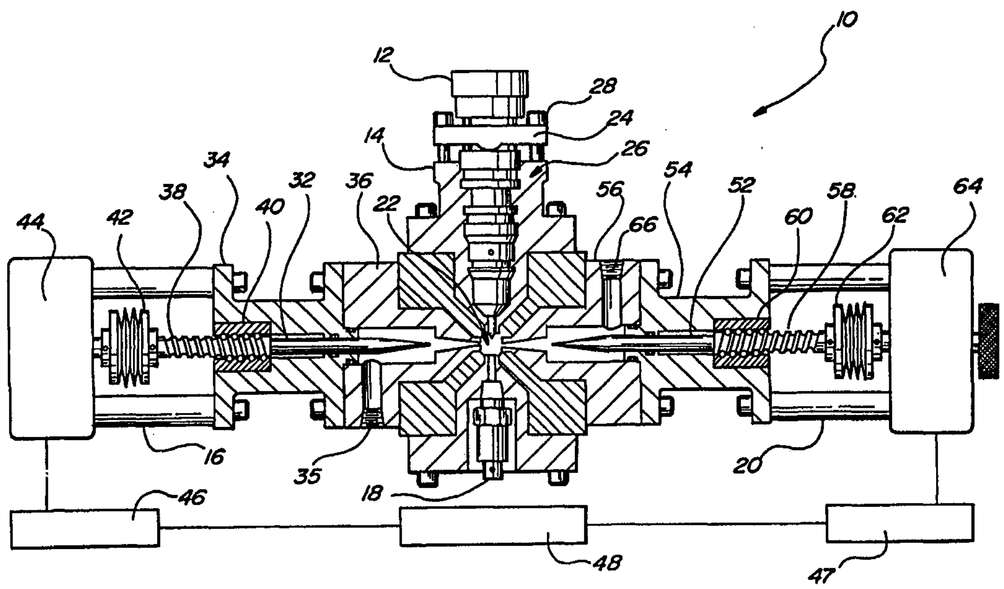

(57) Abstract

The present invention provides a flowmeter (10) which measures the flowrate of a fuel injector (12) by monitoring the pressure drop across a variable orifice valve (52) by use of a pressure sensor (18) with no moving mechanical parts. The present invention has a fuel injector adapter (14) for receiving the fuel injector (12), a flow measurement chamber (22) which fluidly communicates with the injector (12) through the fuel injector adapter (14), a pressure sensor (18) for sensing the pressure of fuel inside the flow measurement chamber (22), and a variable orifice (20) which regulates the pressure in the flow measurement chamber (22). The variable orifice (20) selectively adjusts the pressure drop of the flowrate exiting the flow measurement chamber (22), thereby selectively adjusting the flow and pressure ratios.

FLOWMETER

BACKGROUND OF THE INVENTION

I. TECHNICAL FIELD

The present invention relates generally to a flowmeter and, more particularly, to a flowmeter for measuring the flowrate through a fuel injector.

II. DISCUSSION

In modern engine design, such as in a diesel fired engine, an engine is fitted with fuel injectors, which supply a predetermined flowrate of fuel into the combustion chamber of each cylinder of the engine. Typically, fuel is discharged at 20,000 PSI from the injectors into the combustion chamber at each engine cycle only for a very short period of time. This time frame usually ranges from 2 to 10 milliseconds depending on the engine speed and power load. Because of changing operating conditions of the engine, environmental factors and fuel efficiency requirements on engine manufacturers, precise regulation on the flowrate of these injectors has become increasingly important. Conventional fuel injector manufacturers monitor flowrate characteristics of a fuel injector, for quality control purposes, by using a flow meter to monitor flowrate of the fuel exiting the injector. Most flowmeters in use today employ mechanical moving parts which are slowly responsive to flow changes and generate electrical signals proportional to the flowrate of the fuel exiting the injector.

Fuel injector manufacturers typically analyze the flowrate characteristics of a fuel injector, for quality control purposes, by using a flowmeter to monitor the flowrate of the fuel exiting the injector. Most flowmeters in use today, employ mechanical moving parts which are slowly responsive to flow changes, and generate electrical signals proportional to the flowrate of fuel exiting the injector.

However, this type of flowmeter has certain perceived drawbacks. Because the system is mechanical, it utilizes moving parts which have mass and thus inertia. Therefore, there is an inherent delay in the movement of these parts and thus in the response time of the system in reporting the flowrate. As a result, the response time of this type of flowmeter is generally in milliseconds. Because typical fuel injectors fire for a duration of 2 to 10 milliseconds, the mechanical system can only be used to successfully measure single pulse injector flow, by measuring the total flow of a substantial number of sequential injection samples, then dividing the total flow by the number of samples measured to obtain an average single pulse flowrate. This average single pulse flowrate is a numeric value, which does not provide detailed information, such as what would be provided by a graphical presentation of a true wave form.

Other known flowmeters measure the flowrate of fluid by measuring the pressure drop of the fluid as it passes through an orifice. The pressure of the fluid is measured at the entrance and the exit of the orifice and then converted into a corresponding flowrate by use of known fluid equations.

This type of flowmeter, however, if applied to the measurement of the flowrate of a fuel injector, has certain perceived drawbacks.

Fuel injector test machines of this sort require a flowmetering range of 100 to 1 or higher. Typical fluid flowrate ratios through orifices range from around 5 to 1. Because pressure drop is proportional to the square of the fluid velocity, this 5 to 1 flowrate ratio corresponds to a 25 to 1 pressure ratio, far beneath the required 100 to 1 flow ratio needed by injector test machines. The present invention was developed in light of these drawbacks, among others.

SUMMARY OF THE INVENTION

The present invention overcomes these drawbacks by providing a flowmeter which measures the flowrate of a fuel injector by monitoring the pressure drop across a variable orifice valve through the use of a fixed pressure sensor, having no moving mechanical parts. The present invention includes a fuel injector adapter for receiving the fuel injector, a flow measurement chamber which fluidly communicates with the injector through the fuel injector adapter, a pressure sensor for sensing the pressure of fuel inside the flow measurement chamber, and a variable orifice which regulates the pressure and thus the measurable range of flowrate out of the flow measurement chamber. The variable orifice selectively adjusts the pressure drop for the flow rate exiting the flow measurement chamber, thereby selectively adjusting the flowrate and pressure ratios.

In another aspect of the present invention, the pressure sensor is a piezoelectric sensor. Because this type of sensor measures the force of the pressure against a piezoelectric element, it is fixed in position, i.e., it has no moving parts and there is no dampening caused by mechanical parts. Thus, rapidly fluctuating flowrates exiting the fuel injector may be measured.

According to another aspect of the present invention, the flow measurement chamber is evacuated to stiffen the spring rate of the fluid and help impede resonant frequencies, thus allowing a more accurate measurement of the true flowrate through the fuel injector. The present invention may also be fitted with a flow calibration device which calibrates the pressure sensor to a fixed or known flowrate value.

Additional advantages and features of the present invention will become apparent from the subsequent description and the appended claims taken into conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings which illustrate the best mode presently contemplated for carrying out the present invention:

Fig. 1 is a cross-sectional view of a flowmeter according to the present invention; and

Fig. 2 is a graphical representation of the flowrate from a fuel injector as measured by a flowmeter according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 1, the present invention will now be described. According to Fig. 1, the flowmeter **10**, which is shown with a fuel injector **12** attached, generally comprises fuel injector adapter **14**, flow calibrator **16**, pressure sensor **18**, variable orifice **20**, and flow measurement chamber **22**.

Engine fuel injector **12** has securing plate **24** which is attached to adapter **14** by fasteners **28** shown herein as bolts. Fuel injector **12** is seated in adapter **14** and is secured thereto by screwing bolts **28** through securing plate **24** and into the adapter **14**. Flow calibrator **16** has piston **32** which is slidably engaged with seal area **34** and is insertable into cylinder **36**. Piston **32** has threaded ball screw area **38** which engages with anti backlash ball nut **40**. B Ball screw **38** is driven by stepping motor **44** through anti-backlash bellows coupling **42**. Preferably, stepping motor **44** has a resolution of 200 steps per 1 revolution. Micro-stepping controller **46** operates stepping motor **44** and divides a two phase stepping motor drive signal into 16 parts, thereby increasing the stepping motor resolution to (16 times 200) 3,200 steps per revolution. It is noted that by increasing the effective resolution of stepping motor **44**, greater precision of movement of piston **32** is obtained.

Pressure sensor **18** is a piezoelectric sensor with a rated response time of 1 micro second. Pressure sensor **18** outputs a pressure signal to injector test machine computer **48** which is representative of the pressure within flow measurement chamber **22**.

Variable orifice **20** has needle valve **52** slidably engaged to seal area **54** and insertable into needle valve seat **56**. Needle valve **52** has threaded ball screw area **58** which engages ball nut **60**. Needle valve **52** is driven by stepping motor **64** through anti-backlash bellows coupling **62**. Like stepping motor **44**, stepping motor **64** is driven by a micro-stepping controller **47** which provides a total resolution of approximately 3,200 steps per revolution. Variable orifice **20** also has fuel outlet **66**.

Flow measurement chamber **22** is a cubical enclosure which preferably is less than about 1 cubic centimeter in volume and preferably is evacuated. This evacuation is formed by providing a continuously ascending discharge path from the tip of fuel injector **12** to flow measurement chamber **22**. It is noted, however, that a vacuum pump may also be used to evacuate flow measurement chamber **22**.

The general operation of the present invention will now be described with further reference to Fig. 1. Fuel injector **12** is first secured to adapter **14** by bolting securing plate **24** around the periphery of fuel injector **12** with bolts **28**. Next, flowmeter **10** is calibrated by filling flow measurement chamber **22** with fuel supplied by fuel inlet **35**. Micro-stepping controller **46** next instructs stepping motor **44** to drive piston **32** into cylinder **36** at a predetermined rate. This movement of piston **32** into cylinder **36** causes the fuel within flow measurement chamber **22** to flow through variable orifice **20** at a predetermined flowrate which corresponds to a predetermined pressure within the flow measurement chamber **22**. Pressure sensor **18** reads this pressure and provides a pressure signal to injector test machine computer **48**. Injector test machine computer **48** then compares this measured pressure with a stored pressure which is equal to the predetermined pressure. By comparing the sensed pressure to the predetermined pressure, injector tester computer **48** then calibrates the pressure signal generated from pressure sensor **18**. Thus it should be understood by those skilled in the art that the flowmeter of the present invention is self-calibrating.

When the flowrate from fuel injector **12** is to be determined, fuel injector **12** is instructed to fire fuel into flow measurement chamber **22**. This fuel flows from flow measurement chamber **22**, through variable orifice **20** and out fuel outlet **66**. Because of the position of needle valve **52** within orifice **56**, a pressure drop is created between flow measurement chamber **22** and fuel outlet **66**. This pressure drop corresponds to the flowrate through variable orifice **20** by the equation Q=K times the square root of Delta P. Here, Q equals the mass flowrate of fluid, K is a constant which represents the geometry of variable orifice **20** and the position of needle valve **52** in orifice **56**, and Delta P is equivalent to the difference in pressure (divided by the mass density of the fuel) between the pressure sensed within flow measurement chamber **22** and ambient pressure. Pressure sensor **18** senses the fuel pressure within flow measurement chamber **22** and provides a corresponding pressure signal to injector test machine computer **48**. By knowing the position of needle valve **52** within orifice **56**, and ambient pressure and sensed pressure within flow measurement chamber **22**, injector test machine computer **48** calculates the mass flowrate through variable orifice **20** by use of the above discussed equation. Due to the conservation of mass and energy, as is known, It is noted that the mass flowrate through variable orifice **20** is equivalent to the mass flowrate through fuel injector **12**.

Injector tester computer **48** typically requires a flowmetering range of at least 100 to 1. As shown in the above discussed equation, the sensed pressure is proportional to the square of the fluid velocity. This means that a 5 to 1 flow ratio is equivalent to a 25 to 1 pressure ratio. Because of this insufficient flowmetering range, the accuracy of the flowmeter **10** may be severely restricted. To compensate for this insufficiency, micro-stepping controller **47** may be used to instruct stepping motor **64** to reposition needle valve **52** within orifice **56**. This repositioning is then communicated to injector test machine controller **48** which recalculates a corresponding K value (which is representative of the geometry of variable orifice **20**) for the above discussed equation. By changing this K value, the relation between the flow ratio and the pressure ratio as discussed above may be magnified or reduced depending on the requirements of injector test machine controller **48.**

Needle valves **32** and **52** may be positioned all the way closed within orifices **36** and **56** respectively to provide a complete shutoff condition used for leak testing of fuel injector **12**.

Likewise, needle valve **52** may be moved to a fully open position to allow maximum flowrate through fuel injector **12** for flushing purposes.

With reference to Fig. 2, the accuracy and response time of the present invention is illustrated. In Fig. 2, the event time in micro-seconds (representative of the time from initial firing of fuel injector **12**) is shown on a X axis while the nozzled back pressure sensed by pressure sensor **18** is shown on a Y axis. Here, two flow curves have been generated by the same fuel injector. With respect to the closed rack, the flowrate of fuel injector **12** begins at approximately zero, peaks at approximately at 2,100 micro-seconds, and terminates at approximately 4,500 micro-seconds. Likewise, with respect to the wide open rack condition, fuel injector **12** starts with a flowrate of zero at zero micro-seconds, peaks at approximately 5,100 micro-seconds at a corresponding pressure of 1,400 psig, and terminates at approximately 8,700 micro-seconds.

While the above detailed description describes the preferred embodiment of the present invention, it should be understood that the present invention is susceptible to modification, variation, and alteration without deviating from the scope and fair meaning of the subadjoined claims.

CLAIMS

What is claimed is:

1. A flowmeter which measures a flowrate of a fuel injector, said flowmeter comprising:

a fuel injector adapter, which selectively engages said fuel injector;

a flow measurement chamber in fluid communication with said fuel injector adapter;

a pressure sensor, said pressure sensor sensing a pressure inside said flow measurement chamber; and

a variable orifice in fluid communication with said flow measurement chamber, said variable orifice being selectively adjustable to allow a predetermined flow metering range.

2. The flowmeter as claimed in claim 1, wherein said pressure sensor is a piezoelectric sensor.

3. The flowmeter as claimed in claim 2, wherein said piezoelectric sensor is mechanically rigid such that inertial dampening of a measured flowrate, measured by said flowmeter, is substantially reduced.

4. The flowmeter as claimed in claim 1, wherein said flow measurement chamber is less than about 1 cubic centimeter.

5. The flowmeter as claimed in claim 1, wherein said flow measurement chamber is selectively evacuated.

6. The flowmeter as claimed in claim 1, wherein said variable orifice is selectively adjustable to allow said predetermined flow metering range to be greater than 100 to 1.

7. The flowmeter as claimed in claim 1, wherein said variable orifice is selectively adjustable by a stepping motor.

8. The flowmeter as claimed in claim 1, wherein said variable orifice is selectively adjustable to a fully closed position.

9. The flowmeter as claimed in claim 1, further comprising a flow calibrator, said flow calibrator engageable with said flow measurement chamber, said flow calibrator driving a predetermined flow of fuel through said variable orifice.

10. The flowmeter as claimed in Claim 9, wherein said flow calibrator comprises:

a piston insertable within said flow measurement chamber; and

a stepper motor in mechanical communication with said piston, said stepper motor selectively driving said piston into said flow measurement chamber to cause said predetermined flow of fuel through said variable orifice.

11. The flowmeter as claimed in Claim 1, wherein said fuel injector is used to supply diesel fuel to a diesel engine combustion chamber.

12. A flowmeter which measures the flowrate of fuel flowing through a fuel injector, said flowmeter comprising:

a engine fuel injector;

a fuel injector adapter having a fuel injector clamp, said fuel injector adapter selectively engageable to said engine fuel injector, said fuel injector clamp selectively securing said engine fuel injector to said fuel injector adapter;

a flow measurement chamber in fluid communication with said engine fuel injector and said fuel injector adapter, said flow measurement chamber having a volume of less than about 1.0 cubic centimeter;

a piezoelectric pressure sensor selectively sensing a pressure within said flow measurement chamber;

a variable orifice in fluid communication with said flow measurement chamber, said variable orifice having a needle valve insertable within an orifice, said variable orifice having a stepper motor which selectively inserts said needle valve into said orifice to provide a predetermined flow metering range; and

a flow calibrator in fluid communication with said flow measurement chamber, said flow calibrator having a piston insertable within said flow measurement chamber, said flow calibrator having a stepper motor which selectively inserts said piston into said flow measurement chamber to provide a predetermined flow of diesel fuel through said variable orifice.

13. The flowmeter as claimed in Claim 12, wherein said flow measurement chamber is substantially cube shaped.

14. The flowmeter as claimed in Claim 12, further comprising an injector tester computer, said injector tester computer reading a pressure signal provided by said piezoelectric pressure sensor, said injector tester computer providing an output representative of the flowrate of said fuel through said engine fuel injector.

15. The flowmeter a claimed in claim 12 wherein fuel injector is a diesel engine fuel injector.

16. The flowmeter as claimed in claim 12 further comprising a zero backlash ball screw, said zero backlash ball screw mechanically communicating with said variable orifice such that said zero backlash ball screw selectively positions said needle valve at a predetermined position.

17. The apparatus as claimed in claim 12, wherein said diesel fuel flows through a continuously ascending path from said fuel injector to said flow measurement chamber.

18. An apparatus which measures a flowrate of a fuel injector, said apparatus comprising:

a pressure dropping device, said pressure dropping device having an inlet and an outlet, said pressure dropping device developing a pressure drop along a path defined by a flow of fuel from said fuel injector;

a pressure sensor which measures a pressure at said inlet of said pressure dropping device;

a calculating device which determines said flowrate based on said pressure at said inlet of said pressure dropping device;

a flow calibrator, said flow calibrator selectively supplying a predetermined flowrate of fuel to said pressure dropping device, said calculating device calibrating said pressure sensor in response to said predetermined flowrate.

19. The apparatus as claimed in claim 17, wherein said pressure dropping device is a variable orifice, said variable orifice being selectively adjustable to allow a predetermined flow metering range.

20. The apparatus as claimed in claim 17, further comprising a piezoelectric pressure sensor, said piezoelectric pressure sensor measuring said pressure at said input of said pressure dropping device.

21. The apparatus as claimed in claim 16, wherein said piezoelectric pressure sensor is mechanically rigid such that inertial dampening of a measured flowrate is substantially reduced.

22. The apparatus as claimed in claim 18, further comprising a flow measurement chamber, said flow measurement chamber having an internal portion, said flow measurement chamber being in mechanical communication with said piezoelectric pressure sensor such that said piezoelectric pressure sensor measures a pressure in said internal portion to determine said pressure of said input of said pressure dropping device.

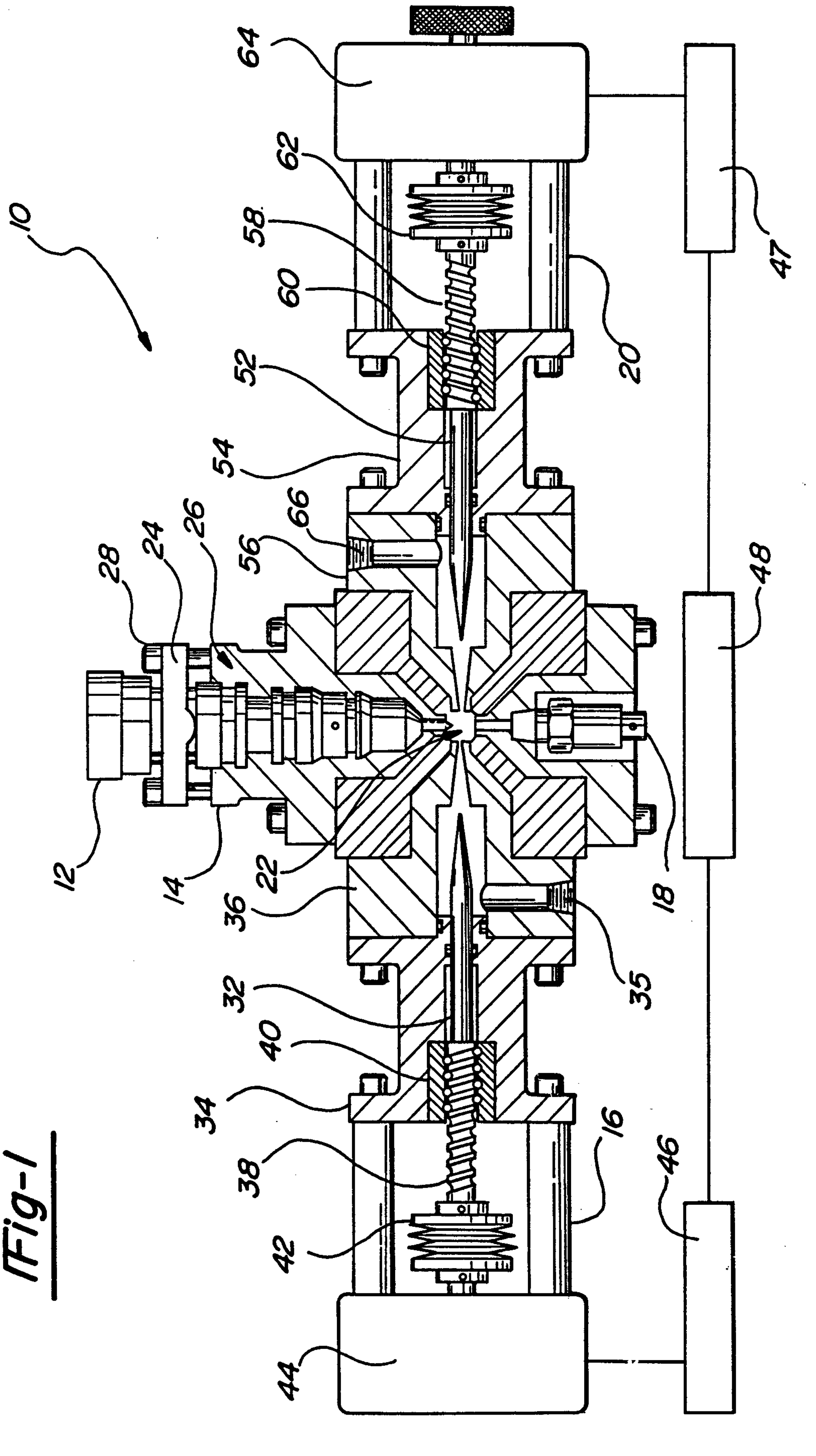
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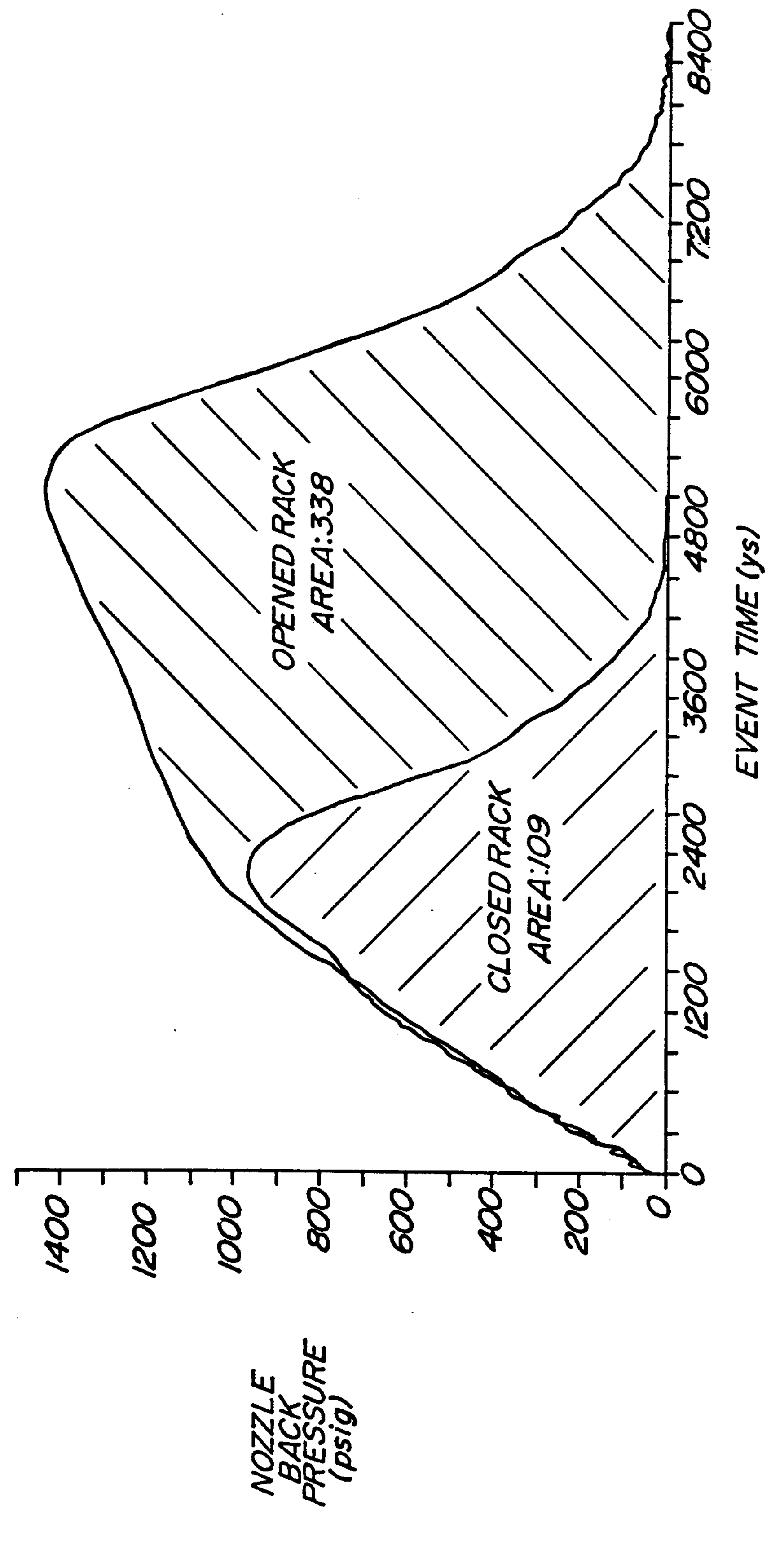
Fig-1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CLOSED RACK AREA:109

Fig-2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13883

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : G01M 15/00
US CL :73/119A
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 73/119A, 116, 117.2, 117.3, 118.1, 118.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
U.S. PTO APS search terms: fuel injector, flow, pressure, sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 5,816,220 A (STUMPP et al) 06 October 1998 (06/10/98) ALL	1-22
A,P	US 5,795,998 A (Smith) 18 August 1998 (18/08/98) all	1-22
A	US 5,614,668 A (Ramirez-Soto) 25 March 1997 (25/03/97) all	1-22
A	US 5,445,019 A (Glidewell et al.) 29 August 1995 (29/08/95) all	1-22
A	US 5,107,700 A (Kuttner et al) 28 April 1992 (28/04/92) all	1-22
A	US 4,977,872 A (Hartopp) 18 December 1990 (18/12/92) all	1-22

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
23 AUGUST 1999	18 OCT 1999

Name and mailing address of the ISA/US	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/13883

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,488,429 A (Ito) 18 December 1984 (18/12/84) all	1-22