UNITED STATES DISTRICT COURT FOR THE
EASTERN DISTRICT OF PENNSYLVANIA

TMC FUEL INJECTION SYSTEM, LLC,	)	
	)	
Plaintiff,	)	Case No.:
	)	
v.	)	DEMAND FOR JURY TRIAL
	)	
FORD MOTOR COMPANY,	)	
	)	
Defendant.	)	
	)	

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiff TMC Fuel Injection System, LLC ("TMC"), for its complaint for patent infringement against Defendant Ford Motor Company ("Ford") alleges as follows:

THE PARTIES

1. Plaintiff TMC is a limited liability company organized and existing under the laws of the State of Delaware, with its principal place of business in Wayne, Pennsylvania.

2. Upon information and belief, Defendant Ford is a corporation organized and existing under the laws of the State of Delaware, with its principal place of business in Dearborn, Michigan.

JURISDICTION AND VENUE

3. This action arises under the United States patent laws, 35 U.S.C. §§ 101, *et seq.* The Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331 and 1338(a).

4. The Court has personal jurisdiction over Ford because Ford transacts business within this judicial district and has committed acts of patent infringement within this judicial district.

5. Venue is proper in this judicial district pursuant to 28 U.S.C. §§ 1391(b)-(c) and 1400(b).

BACKGROUND

6. On May 10, 2002, Patent Application Serial No. 10/143,657 ("the '657 application") was filed with the United States Patent and Trademark Office. The '657 application claimed a novel and innovative fuel delivery technology ("the Patented Technology").

7. Dr. Shou L. Hou was the sole inventor named on the '657 application.

8. Dr. Hou graduated magna cum laude from National Taiwan University with a Bachelor of Science degree in Electrical Engineering, earned a Master of Science degree in Electrical Engineering from University of Minnesota, earned a Ph.D. in Applied Physics from Harvard University, and was a recipient of a Fulbright Scholarship and a Gordon McKay Fellowship.

9. Dr. Hou is the author of 34 technical publications and a named inventor or co-inventor on at least 27 issued patents worldwide.

10. In a telephone conversation on or about December 7, 2004, Dr. Hou described the Patented Technology to Chris Woodring ("Woodring"). Upon information and belief, on December 7, 2004, Woodring was employed by Ford or a Ford subsidiary as Manager of Ford Fuel Systems.

11. On or about March 17, 2005, Dr. Hou sent to Graham Hoare ("Hoare") a document and figures describing the Patented Technology. *See* Exhibit B at 1. Upon information and belief, on March 17, 2005, Hoare was employed by Ford or a Ford subsidiary as Director, Ford Powertrain Research and Advanced Engineering.

12. On March 24, 2005, Chinu Bhavsar ("Bhavsar") sent an email to Dr. Hou. *See* Exhibit B at 2. Upon information and belief, on March 24, 2005, Bhavsar was employed by Ford or a Ford subsidiary as a Senior Staff Technical Specialist, Powertrain Research & Advanced Engineering. *See id.* The email from Bhavsar stated, in part, that "Mr. Mike Soltis, Manager, Fuel Systems engineering is an expert in the fuel system control area and he can review/assess your proposal." *Id.* Bhavsar also stated in the email to Dr. Hou that "you must provide us a signed ford [sic] Confidential Disclosure Waiver (attached) before we can respond to your request." *Id.*

13. On March 25, 2005, Dr. Hou transmitted by facsimile to Bhavsar and Hoare a signed copy of Ford's Confidential Disclosure Waiver. *See* Exhibit B at 13-14.

14. In a March 31, 2005 email from Bhavsar to Dr. Hou, Bhavsar advised Dr. Hou that his inquiry had been forwarded to Mike Soltis ("Soltis"). The email further stated that Soltis "will advise you of his assessment of the TMC fuel concept." Exhibit B at 15-16.

15. During a telephone call on or about June 14, 2005, Dr. Hou and Hoare discussed the Patented Technology. *See* Exhibit B at 17. On July 20, 2005, Dr. Hou sent a letter by facsimile to Hoare thanking him for "confirming some of the features of TMC proposed improvement system through your test, which included quick response time and eliminating at least one of the pressure regulators." *Id.* The letter also stated that "You promised to send me the evaluation comment by your engineering expert and a discussion by phone before sending me any proposal." *Id.* The letter further stated that "TMC would like to license the invention to Ford Motor Company." *Id.*

16. On July 28, 2005, Bhavsar sent a letter to Dr. Hou indicating that Soltis "has reviewed the TMC concept and concluded that Ford Motor Company is not interested in pursuing it." Exhibit B at 18.

17. On January 15, 2008, United States Patent No. 7,318,414 ("the '414 patent"), entitled "Constant-Speed Multi-Pressure Fuel Injection System for Improved Dynamic Range in Internal Combustion Engine," was duly and legally issued by the United States Patent and Trademark Office from the '657 application. A copy of the '414 patent is attached as Exhibit A.

18. On March 10, 2008, Dr. Hou sent a letter to Barb Samardzich ("Samardzich"), explaining that the '414 patent "has just been granted," and offering to discuss with Ford an opportunity to license the '414 patent. *See* Exhibit B at 19-20. The letter indicates that a copy of the '414 patent was attached thereto. *See id.* Upon information and belief, on March 10, 2008, Samardzich was employed by Ford or a Ford subsidiary as Vice President, Powertrain, Product Development Center.

19. On April 25, 2008, Samardzich sent an email to Dr. Hou indicating that Samardzich forwarded Dr. Hou's information to "our advanced group - Dan Kapp. He would be the right one to follow up with." Exhibit B at 21. Upon information and belief, on or about April 25, 2008, Dan Kapp ("Kapp") was employed by Ford or a Ford subsidiary as Director, Powertrain Research & Advanced Engineering.

20. On April 28, 2008, Dr. Hou sent an email to Kapp and Samardzich. *See* Exhibit B at 22. The subject line of the email was "Improved Fuel Injection System Developed At TMC." *Id.* Dr. Hou asked in the email if he could "offer any help to further our discussion?" *Id.* On April 29, 2008, Kapp sent an email to Dr. Hou indicating that Kapp would have his "technical experts do an assessment and give you some feedback relative to our interest." *Id.*

21. On June 10, 2008, Kapp sent a letter to Dr. Hou stating that he "had the Constant-Speed Multi-Pressure Fuel Injection System for Internal Combustion Engine material that [Dr. Hou] sent to Ford Motor Company reviewed by our fuel system technical specialist and have concluded that Ford Motor Company is not interested in participating in a program to develop the system." Exhibit B at 23. The letter further stated that "[o]ur conclusion is that a fuel system of this concept would not achieve efficiencies greater than our existing engines." *Id.*

22. On July 8, 2008, Dr. Hou sent a letter to Kapp further describing the benefits of using the invention claimed in the '414 patent, and that such invention will "move closer to fulfill Government emissions and fuel economy requirements." Exhibit B at 24-26. Dr. Hou also further expressed a willingness to license the '414 patent to Ford. *Id.*

23. On August 20, 2008, Kapp sent a letter to Dr. Hou stating, in part, that "there is no interest from our side to pursue." Exhibit B at 27.

<u>FIRST CAUSE OF ACTION</u>
(FORD'S INFRINGEMENT OF U.S. PATENT NO. 7,318,414)

24. TMC restates and realleges the allegations set forth in paragraphs 1 through 23 above and incorporates them by reference.

25. TMC is the lawful owner of the entire right, title and interest in United States Patent No. 7,318,414 ("the '414 patent"), entitled "Constant-Speed Multi-Pressure Fuel Injection System For Improved Dynamic Range In Internal Combustion Engine" which was issued on January 15, 2008.

26. Despite informing Dr. Hou that it had "no interest" in the Patented Technology, Ford has been and now is infringing the '414 patent, within this judicial district and elsewhere, by making, using, offering for sale, and/or selling motor vehicles incorporating fuel delivery

systems that infringe the '414 patent without authority or license from TMC. Such motor vehicles include, without limitation, the Ford F-150.

27. Upon information and belief, the infringement of one or more claims of the '414 patent by Ford is, and has been willful and deliberate. As a result, TMC is entitled to increased damages under 35 U.S.C. § 284 and to attorney fees and costs incurred in prosecuting this action under 35 U.S.C. § 285.

28. TMC has been damaged by Ford's infringement of the '414 patent, has been irreparably harmed by that infringement, and will suffer additional damages and irreparable harm unless this Court enjoins Ford from further infringement.

PRAYER FOR RELIEF

WHEREFORE, TMC prays for judgment:

A. that Ford has infringed and is infringing United States Patent No. 7,318,414;

B. enjoining Ford, its officers, agents, servants, employees, attorneys, successors and assigns and all other persons in active concert or participation with any of them from infringing United States Patent No. 7,318,414;

C. awarding TMC compensatory damages for Ford's infringement, together with interest and costs pursuant to 35 U.S.C. § 284;

D. trebling the amount of compensatory damages for patent infringement pursuant to 35 U.S.C. § 284;

E. awarding TMC reasonable attorneys' fees pursuant to 35 U.S.C. § 285; and

F. granting TMC such other and further relief in law or in equity as this Court deems just or proper.

DEMAND FOR JURY TRIAL

TMC demands a trial by jury on all issues so triable.

SHRAGER, SPIVEY & SACHS

By: Robert L. Sachs, Jr.

Robert L. Sachs, Jr.
2300 One Commerce Square
2005 Market Street
Philadelphia, PA 19103
215-568-7771

ATTORNEYS FOR PLAINTIFF

Dated: August 27, 2012

EXHIBIT A

US007318414B2

(12) **United States Patent**
Hou

(10) **Patent No.:** **US 7,318,414 B2**
(45) **Date of Patent:** **Jan. 15, 2008**

(54) **CONSTANT-SPEED MULTI-PRESSURE FUEL INJECTION SYSTEM FOR IMPROVED DYNAMIC RANGE IN INTERNAL COMBUSTION ENGINE**

(75) Inventor: **Shou L. Hou**, Wayne, PA (US)

(73) Assignee: **TMC Company**, Wayne, PA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 440 days.

(21) Appl. No.: **10/143,657**

(22) Filed: **May 10, 2002**

(65) **Prior Publication Data**

US 2003/0209232 A1 Nov. 13, 2003

(51) **Int. Cl.**
F02M 59/36 (2006.01)
F02M 37/00 (2006.01)

(52) **U.S. Cl.** **123/458**; 123/510; 123/511; 123/514

(58) **Field of Classification Search** 123/457, 123/458, 506, 446, 447, 497, 510–511, 514
See application file for complete search history.

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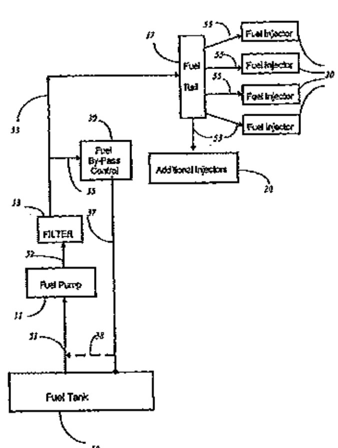
(Continued)

Primary Examiner—Thomas N. Moutis
(74) *Attorney, Agent, or Firm*—Stephen H. Eland; Dann, Dorfman Herrell & Skillman

(57) **ABSTRACT**

A fuel injection system operates under a substantially constant pump speed and creates multi-pressure levels by diverting the fuel flow. Fuel pressure can be switched from one steady pressure level to another level on-demand instantly. This superimposes and overlaps typical fuel injection events in the linear operating ranges under different pressure levels, significantly increasing the fuel injection dynamic range. Lower fuel injection when idle or during city driving reduces fuel consumption per mile traveled and reduces exhaust emission that causes smog in metropolitan areas. The system delivers additional power to the engine instantly at peak load on-demand, reduces idle speed with the engine running smoothly, does not change fuel tank temperature, and may enhance the life of the fuel pump.

46 Claims, 6 Drawing Sheets



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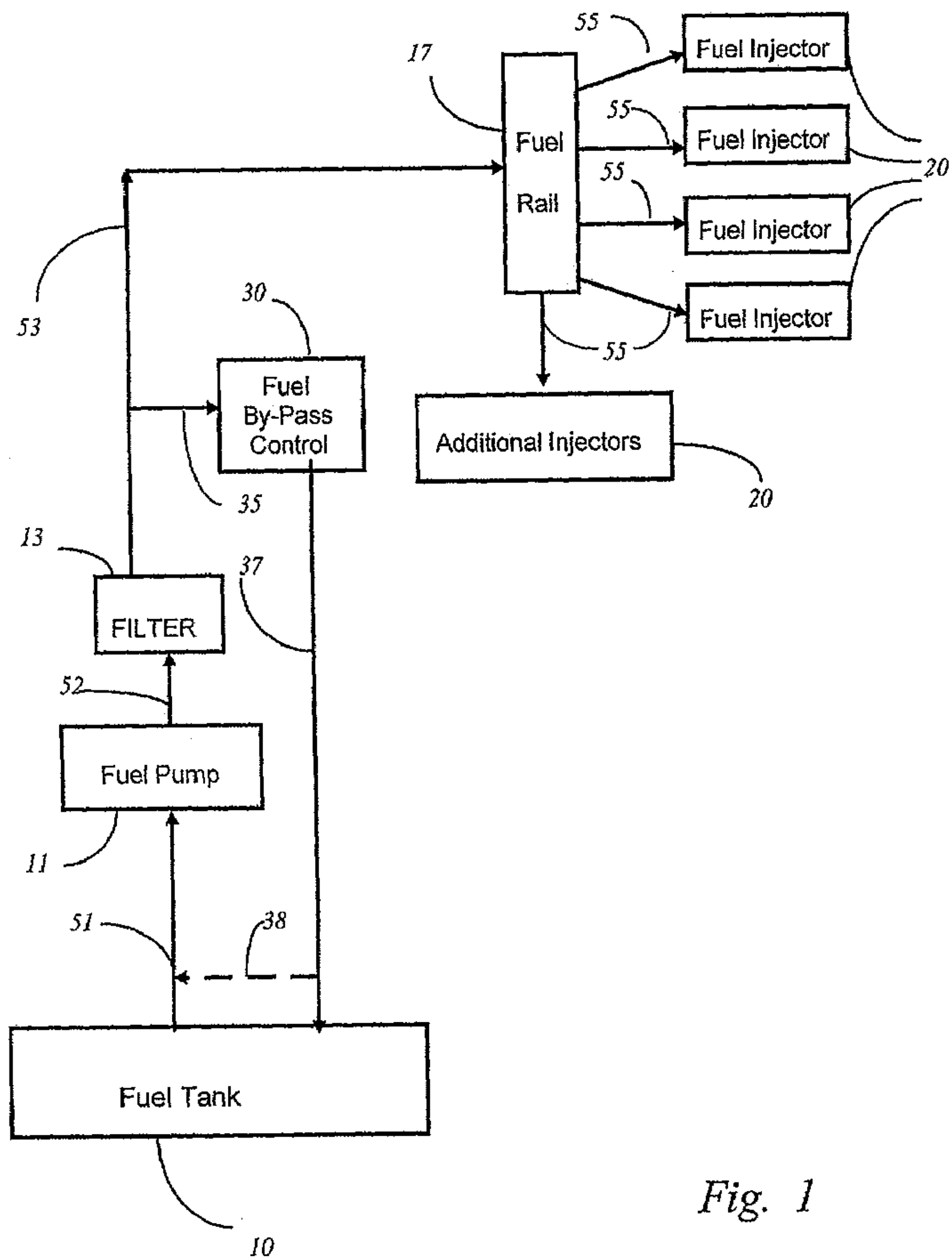

55
Fuel Injector
17
Fuel
Rail
55
Fuel Injector
20
55
Fuel Injector
Fuel Injector
53
30
Fuel
By-Pass
Control
55
Additional Injectors
20
35
13
37
FILTER
52
Fuel Pump
11
51
38
Fuel Tank
10

Fig. 1

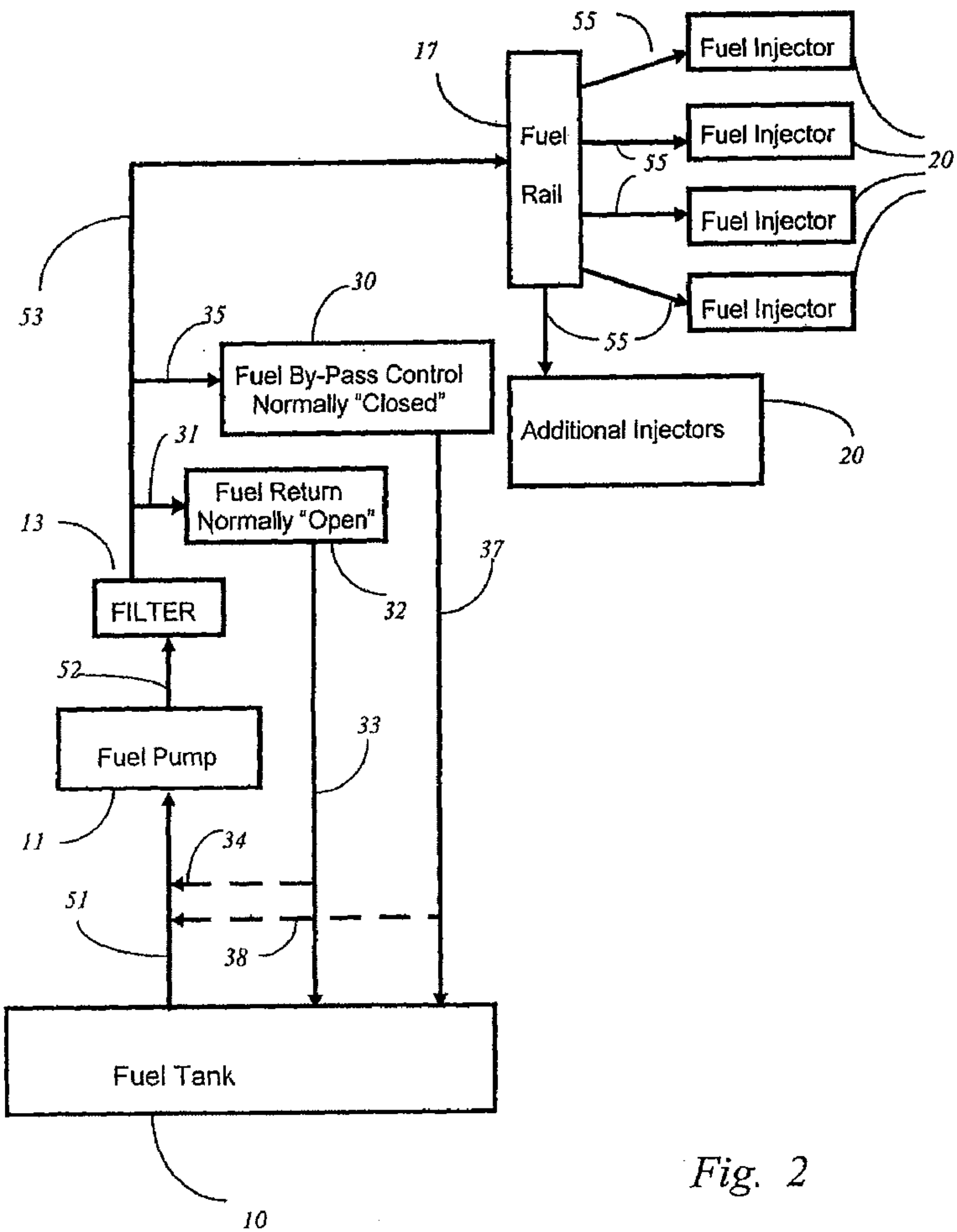

55
17
Fuel Injector
Fuel
Rail
Fuel Injector
55
20
55
Fuel Injector
53
35
30
Fuel Injector
55
Fuel By-Pass Control
Normally "Closed"
Additional Injectors
31
20
Fuel Return
Normally "Open"
13
37
FILTER
32
52
Fuel Pump
33
11
34
51
38
Fuel Tank
10

Fig. 2

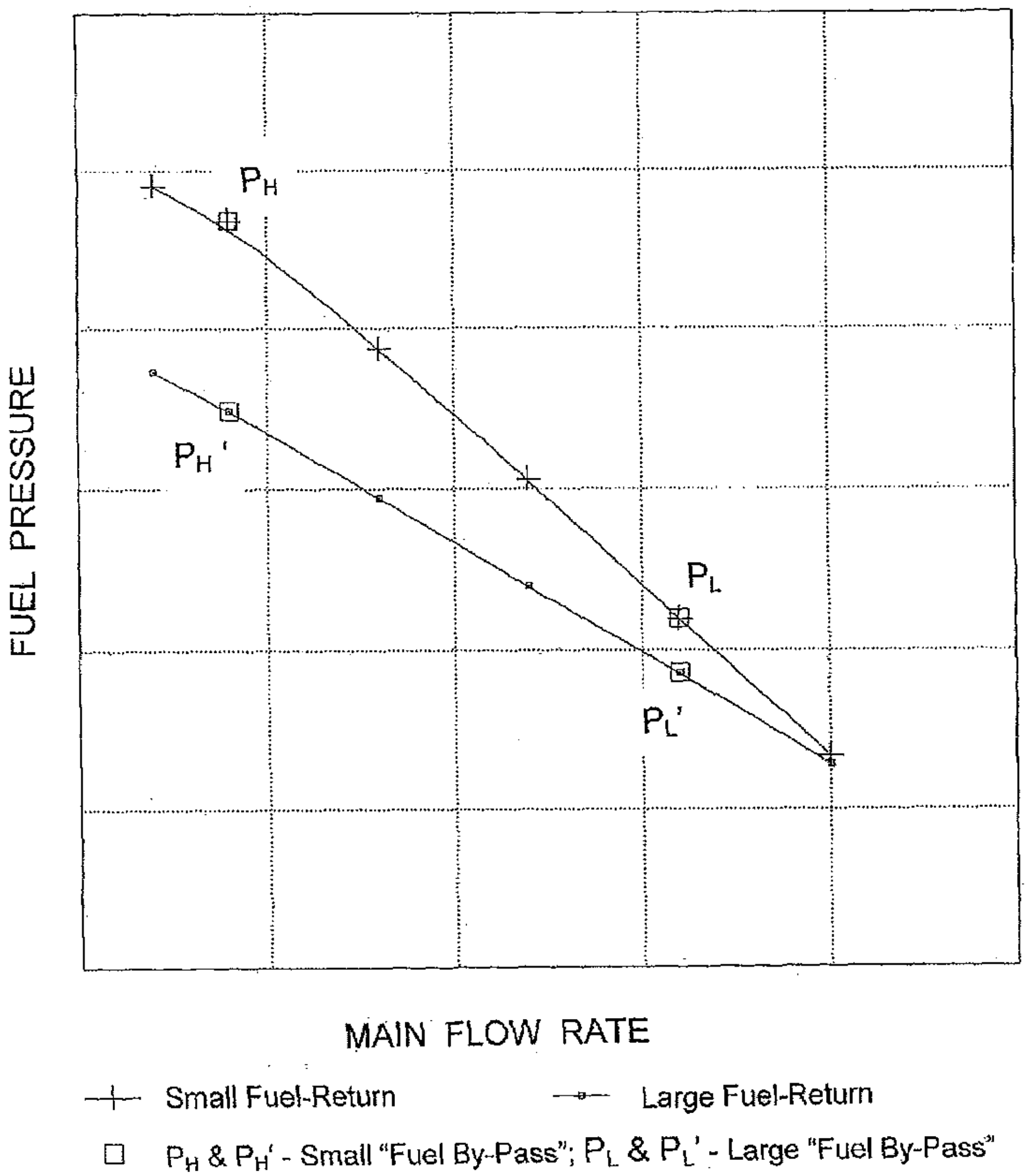
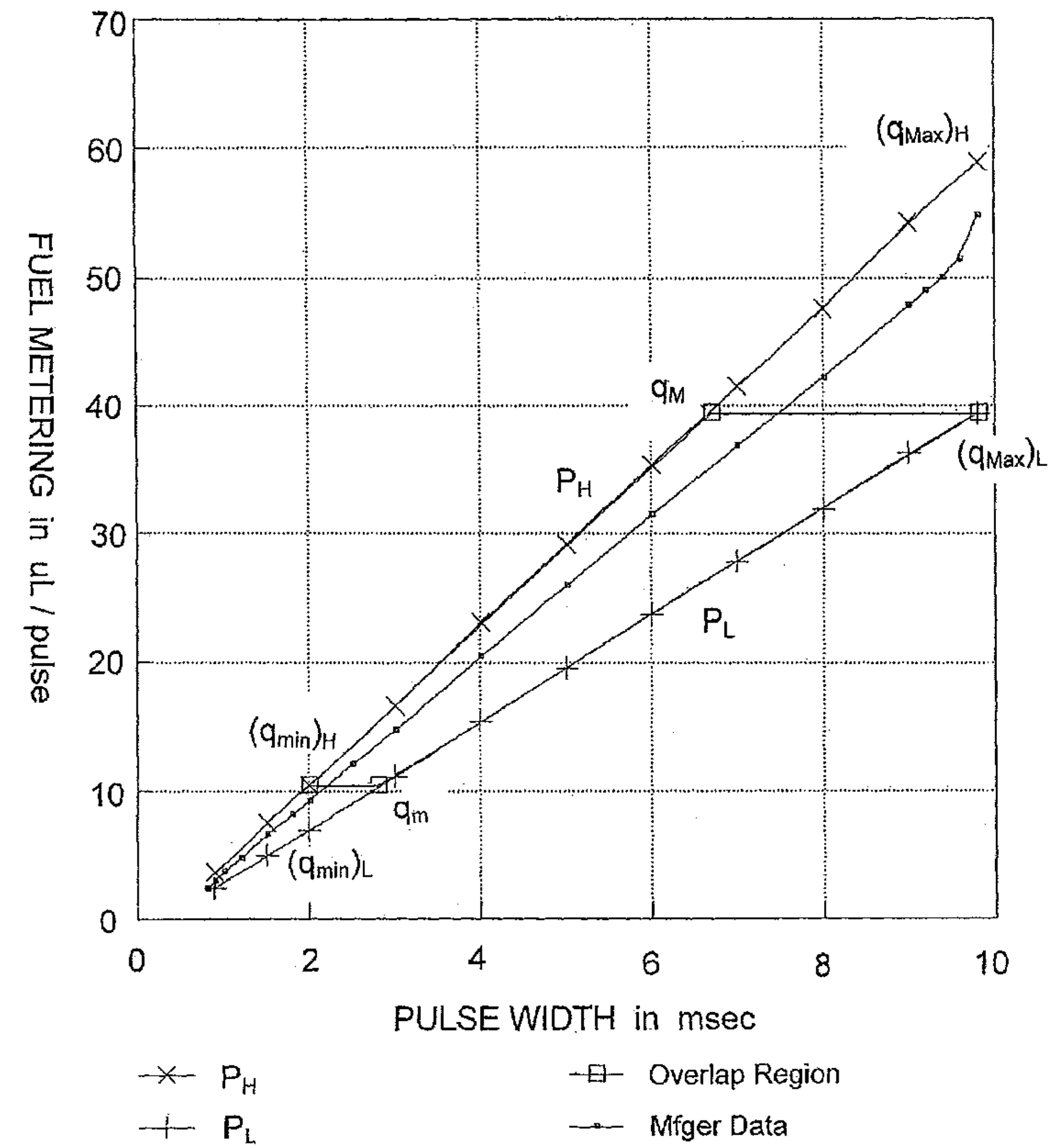

FUEL PRESSURE
MAIN FLOW RATE
PH
PH '
PL
PL'
Small Fuel-Return
Large Fuel-Return
PH & PH' - Small "Fuel By-Pass"; PL & PL' - Large "Fuel By-Pass"

Fig. 3



Data From An Injector Manufacturer

Fig. 4

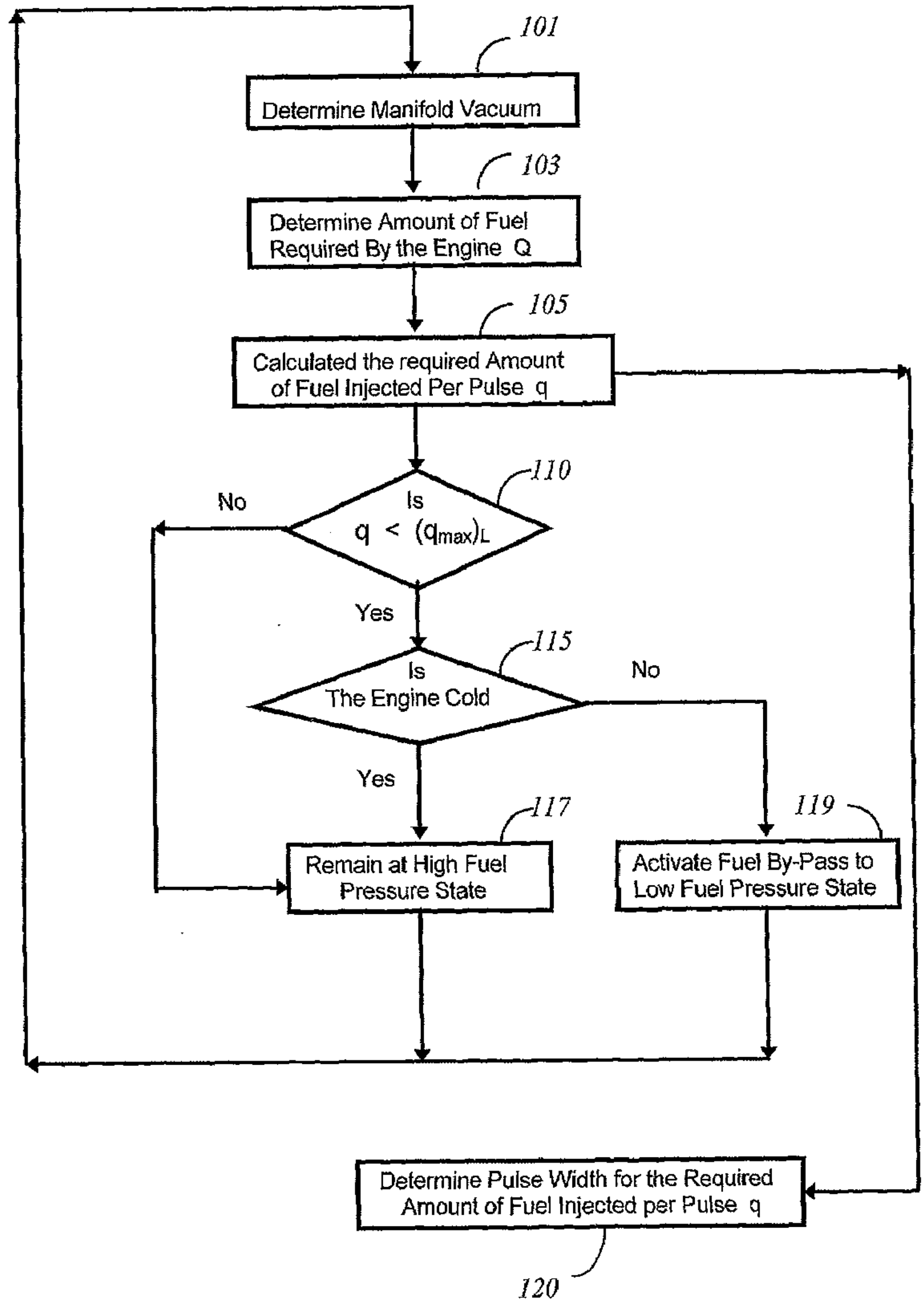

101
Determine Manifold Vacuum
103
Determine Amount of Fuel Required By the Engine Q
105
Calculated the required Amount of Fuel Injected Per Pulse q
110
Is q < (qmax)L
No
Yes
115
Is The Engine Cold
No
Yes
117
Remain at High Fuel Pressure State
119
Activate Fuel By-Pass to Low Fuel Pressure State
Determine Pulse Width for the Required Amount of Fuel Injected per Pulse q
120

Fig. 5

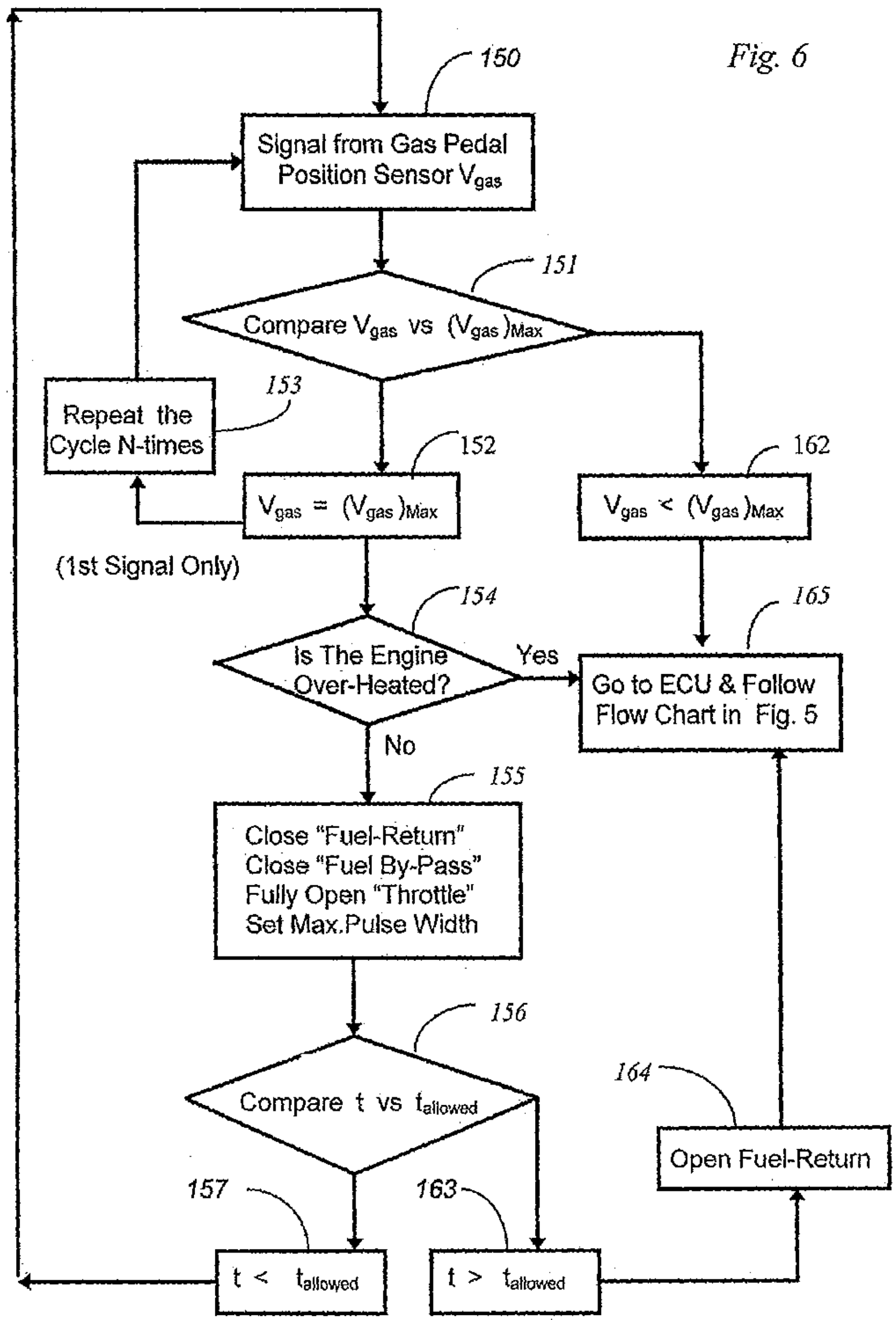


Fig. 6
150
Signal from Gas Pedal Position Sensor V_{gas}
151
Compare V_{gas} vs $(V_{gas})_{Max}$
153
Repeat the Cycle N-times
152
$V_{gas} = (V_{gas})_{Max}$
162
$V_{gas} < (V_{gas})_{Max}$
(1st Signal Only)
154
Is The Engine Over-Heated?
Yes
165
Go to ECU & Follow Flow Chart in Fig. 5
No
155
Close "Fuel-Return"
Close "Fuel By-Pass"
Fully Open "Throttle"
Set Max.Pulse Width
156
Compare t vs $t_{allowed}$
164
Open Fuel-Return
157
163
$t < t_{allowed}$
$t > t_{allowed}$

CONSTANT-SPEED MULTI-PRESSURE FUEL INJECTION SYSTEM FOR IMPROVED DYNAMIC RANGE IN INTERNAL COMBUSTION ENGINE

FIELD OF THE INVENTION

This invention relates to engines, specifically a fuel system used for engines making use of a fuel injection system.

BACKGROUND OF THE INVENTION

Engine emission, such as auto emission, is one of the most contributing factors to air pollution. It is most noticeable in metropolitan areas during traffic jams, and around airports where numerous airplanes are idling in the secondary runway for 20 to 40 minutes on the average before taking off. Reducing the idle speed in internal combustion engines will save fuel when an engine is not doing much work other than keeping it alive. It also reduces exhaust emission, which converts to smog. The problem is most serious in metropolitan areas because there are close to 100-million cars and trucks in the U.S., most of which are concentrated in the metropolitan areas. Perhaps a more meaningful way of reducing pollution and improving energy is by measuring how much fuel is consumed per mile traveled by any vehicle at any speed. This measurement indicates the amount of fuel consumed and exhaust generated in the distance traveled. It becomes apparent that a better control of fuel consumption at slow speed (or idle) will have more impact on pollution control, fuel saving, and improvement on the city driving mileage.

Improving control of fuel consumption at low speeds must not adversely affect performance of the engine. For example, it is commonly known in physics that the kinetic energy of a moving vehicle is directly proportional to its mass (or weight). More energy is required to maintain a heavier vehicle at any speed than a lighter vehicle at the same speed. On the other hand, the amount of energy delivered by a gallon of gasoline is constant. As a result, more fuel is needed to move a heavier vehicle than a lighter one in highway driving. More fuel is also needed to accelerate a vehicle quickly. In view of these considerations, it is desirable to meet the energy demands of the engine over the full range of load conditions while also lowering fuel consumption, especially during idle.

Engine pistons deliver torque T to the flywheel. This is balanced by frictions of the engine and the drag by accessories like the cooling flywheel fan and generator when idle. To the first order of approximation, the balancing torque is proportional to the speed of rotation R. The power required to keep the flywheel idling at a speed of rotation R is TR. It is supplied by fuel injected per second Q. The kinetic energy of the flying wheel is transmitted to the moving vehicle through mechanical means.

Since Energy delivered to the engine per second~Q~Tω Power produced by the engine and

$$Q \sim \omega q$$

$$\text{hence, } q \sim T \sim I\alpha \sim M\omega \quad (1)$$

$$\text{and } Q \sim q^2 \quad (2)$$

where ω is the engine speed in rps (or in rpm/60),

M is the effective mass of the engine flying wheel,

T is the torque, "α" is the angular acceleration,

I is the angular moment of inertia of the flying wheel,

Q is the total amount of fuel injected per second, and

q is the amount of fuel injected per pulse.

In other words, to the first order of approximation, the engine idling speed ω is directly proportional to the amount of fuel injected per pulse q, and the total amount of fuel consumption rate Q is proportional to the square of the amount of fuel injected per pulse q. A 10% reduction to the fuel injected per pulse will save about 19% of total fuel consumption per second when idle.

Fuel injectors are commonly used in today's automotive vehicles to replace earlier fuel feeding through carburetors. A fuel system generally has a fuel pump which may be either submerged in the fuel tank or positioned outside the tank, and which pumps fuel under pressure through the fuel line, to the fuel rail, into the fuel injectors. A fuel injector with a proper nozzle design sprays fuel mist at the air in-take manifold of a cylinder in an engine block. Fuel mist combined with air in proper ratio is drawn into an engine cylinder during the in-take stroke. An optimum air/fuel mix has a stoichiometric ratio of 14.7 to 1 that makes detonation easier and combustion more complete. Fuel injectors are located near (or inside) the engine cylinder at an elevated temperature. A spring loaded electro-mechanically controlled ball valve is used to seal off the nozzle of the fuel injector. This prevents pressurized fuel from seeping into the engine block when it is not running. Pressurized fuel reduces fuel vapor in the fuel line, which minimizes vapor lock; vapor lock may interfere with hot engine start-up. When an operator pushes the gas pedal, the pushing of the pedal is converted into an electric signal sent to a microprocessor. Together with the engine operating information from various sensors, the microprocessor then activates the fuel injector to deliver a pre-determined quantity of fuel to the engine cylinder through the fuel injection process.

The amount of fuel injected per pulse q is linearly proportional to the pulse width of the electrical pulse sent.

$$q = k(t - C) \quad (3)$$

$$\text{and } k \sim P^n \quad (4)$$

where q is the amount of fuel injected per pulse,

k is a constant that reflects the continuous injection rate per second,

t is the pulse width of fuel injection pulse,

C is a correction constant, and

n is a constant.

The continuous injection rate k is a strong function of fuel pressure P. The quality of sprayed mist also depends upon the design of the shape of the nozzle. To the first order of approximation, "n" is about ½. The actual value varies between ½ and ⅓ with the latter value toward higher pressure. In other words, to double the fuel injection rate under identical operating conditions, the fuel pressure must be increased by at least 4-fold. The linearity and reproducibility must be maintained to within 1% in the linear operating range to avoid irregular engine behavior when vehicles are mass-produced. The microprocessor receives information from various sensors in the engine and determines the pulse width based upon the amount of fuel needed.

In sequential multi-port injection, a fuel injector is mounted to the fuel in-take port to a given engine cylinder (or directly into the cylinder).

At full power, where maximum fuel injection is used, an exemplary engine is running at about 6,000 rpm. Fuel in-take strokes generally last only about 5 milliseconds. In the mean time, just "opening" and "closing" a spring-loaded ball valve physically takes more than one millisecond. This sets the minimum pulse width for fuel injection during idling to no less than 2 milliseconds. The fuel injection pulse width is thus limited by the time needed for operating a spring loaded ball valve and, as a result, may have an unpredictable amount of fuel injection and cause erratic engine performance. The typical linear range to operate a fuel injector is between 2 to 10 milliseconds, for a variety of different internal combustion engines. A manufacturer generally must choose the diameter of the nozzle at a given fuel pressure to achieve maximum power at a maximum pulse width. This limits the so-called dynamic range of the fuel injection system, as the system parameters need to be chosen to achieve the desired power with the available pulse width. As a result, fuel injection systems often have too much fuel injected at the lower end of the range, that is, where there is a minimum pulse width, when idling. Thus, the dynamic range of fuel injection has room for improvement.

For example, U.S. Pat. No. 5,355,859 to R. E. Weber changes the voltage applied to a fuel pump to generate and maintain variable fuel pressure. U.S. Pat. No. 5,762,046 to J. W. Holmes et al. uses a resistor in series with the fuel pump coil. By selectively bypassing the series resistor per control signal from the microprocessor, a fuel pump will have different applied voltages to create dual speed for the fuel delivery system. However, because a fuel pump generally has a large inductive load, varying the voltage applied to the fuel pump generally does not stabilize fuel pressure for a period of seconds. This delay in fuel pump stabilization in turn causes a delay in engine response and needs fine adjustment to compensate the voltage drop across the resistor in order to maintain smooth operation. Furthermore, since only a minute quantity of fuel is needed to keep an engine alive when idle, to assure the injection is operating within appropriate linear range, the fuel pump generally must run at very low speeds. To achieve such very low speeds in the fuel pump, the voltage applied to the pump generally must also be correspondingly low. When operated on such correspondingly low voltages, the fuel pump may run sluggishly, resulting in undesirable pressure fluctuations. Also, the pump may have a shorter life and decreased reliability if it runs at variable speeds with the associated frequent and sudden acceleration/decelerations of such variances.

The response time required to change the speed of the fuel pump is unacceptably slow in comparison to the fuel injection process. Since fuel metering depends on how much fuel is being delivered by the fuel pump, undesirable pressure fluctuation generally occurs at the time when fuel injection pulses are taking place. The attempts of the art to address the above-outlined drawbacks have had mixed results at best. Excess fuel supply, a pressure regulator, and a pressure gauge are often used to minimize the pressure fluctuation during fuel injecting. A pressure release valve and an excess-fuel-return line from the fuel rail are also installed to bleed the excess fuel accumulated in the fuel rail back to the fuel tank. The hot fuel returned to the fuel tank raises the temperature in the fuel tank during prolonged operation. Precautions are also needed to recover the hot fuel vapor in the fuel system.

SUMMARY OF THE INVENTION

A constant speed multi-pressure fuel injection system has been developed. The fuel system has a pump running at a constant drive (or at a constant speed) while at the same time multiple pressure levels are created through different means. It provides the capability to instantly increase fuel supply to an engine on-demand instead of waiting for the system to stabilize before being capable of delivering more fuel. The same system is also capable of delivering much less fuel to keep the engine running when idle to save fuel.

This invention describes the structure and process of fuel injection delivery systems which create multi-pressure-levels on-demand instantly by restricting the fuel flow at a given steady fuel pump speed. This increases the dynamic range of fuel injection and minimizes fuel pressure fluctuation. Hence, the same engine that incorporates the invention is capable of doing the following: (1) Delivering more power instantly at peak load on-demand, which accelerates the vehicle from stand still to 60 miles per hour in seconds; (2) Reducing the idle speed with the engine still running smoothly, which saves fuel, improves city-driving mileage, and further reduces exhaust when idle; (3) Not changing the fuel tank temperature regardless of how long the engine is in operation; and (4) Enhancing the life of the fuel pump because the pump is running at a constant speed without frequent acceleration/deceleration. Although fuel saving and exhaust control may not seem much to a single vehicle, the cumulative effect should be noticeable in a traffic jam, or anywhere large number of vehicles are crawling with engines running. The invention can be applied to internal combustion engines used in automobiles, airplanes, and diesel engines. Thus, it saves fuel to achieve better city-driving mileage. Most of the existing vehicles already in operation for years can also be modified with minimum effort to achieve a reduced idle speed and still be able to run smoothly. When the invention is applied to a large number of vehicles, the public can enjoy the cumulative effect of cleaner air in metropolitan areas.

By adjusting constrictions of fuel flow, the fuel injection system has a wider dynamic range (defined as the ratio of the maximum amount versus minimum amount of fuel injected per second) so that it can provide instantly very low yet steady fuel pressure to deliver a minute quantity of fuel to be injected per pulse to keep the engine running smoothly even at very low speed (or idle). The same fuel injection system can also provide additional fuel pressure on-demand instantly to deliver more power when the operator has to quickly accelerate. All of these functions are accomplished while the fuel pump is running steadily at a constant speed.

In addition, a fuel-return line diverts a small portion of fuel from the output of the pump (or from the main filter) to the fuel tank to stabilize the fuel system at the predetermined pressure. In other words, the fuel-return line system minimizes fuel pressure fluctuation caused by pump metering action. It also takes away the need to bleed the excess hot fuel at the fuel rail and return it to the fuel tank to avoid pressure built-up at the fuel rail. Without hot fuel returning to the tank, the temperature in the fuel tank will remain unchanged regardless of how long the vehicle is in operation.

Depending upon the operator's desire and sensor signals from the engine, such as, but not limited to, airflow, engine speed, torque, and temperature, the fuel system can be switched from one steady state to another state at a new pressure level almost instantly without changing the drive (or speed) of the fuel pump. The stabilization of fuel pressure allows a microprocessor to predict a proper fuel injection pulse width for delivering the desired amount of fuel per pulse. It also minimizes the guessing processes to deliver a proposed fuel quantity per pulse in the split injection process commonly used in a diesel engine.

An important objective of this invention is the capability to change the fuel pressure from one steady state to another state instantly and precisely, while the pump is running at a constant speed. The pressure at each state is steady with minimum pressure fluctuation. It assures a more accurate estimate of the amount of fuel to be delivered to the engine.

Another objective of this invention is to be able to change from a normal operating fuel pressure to a very low and steady pressure instantly with minimum ripple for idle and for low speed driving while the pump is running at a constant speed at a comfortable voltage.

A further objective of this invention is to instantly switch from normal operating pressure to a higher fuel pressure on-demand for quick acceleration without changing the driving voltage applied to the fuel pump.

Yet a further objective of this invention is to constantly circulate fuel through the fuel-return line to maintain a constant fuel pressure and to avoid excess fuel and pressure built-up at the fuel-rail. Thus, hot fuel from the fuel rail does not need to return to the fuel tank and the temperature in the tank will remain unchanged regardless of how long the vehicle is in operation. Constant fuel pressure also assures a more predictable amount of fuel injected per pulse.

All of these objectives can be achieved while the fuel pump is running at a constant speed (or the drive voltage applied to the fuel pump is set at a constant value well within a comfortable linear operating range of the fuel injector). Because the fuel pump is not subjected to frequent and sudden acceleration/deceleration, the life of the pump may be prolonged.

In the drawings, which are discussed below, one or more preferred embodiments are illustrated, with the same reference numerals referring to the same pieces of the invention throughout the drawings. It is understood that the invention is not limited to the preferred embodiment depicted in the drawings herein, but rather it is defined by the claims appended hereto and equivalent structures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic drawing of a dual pressure fuel injection delivery system according to the present invention.

FIG. **2** is a schematic diagram of a multi-pressure fuel injection delivery system that uses a Fuel-Return Line to stabilize fuel pressure according to the present invention.

FIG. **3** is a representative relationship between fuel pressures versus the total fuel flow rate through a fuel pump at a constant speed in a fuel system like those shown in FIG. **1** and FIG. **2** according to the present invention.

FIG. **4** is a typical fuel injection event between fuel injected per pulse and pulse width under different fuel pressures and constant pump speed.

FIG. **5** is a flow chart of a microprocessor electronic signal execution sequence that shows the operation of a dual pressure single speed fuel injection delivery system according to the present invention.

FIG. **6** is a flow chart that shows the operations of the invention when an operator desires instant maximum power on-demand.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, the invention will now be further described by reference to the following detailed description of preferred embodiments taken in conjunction with the above-described accompanying drawings.

The structures of fuel injection systems of the current invention are shown in FIG. **1** and FIG. **2**. The illustration of its operations and its properties will refer to both figures. Not shown in those figures yet well understood to technical professionals in microelectronics is the set-up of microelectronics used to control the system. An embedded controller, a microprocessor, or a programmable logic circuit can be used as the brain. It may be a standalone unit, or a subroutine of the main CPU (or ECU) of the vehicle. The program may be embedded in ROM, PROM, EPROM, or other conventional storage media like hard disk, CD-ROM, tape drive, etc. The program is executed by the microprocessor through the RAM. The sequence and logic of the control are shown in FIG. **5** and FIG. **6**.

A. Basic Fluid System that Creates Dual-Pressure Instantly

FIG. **1** is one embodiment of the invention. The inventive fuel injection fluid system comprises the following parts: fuel tank **10**; fuel pump **11** (which may be submerged in the fuel tank, or installed outside the tank); main fuel filter **13**; fuel supply lines **51**, **52**, **53**, **55** which connect the various components of the system in fluid communication; fuel rail **17** to which all of the fuel injectors **20** are connected; fuel by-pass control **30**; and fuel by-pass lines **35**, **37** which feed the extra by-pass fuel from the main fuel line **53** to fuel tank **10** or through line **38** to the fuel in-take line **51** to the fuel pump **11** for re-using in the fuel injection process. Fuel pump **11** runs at a constant speed well within the comfortable operating range of a pump.

Fuel by-pass control **30** preferably has an electromechanically controlled valve (normally closed or open depending upon its operation). Lines **35**, **37** and by-pass control **30** comprise a by-pass for fuel to be partially diverted from the main fuel line **53**. When fuel by-pass control **30** is normally closed, fuel pump **11** supplies fuel to the fuel injectors only. When by-pass control **30** is open, fuel pump **11** will deliver additional fuel to be by-passed through fuel lines **35**, **37** back to fuel tank **10** (or pass through line **38** to fuel in-take line **51** to fuel pump **11**.)

Proper restrictions are imposed on the by-pass fuel flow outlined above. For example, one may choose the size of the fuel by-pass lines **35**, **37**, **38** so that they provide proper flow resistance or introduce a restriction by other means. For those familiar with fluid control, the means include, but are not limited to, using a needle valve or a diaphragm-like plate with a hole that has a proper diameter for fuel restriction. Regardless of what the state of fuel by-pass control **30** is in (open or closed), fuel pump **11** runs continuously under a constant voltage drive (or at a constant speed). The changes in the fuel flow rate through the fuel pump under a constant drive create different steady fuel pressure states for the fuel supply system.

A fluid system has certain similarities to an electrical circuit, where the fuel pump is equivalent to a power source and the fuel flow rate is equivalent to current in an electrical circuit. The fluid supply system as a whole provides a steady state impedance to the pump. When the fuel by-pass control is closed (normal operating condition), the fluid system is stabilized at a quiescent state at pressure P_H for a given fluid flow rate F_1 (FIG. **3**). When fuel-by-pass control **30** lets additional fuel F_2 flow through fuel by-pass lines **35**, **37** to fuel tank, more fuel is fed through the fuel pump creating a new quiescent state at a lower pressure P_L as shown in FIG. **3**. Similarly, if the fuel by-pass control is normally open, closing the fuel-by-pass control will reduce the amount of fuel flowing through the pump. This will switch the pressure of the fuel system from the quiescent pressure state P_L to a higher quiescent pressure state P_H. The switching over between the quiescent states is quick and the new pressure is achieved in just a few milliseconds which is the time for the pressure wave to travel from the control valve to fuel injectors at the acoustic velocity of fuel. Thus, it makes predictions to obtain the required amount of fuel per injected pulse a lot easier.

In this invention, the higher fuel pressure P_H is set for start-up and normal operation, and the maximum pulse width (about 10 milliseconds) is set for the nominal maximum power (or slightly more). When the vehicle is operating in idle or driving at slow speed, the fuel-by-pass control is switched to open. This makes the fuel system operate at a lower pressure state P_L while the fuel pump is running at the same speed as before. Because not much fuel is needed other than keeping the engine alive when the vehicle is idling, a manufacturer can set fuel injection pulse width at a minimum rate (about 2 milliseconds) and set a constraint on the fuel-by-pass line to obtain the lowest fuel pressure P_L which accomplishes the fuel spraying properly and allows the engine still to run smoothly. The amount of fuel injected can be very small so that it barely keeps the engine running while still running the engine smoothly.

The action to open or close the fuel by-pass control can be done manually by flipping a control switch. It can also be controlled using an embedded controller where an electronic signal is sent to activate a control circuit which activates the actuator of the fuel by-pass control switch. Suitable programming logic is used by the controller, the steps of which are shown in the flow-charts of FIG. **5** and FIG. **6**, and the operation of which is discussed subsequently in section D.

Generally, under a given quiescent fuel pressure P, a fuel injector operating within its linear range (typical pulse width about 2- to 10-milliseconds) has a dynamic range as shown in FIG. **4** by the plotted points therein. Superposition of two linear operating ranges under two different fuel pressures will make the dynamic range wider (also shown in FIG. **4**), where the smallest fuel injected per pulse $(q_{min})_H$ under higher pressure P_H at minimum allowed pulse-width is equal to or less than the highest fuel injected per pulse $(q_{Max})_L$ under lower fuel pressure P_L at maximum pulse-width, i.e. $(q_{min})_H<(q_{Max})_L$. As a result, the design team can assign the higher pressure P_H for start-up, normal operation, and choose the pressure so that maximum nominal power is achieved at the longest allowed pulse width; the lower pressure P_L for city driving and for idling can also be assigned. The pressure P_L is tuned for idle so that the smallest fuel injected per pulse $(q_{min})_L$ under the shortest allowed pulse width makes the engine run at the slowest possible speed yet still run smoothly. Hence, it reduces fuel consumption when idle and increases the dynamic range of fuel injection. When the desired amount of fuel injected per pulse q is within the overlapping region, i.e.,

$$(q_{Max})_L>q>(q_{min})_H,$$

two values of pulse width exist for any given q. The design team chooses between higher pressure P_H and lower pressure P_L depending upon the expected driving condition and for a smooth transition without feeling roughness during the transition of pressure switching over. For those who are familiar with the state of the art of the technology, many alterations and combinations to the values for q, P_H, and P_L can be selected for different applications. The voltage applied to the fuel pump can also be changed to create different sets of pressure P. The combination of the new fuel system design and the changes in applied voltage will provide enough flexibility for any vehicle to run smoothly from the fuel injection point of view.

FIG. **4** is a typical relationship between the amounts of fuel injected per pulse q versus pulse width in a dual pressure fuel injection system. In comparison with the actual fuel injection measurement by a fuel injector manufacturer for a 2.0-liter displacement engine, a dual pressure fuel injection system is capable of delivering more fuel injected per pulse at maximum pulse width $(q_{Max})_H$; the system is also capable of delivering less fuel per pulse at minimum pulse width $(q_{min})_L$ i.e.,

$$(q_{Max})_H>q_{Max},\ (q_{min})_L<q_{min};$$

and

$$(q_{Max})_H/(q_{min})_L>q_{max}/q_{min}. \qquad (5)$$

Using the dual pressure injection system can save fuel when compared to actual single pressure injection. For example, FIG. **4** shows a 25% fuel saving per pulse in a multi-point sequential injection when idle (compared to the actual data from an injector manufacturer). That means the same vehicle will consume about 40% less fuel per second at idle speed according to Eq. (2). It also means that the vehicle will generate 40% less auto emission which improves city-driving mileage. Although fuel saving and exhaust reduction may not seem much to a single vehicle, the cumulative effect on a congested highway or during a traffic jam in a city street where hundreds to thousands of vehicles are crawling, the affect will be noticeable. It would provide a lot of comfort to drivers, to people walking on the street, and to residents living nearby.

B. Fuel-Return Line for Fuel Pump Stabilization, Temperature Stability in Fuel Tank, and Delivering an Instant Excess Power On-Demand

Using the same principle as described in the previous section, we can further improve the fuel injection fluid system by adding an extra fuel-return as shown in FIG. **2**. Fuel-return-line **31** is connected from the output of fuel pump **11** (or at the output of filter **13**) through fuel-return-control **32** (which is normally "Open"), line **33** back to fuel tank **10** (or through line **34** to intake line **51** of the fuel pump). Line **33** may also be connected to line **37** to decrease the cost. Fuel-return-control **32** can be an electromechanical valve, which may be controlled manually or electronically by using a microprocessor or an embedded controller. The amount of fuel through fuel-return may be adjusted to obtain different high pressure P_H as shown in FIG. **3** where two linear lines represent two different pressures. If the flow of the fuel-return is larger than the flow for fuel injection, the structure will regulate the pressure of the fuel system to be almost constant.

The structure minimizes the dependence for the fuel pump to provide the exact amount of fuel for fuel injection and eliminates the need to return the unused excess fuel from fuel rail **17** (hot fuel) to fuel tank **10** to avoid pressure built-up. The structure also reduces the critical dependence to a fuel regulator, which contains numerous high-precision mechanical parts. Hence, the small amount of the fuel through a fuel-return line **31**, **33** can stabilize the pressure and make the operation of the fuel pump steady. This minimizes the pulsating pressure spikes during fuel metering. Since no more hot fuel is returned to the fuel tank, fuel temperature in the fuel tank will remain unchanged regardless of how long the vehicle is in operation.

The amount of flow restriction imposed by fuel-return line **33** determines the value of the first quiescent pressure P_H. Typically, the lower the amount of fuel flowing through the fuel-return line, the higher the quiescent pressure P_H will be. FIG. **3** has two plotted lines representing two different pressures P_H which are created by a different amount of fuel-return. In addition, should there be a desire for the operator to obtain excessive power in a hurry, the ECU can electro-mechanically cut off the flow through fuel-return-lines **31**, **33** and fuel-by-pass-lines **35**, **37** resulting in a quick increase in fuel pressure for a short duration which delivers additional maximum power on-demand instantly for quick acceleration. The electro-mechanical "Off/On" action may be directed by a microprocessor or be controlled manually. Details on how to incorporate signals from various sensors to control the fuel pressure states and to determine the amount of fuel injected will be discussed in Section D and shown in a flow chart in FIG. **6**.

C. Fuel Injection System that Incorporates Both Inventive Features

FIG. **2** is a complete fuel injection supply system that incorporates both features of the invention using fuel-by-pass control **30** (normally closed) and fuel-return control **32** (normally open). With fuel-return-control **32** normally open, the fuel pump is stabilized and there is no need to return hot fuel to the fuel tank. With fuel by-pass control **30** normally closed, the fuel injection system is similar to today's existing fuel injection supply systems, except that it is optionally designed to operate at a higher pressure P_H than normally available with the more limited dynamic range of current systems. The operation under normal setting is similar to that in today's vehicles. It will be used for start-up, normal driving, engine warm-up, etc. Yet, when the engine has warmed up and the vehicle is being used for city (urban) driving or is idling, the fuel-by-pass control **30** can be opened electronically, which switches the fuel pressure from a higher pressure P_H to the lower pressure P_L. The vehicle will be operating in the fuel saving mode and will reduce auto emission. Because the new system has a wider fuel injection dynamic range, as mentioned above, P_H can be set slightly higher so that the same engine can deliver a little more power, yet the same engine can still reduce fuel consumption when idling to improve city-driving mileage and achieve fuel emission reduction.

Should the operator or system designer have a strong desire for instant high power on-demand, the system is structured to respond by closing both fuel-by-pass control **30** and fuel-return control **32** for quick acceleration. Such an operation may exceed the rating of the engine. Hence, the system should preferably allow the operator, or be otherwise designed, to perform such an operation under emergency bases and only for short time periods.

D. Flow Chart of the Microprocessor Controlled Fuel Injection Supply System

In a fuel injection supply system as shown in FIG. **2**, a microprocessor is preferably used for collecting the input information from various sensors and executing the operating sequences. The microprocessor may be a standalone unit, multiple embedded controller units to execute more extended features, or shared with the main CPU (ECU, or ECM unit) to execute the fuel injection subroutine. One set of the I/O ports from the microprocessor is designated to receive sensor signals in regard to engine temperature, engine speed, engine power and torque, fuel pressure, throttle position, air flow and pressure, etc. Another set of I/O ports are connected to storage devices, such as ROM, PROM, EPROM, hard diskette, floppy diskette, CD-ROM, etc. The storage media are used to store the chart of fuel injection requirements, engine operating parameters, and the embedded program for executing the fuel injection control processes. All processing and calculations are done in the RAM also attached to the third set of I/O ports of the microprocessor. The last set of I/O ports is designated as the control signal outputs. The output signals are used to trigger the actuation circuits for valve action control.

FIG. **5** is a microprocessor electronic signal flow chart for the fuel system as shown in FIG. **1** where the fuel by-pass control is normally closed. The microprocessor detects the needs of the engine and measures the pressure differences between air manifold (not shown) and fuel rail in step **101**, determines the amount of fuel needed by the engine Q in step **103**, calculates the required amount of fuel injected per pulse q in step **105**, and determines the pulse width for the fuel injected per pulse q in step **120**. In decision block **110**, if the calculated q is less than the maximum amount of fuel injected per pulse under the low fuel pressure state $q<(q_{max})_L$ and the engine is warm, according to decision block **115**, the microprocessor will send an electronic signal to activate the control circuit that actuates fuel-by-pass control valve to open (step **119**). This switches the fuel system to a lower fuel pressure state P_L. On the other hand, if $q>(q_{max})_L$ **110** or the engine is cold, fuel-by-pass-control stays Closed. Fuel pressure will remain in the higher-pressure state P_H, as indicated by **117**. In either pressure state, the microprocessor will detect the new fuel pressure and determine the pulse width for the fuel injected per pulse q (step **120**) in the next fuel injection cycle.

An electronic pulse of the pulse width is sent to a control circuit (not shown in the FIG. **5**) that actuates the fuel injector valves under the pre-determined pulse width. Sensor signals of the actual engine performance are collected and used to compare with the original data of the anticipated results. The microprocessor makes proper adjustment and determines the revised pulse width, then sends the next round of control signals.

FIG. **6** is an electronic signal flow chart for the fuel system as shown in FIG. **2** where the fuel by-pass control is normally closed and the fuel-return control is normally open. Fuel-return is installed to stabilize the fuel pump operation and to minimize the pressure fluctuation of the fuel system. The fuel-return control is normally open. Hence the flow chart for the control processes of fuel-by-pass is the same as those shown in FIG. **5**. However, when the operator has a strong desire to demand maximum power instantly **150**, **151**, **152**, the signal from the pedal position sensor is compared with the maximum electronic signal from gas pedal position sensor $V_{gas}=(V_{gas})_{Max}$ repeatedly for N times **153**, where N is pre-set and maybe in the range of 30 to 100 to assure the validity of the urgent needs. If the engine is not over-heated **154**, the microprocessor will send a flag **155** to over-ride any command to the fuel injection system, close the fuel-return control and fuel-by-pass control, over-ride the engine temperature sensor "Warm/Cold," and send a maximum pulse width signal to the fuel injectors. This is the only time the fuel-return is activated to close and extra fuel pressure is added to the system to deliver additional amount of fuel per pulse for extra maximum power. Simultaneously, the microprocessor will activate all throttle valves to open fully allowing in-take air to flow at its maximum.

The only overriding signal occurs when the engine is overheating. In that case, the fuel-return valve will remain Open and the fuel-by-pass valve is closed. The fuel system will stay at a higher-pressure state P_H. Because the engine may operate beyond its normal rating, the operation as described in FIG. 6 should only be operated for a short time, i.e. $t<t_{allowed}$. The design team can pre-set the allowed time $t_{allowed}$, which may be in the range of 10 to 60 seconds. When the operation exceeds the pre-set time $t>t_{allowed}$ **163**, the controller will open fuel-return **164**. All of process **165** will follow the flow chart as shown in FIG. **5**.

E. Modification of Vehicles Already In-Use for Improved City-Driving-Mileage & Reduced Auto Exhaust

Any vehicle already in use which uses a single pressure fuel injection system can be modified easily to include the present invention and thereby increase its city-driving mileage, save fuel, and reduce auto exhaust emission. The modification adds an electromechanical fuel-by-pass control **30** (normally closed) and fuel by-pass lines **35**, **37** that connect from the output of fuel filter **13** (or output of fuel pump **11**) to fuel tank **10** (or to the fuel in-take line **51** to fuel pump **11**) as shown in FIG. **1**. For vehicles that have a hot fuel return line from a fuel rail, the fuel by-pass line may be connected from the output of the fuel pump to the hot-fuel-return line for easier modification and cost saving.

Fuel by-pass control **30** is normally closed. The modification will not effect the normal operations of the existing vehicle. When the vehicle is being used for city driving or is sitting idle, the fuel by-pass control will be open. Fuel by-pass lines **35**, **37** add extra fuel through the fuel pump resulting in a reduced steady pressure P_L. Hence, less amount of fuel will be injected per pulse for the same pulse width. This reduces engine idle speed, saves fuel, improves city-driving mileage, and reduces auto emission. The modification is simple and inexpensive. The benefits are especially significant in metropolitan areas where large numbers of vehicles are in operation.

The invention provides different fuel pressure levels under a constant fuel pump speed and has been described with reference to certain internal combustion engines. The invention, however, applies to any number of internal combustion engines or other engines making use of a fuel injection system. As such, the invention is applicable to diesel engines and aircraft engines that use fuel injection processes. One skilled in the art would have no difficulty applying the invention to other kinds of engines.

Additional advantages and variations will be apparent to those skilled in the art, and those variations, as well as others which skill or fancy may suggest, are intended to be within the scope of the present invention, along with equivalents thereto, the invention being defined by the claims attended hereto.

The invention claimed is:

1. A multi-pressure fuel injection system for use with an engine, comprising;

a fuel supply for the system;

a fuel pump connected to the fuel supply and adapted to be operated at a predetermined speed;

at least one fuel injector,

a main fuel line, providing fluid connection from the outlet of the fuel pump to the at least one fuel injector;

a fuel by-pass line with flow constraint having one end connected to some location on the main fuel line including the outlet of the fuel pump avoiding fuel rail and fuel injector, and the other end connected to some location in the fuel supply, including the inlet of the fuel pump, to provide fuel flow back to the fuel supply when the system is operating; and

a fuel by-pass control in the fuel by-pass line, capable of opening and closing almost instantaneously, changing the pressure of the system between two designed pressure states, including a higher pressure state and a lower pressure state thereby essentially instantaneously changing the pressure of the fluid in the main fuel line between the two pressure states and the rate of fuel delivery at the at least one fuel injector.

2. A multi-pressure fuel injection system for use with an engine, comprising:

a fuel supply for the system;

a fuel pump connected to the fuel supply and adapted to be operated at a predetermined substantially constant speed;

at least one fuel injector connecting to fuel rail,

a main fuel line, providing fluid connection from the outlet of the fuel pump to the fuel rail and the at least one fuel injector;

a fuel-return path having one end communicating with the main fuel line including the outlet of the fuel pump and avoiding fuel rail and fuel injectors, and the other end communicating with the fuel supply to the fuel pump inlet, and means for controlling additional flow through the fuel-return path to create a fuel recirculating loop to divert sufficient amounts of fuel during most of the operating conditions of the engine to substantially stabilize the pressures on the fuel pump to render the fuel system substantially self-regulating and to minimize the need of a hot fuel return; and

a fuel by-pass line with flow constraint having one end connected to some location on the main fuel line including the outlet of the fuel pump and avoiding fuel rail and the at least one fuel injector, and the other end connected to some location in the fuel supply, including the inlet of the fuel pump, to provide fuel flow back to the fuel supply when the system is operating; and

a fuel by-pass control in the fuel by-pass line, capable of opening and closing almost instantaneously, changing the pressure of the system between the two designated pressure states, including a higher pressure state P_H and a lower pressure state P_L thereby essentially instantaneously changing the pressure of the fluid in the main fuel line between the two pressure states and the rate of fuel delivery at the at least one fuel injector.

3. The system of claim **2**, further comprising a fuel pump which maintains substantially constant speed irrespective of which of the pressure states the system is in and the by-pass control being effective so that the change of pressure is effective immediately.

4. The system of claim **2**, further comprising a computer programmed to actuate the fuel injector to deliver pulses of fuel, the computer receiving signals indicating operating conditions of the engine in order to select between the pressure states and varying the pulse width to control the sizes of the injected fuel pulses over a dynamic range at the selected pressure state, the dynamic range being widened by switching between the pressure states, the computer delivering the pulses under the high pressure state under some operating conditions and under the lower pressure state under other operating conditions.

5. The system of claim **4**, wherein the operating conditions are sensed from signals, including but not limited to engine temperature, speed, torque, fuel pressure and air pressure, pedal position sensing, operators intention, end adjustments are made as needed by a computer.

6. The system of claim **4**, wherein the computer includes programming to signal the fuel bypass control to open and create the low pressure state in response to signals from engine management control that the engine is sufficiently warm and the amount of fuel per pulse being demanded is less than the maximum pulse amount available under the low pressure state.

7. The system of claim 4, wherein the fuel by-pass is adapted for the two pressure states to have overlapping fuel pressure operating ranges, the two ranges creating the widened dynamic range while the fuel pump runs at a substantially constant speed.

8. The system of claim 2, further comprising means for constraining the fuel flow, wherein said means comprises one of the following: an orifice plate with a hole of predetermined diameter, a needle-valve-like device, or a device compressing the fuel by-pass end the fuel-return line to create various fuel-return-flow and fuel-by-pass flow constraint.

9. A fuel injection system comprising:

a fuel supply,

at least one fuel injector,

a fuel pump connected to the fuel supply and driven at a substantially constant speed;

a fuel supply line from the outlet of the fuel pump to the at least one fuel injector.

a fuel return path with flow constraint from the main fuel line, including the outlet of fuel pump and avoiding fuel rail, to fuel tank including the inlet of fuel pump;

at least one fuel by-pass line, avoiding fuel rail and fuel injectors, with flow constraint connected between some location in the main fuel supply line, including the outlet of the fuel pump to some location in the fuel supply, including the inlet of the fuel pump, and

a fuel by-pass control including programming to separately open and close each fuel bypass line essentially, instantaneously, the opening or closing of each by-pass control instantaneously changing the pressure of the system between a higher pressure state and a lower pressure state.

10. The system of claim 9, wherein the computer controls the opening or closing of each fuel-return line to create multiple pressure states at preset pressure levels.

11. The system of claim 9, wherein all fuel by-pass lines for fuel-return and fuel by-pass include a flow-constraint structure.

12. The system of claim 9, wherein the fuel by-pass control comprises an electromechanical valve and means for actuating the valve in response to fuel demand.

13. The system of claim 9, wherein a computer is provided to actuate fuel by-pass controls and includes programming to open and close the selected by-pass lines in response to varying fuel demands.

14. The system of claim 13, wherein there is a normally closed fuel by-pass line and the fuel by pass control includes programming to open the control in that normally closed fuel by-pass line during idling to create a lower pressure state, and the computer selects a corresponding minimum fuel pulse according to the lower pressure state to conserve fuel when gas pedal is released and during the idling.

15. The fuel injection system of claim 9 in which a computer is used for selectively opening or closing by-pass's controls in one or more selected bypass fuel lines in response to operating conditions of the engine to instantly create different selected fuel pressure states in the system for fuel demand.

16. The system of claim 9, wherein the fuel pump has another predetermined speed to further enhance fuel injection dynamic range.

17. A multi-pressure fuel injection system for use with an engine, comprising,

a fuel supply for storing fuel for the system,

a fuel pump adapted to be operated at predetermined speed,

at least one fuel injector,

a main fuel line providing fluid connection from the outlet of the fuel pump and to the at least one fuel injector,

at least two fuel by-pass lines with flow constraint having one end connected to some location on the main fuel line avoiding the fuel rail and fuel injectors, and the other end connected to some location in the fuel supply, including the inlet or the fuel pump,

a fuel by-pass control in each fuel by-pass line capable of opening and closing its line almost instantaneously, thereby essentially instantaneously changing the pressure of the fluid in the main fuel line between two pressure states and the rate of fuel delivery at the at least one fuel injector,

a computer to open and close selectively each fuel by-pass control.

18. The system of claim 17, wherein the computer includes programming to open and close selected by-pass lines selectively to create at least three pressure levels.

19. The system of claim 17, comprising two fuel by-pass lines, one a normally closed fuel by-pass and the other normally open fuel-return line.

20. The system of claim 19, wherein the fuel-return line is normally open to allow fuel recirculation in the fuel system to stabilize pump operation and minimize the need of a hot fuel return.

21. The system of claim 20, wherein the computer includes programming to process signals corresponding to power demands of the user and to dose both fuel return lines to create additional, available maximum engine power.

22. The fuel injection system of claim 17 in which the computer receives control signals based on the amount of fuel being demanded in response to engine operating conditions, including operators input and the engine temperature, to generate signals to open or close the fuel by-pass control in each fuel by-pass line to allow selected pressure at the at least one fuel injector, and to adjust the fuel injection pulse width according to engine fuel demand.

23. The fuel injection system of claim 17 in which the computer also adjusts the injection pulse width of a plurality of fuel injectors used in a particular system.

24. A fuel injection system for delivering fuel from a fuel supply to fuel injectors of an engine, the system comprising:

a fuel supply;

a fuel pump driven at a substantially constant speed;

at least one fuel injector;

at least one fuel by-pass line avoiding fuel rail and fuel injectors, connecting the outlet of the fuel pump and the fuel supply;

a fuel by-pass control in each fuel by-pass line for opening and closing substantially instantaneously in a selected by-pass line in response to operating conditions of the engine to create different fuel pressures in the system,

a computer for determining the amount of fuel required per pulse for fuel injection, for determining whether the required amount of fuel is within the limit of one or more of the fuel pressures producible in the system, and

for selecting the appropriate one of the fuel pressures in response to (a) operating condition of the engine, (b) the demand for engine power, or (c) manual control by the operator.

25. The system of claim 24, wherein the computer actuates the by-pass control in selected fuel by-pass lines during cold engine operations to create a first, higher pressure state,

the computer receiving signals from engine management control that the engine is warm and the demanded fuel pulse is less than the maximum fuel pulse which the lower pressure slate can supply, opening the fuel by-pass path to create the lowest pressure state which is, higher than the minimum pressure needed to assure proper fuel spraying.

26. A method of improving city-driving fuel efficiency in a fuel injection engine comprising,

pumping fuel from a fuel tank to a fuel rail and at least one fuel injector for the engine at a predetermined substantially constant speed,

by-passing some fuel from main fuel line, including the outlet of the fuel pump, avoiding the fuel rail and fuel injector, back to the fuel tank by a normally closed connection with flow constraint,

opening on-demand the normally closed connection to instantaneously vary the fluid pressure of the fuel from higher pressure state P_H to the lower pressure state P_L thereby instantaneously reducing fuel pressure and the amount of injected fuel at the at least one fuel injector every time the gas pedal is released for fuel saving in city driving.

27. The method of claim **26** in which the two pressure states include one P_L near the lowest minimum pressure at which fuel can be effectively injected for fine fuel spraying and one P_H near the nearest state to that desired to produce maximum power.

28. The method of claim **27** in which further control of fuel feed at each state can be accomplished by varying the pulse width of injection pulses at each injection nozzle to vary me amount of fuel injected at each pulse, wherein the minimum allowed pulse width at low pressure state is used when the gas pedal is released and for idling to save fuel in city driving, and the maximum pulse width at high pressure state is used to produce maximum power rated for me engine.

29. A method of providing exceptional high-performance and improving city driving fuel efficiency in a fuel injection engine comprising,

pumping fuel from a fuel tank to at least one fuel injector for the engine at a substantially constant predetermined speed,

by-passing some fuel from the fuel pump outlet back to the fuel tank by a normally closed connection with flow constraint avoiding the fuel injector,

returning same fuel from the fuel pump outlet back to the fuel tank by another normally open connection with flow constraint avoiding the fuel rail and the fuel injector to form a fuel circulating loop stabilizing the fuel pump operation and minimizing the need of hot fuel return line, and

opening and closing both or one of the connections with essentially no time lag to instantaneously vary the fluid pressure of the fuel among at least three pressure states and thereby instantaneously varying the amount of injected fuel pulses for a given pulse width at the at least one fuel injector for each pressure state.

30. The method of claim **29** in which the at least two lower pressure states among the three pressure states include one near the lowest minimum pressure required for fine fuel spraying and one near the nearest state to that desired to produce maximum power.

31. The method of claim **29** in which further control of fuel feed at each state can be accomplished by varying the injection pulse width at each injection nozzle the amount of fuel injected at each pulse, where the minimum allowed pulse width at low pressure state is used for city driving when gas pedal is released and for idling and the maximum pulse width at high pressure state is used to produce maximum power rated for the engine.

32. The method of claim **29** in which after repeated verifications of operator's urgent needs for maximum power the $V_{gas}=(V_{gas})_{max}$ for N times to avoid faulty electronic signal and the engine is not overheating, activating signals to close both fuel-return and fuel by-pass lines creating the 3rd high pressure state, opening the throttle valve and other air accessories for maximum air in-take, and delivering maximum fuel injection for extraordinary power exceeding the maximum rating of the engine for a short duration.

33. A method of modifying existing vehicles with fuel injection engines to achieve better fuel efficiency in city-driving comprising,

connecting at least one normally closed fuel by-pass line with flow constraint and a controller from the main fuel line avoiding fuel rail back to the fuel supply or the intake side of the fuel pump, and

opening the normally closed fuel by-pass line with fuel constraint on demand when the engine is warm to reduce the fuel pressure, thus saving fuel every time when gas pedal is released and during idling to achieve fuel efficiency in city-driving.

34. The method of claim **33**, creating and storing in a controller memory a separate set of fuel injected per pulse versus pulse width values for the new low pressure state as the look up chart so that engine management controller can deliver proper amount of fuel when engine is operating at the new low pressure state to reduce idling speed and every time when gas pedal is released, thus achieving fuel efficiency in city-driving.

35. A fuel injection system comprising:

a fuel supply,

at least one fuel injector,

a fuel pump connected to the fuel supply and driven at a substantially constant speed,

a main fuel line from the outlet of the fuel pump to the at least one fuel injector,

at least two fuel bypass lines with flow constraint connected from some location in the main fuel line including the fuel pump outlet avoiding fuel rail and fuel injectors, to some location in the fuel supply, including the fuel pump inlet, and

a fuel by-pass control in at least one fuel bypass line which can selectively open and close the by-pass line to instantaneously change system fuel pressure states.

36. A fuel injection system providing exceptional high performance and still achieving fuel saving in city driving comprising:

a fuel supply,

at least one fuel injector,

a fuel pump having an outlet and an inlet connected to the fuel supply and driven at a substantially constant speed,

a main fuel line from the outlet of the fuel pump to the at least one fuel injector,

two fuel bypass lines with flow constraint connected from the main fuel line, including the fuel pump outlet but excluding fuel injector, to the fuel supply including the inlet of the fuel pump, or both, and

a fuel by-pass control in each fuel bypass line which can be opened or closed essentially instantaneously, the control in one bypass line being normally open so that its line normally allows fuel recirculation in the system to stabilize the fuel pump operation and to minimize the need of hot fuel return line, and the fuel by-pass control in the other fuel bypass line being normally closed so that its line can be opened to reduce fuel pressure as needed for fuel saving in city driving.

37. The fuel injection system of claim **36** in which a computer is provided to determine when conditions are right for either of the two conditions:

(a) of one normally closed controller being open for fuel saving in city driving, or

(b) both controls being closed to provide for greater acceleration for limited periods when the engine temperature will permit it and other conditions are appropriate, at which time, upon operation demand, both fuel line controls are closed to greatly increase the pressure above the higher of the two pressure states.

38. A fuel injection system for delivering pressurized fuel from a fuel supply to fuel injectors of an engine which uses a fuel recirculation loop to minimize or eliminate the need of a hot fuel return line and a low pressure regulator comprising:

a fuel supply,

a fuel rail in fluid communication with at least one fuel injector,

a fuel pump having an outlet and an inlet, the inlet being connected to the fuel supply and driven at a substantially constant speed,

a main fuel supply line connected from the outlet of the fuel pump to the fuel rail in fluid communication with the at least one fuel injector,

a fuel return path with flow constraint, connected from some location in the main fuel supply line, including the outlet of the fuel pump, avoiding fuel rail to some location in the fuel supply including the inlet of the fuel pump, allowing fuel recirculation to stabilize the pump operation, and creating stable fuel pressure.

39. The fuel injection system of claim **38** comprising

at least one additional fuel by-pass line connected between some location in the main fuel supply line, including the outlet of the fuel pump avoiding fuel rail to some location in the fuel supply, including the inlet of the fuel pump, and

a fuel by-pass control to open and close each additional fuel by-pass line, the opening or closing of each fuel by-pass control instantaneously changing the pressure of the system between a higher pressure state and a lower pressure state.

40. A fuel injection system for delivering fuel from a fuel supply to fuel injectors of an engine which uses a fuel recirculation loop to minimize the need of a hot fuel return line and a low pressure regulator, comprising:

a fuel supply,

a fuel rail in fluid communication with at least one fuel injector,

a fuel pump having an outlet and an inlet, the inlet being connected to the fuel supply and driven at a substantially constant speed,

a main fuel supply line connected from the outlet of the fuel pump to the fuel rail in fluid communication with at least one fuel injector,

a fuel return path with flow constraint, provided by an orifice of predetermined diameter in the return path connected from some location in the main fuel supply line, including the outlet of the fuel pump avoiding fuel rail, to some location in the fuel supply including the inlet of the fuel pump, allowing fuel recirculation to stabilize the pump operation creating stable fuel pressure.

41. A fuel injection system for delivering fuel from a fuel supply to fuel injectors of an engine, which uses a fuel

recirculation loop to minimize the need of a hot fuel return line and a low pressure regulator, comprising:

a fuel supply,

a fuel rail in fluid communication with at least one fuel injector,

a fuel pump having an outlet and an inlet, the inlet being connected to the fuel supply and driven at a predetermined substantially constant speed,

a main fuel supply line connected from the outlet of the fuel pump to the fuel rail in fluid communication with the at least one fuel injector,

a fuel return path with flow constraint provided by a needle valve in the return path, connected from some location in the main fuel supply line, including the outlet of the fuel pump, avoiding the fuel rail, to some location in the fuel supply including the inlet of the fuel pump, avoiding fuel recirculation to stabilize the pump operation creating stable fuel pressure.

42. A fuel injection system for delivering pressurized fuel from a fuel supply to fuel injectors of an engine which uses a fuel recirculation loop to minimize the need of a hot fuel return line and a low pressure regulator, comprising:

a fuel supply,

a fuel rail in fluid communication with at least one fuel injector,

a fuel pump having an outlet and an inlet, the inlet being connected to the fuel supply and driven at a substantially constant speed,

a main fuel supply line connected from the outlet of the fuel pump to the fuel rail in fluid communication with at least one fuel injector,

a fuel return path with flow constraint, provided by a device compressing the fuel by-pass or the fuel-return path, connected from some location in the main fuel supply line, including the outlet of the fuel pump avoiding fuel rail, to some location in the fuel supply including the inlet of the fuel pump, allowing fuel recirculation to stabilize the pump operation creating stable fuel pressure.

43. A method of obtaining highest pressure instantaneously to deliver maximum fuel injection pulses for start-up of cold direct injection engine and for short burst of power for acceleration, comprising:

closing all fuel by-pass lines, and

closing all fuel return lines including closing all excess fuel return lines from pressure regulators if there is any.

44. A kit providing fuel saving and auto exhaust reduction in city driving for vehicles with a fuel injection system for internal combustion engines currently in production or earlier models of vehicles already in use, comprising,

a by-pass fuel line with flow constraint including a normally closed electromagnetic valve, for connecting from the main fuel line back to fuel tank to provide a fuel pump by-pass path without changing normal fuel delivering flow, hardware connection, such as a T, allowing connection of the by-pass fuel line into main fuel line, including the outlet of fuel pump, avoiding fuel rail and fuel injector, hardware connection permitting the other end of the fuel by-pass line to be connected into a fuel return line, or directly into the fuel tank in a manner to prevent leakage of fuel vapor to the air, and

means for opening the normally closed electromagnetic valve in the by-pass line when engine is warm and the vehicle is in the city driving mode to instantaneously reduce the fuel pressure to a predetermined level to save fuel every time the gas pedal is released including during idling.

45. The kit of claim **44** which include a conveniently positionable manually actuated switch in the control circuit of the electromagnetic valve that allows the operator in observing the engine temperature gauge to instantaneously open the normally closed fuel valve in the fuel by-pass line to choose the lower pressure state P_L for fuel saving in city driving.

46. The kit of claim **44** which includes programs to be installed in memory supplementing the existing E.C.U. and Engine Management Control for operating the electromagnetic valve in the fuel by-pass line, comprising:

additional look-up chart of fuel pulse versus pulse width curves under the lower pressure state P_L and under the higher pressure state P_H, end

operating software program including the selection of a proper pressure state from the lower pressure state P_L for city driving, or the higher pressure state P_H for highway driving.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,318,414 B2
APPLICATION NO. : 10/143657
DATED : January 15, 2008
INVENTOR(S) : Shou Hou

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

Claim 5, line 62, col. 12 "intention, end" should read -- intention, and --;

Claim 8, line 13, col. 13 "by-pass end" should read -- by-pass and --;

Claim 17, line 11, col. 14 "inlet or" should read -- inlet of --;

Claim 21, line 32, col. 14 "to dose both" should read -- to close both --;

Claim 25, line 5, col. 15 "pressure slate" should read -- pressure state --;

Claim 28, line 31, col. 15 "vary me" should read -- vary the --;

Claim 28, line 35, col. 15 "rated for me" should read -- rated for the --;

Claim 29, line 46, col. 15 "returning same" should read -- returning some --;

Claim 41, line 18, col. 18 "pump, avoiding" should read -- pump, allowing --;

Claim 46, line 5, col. 20 "P_H, end" should read -- P_H, and --;

Signed and Sealed this

Twentieth Day of May, 2008

JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT B

This message is not flagged. [Flag Message - Mark as Unread]

Date: Thu, 17 Mar 2005 12:34:43 -0800 (PST)

From: "S. L. Hou, TMC Co." <tmccompany@yahoo.com> Add to Address Book

Subject: Fuel Injection Fuel System Developed at TMC (Document No.: #TMC-FIJ-005)

To: "Graham Hoare" <ghoare2@Ford.com>

Dear Mr. Hoare:

Thank you for asking Lori to inform me to send the material by e-mail. I am attaching the Document No.: #TMC-FIJ-005 for your review. Six charts (or Figs. 1 6) can not be sent by e-mail. Hence, the figures are sent by FAX to: 313-337-3502. The materials were basically the same as that discussed with Chris Woodring by phone on December 7, 2004.

TMC seeks licensing to an auto or OEM system/parts manufacturer. I will be in Detroit for the SAE 2005 World Congress from April 10 15, 2005. I would appreciate very much if we have a chance to meet. Please let me know the best time for us to get together. Regards,

S. L. Hou, TMC Co.

Attachment: Document: #TMC-FIJ-005
(Text portion only 6 pages)
6 Figures to be sent by FAX to
313-337-3502

3/24/05 Chino Bhabsar. Need NDA. 313-337-5214
Mike Soltis will review

TMC Co.

FACSIMILE TRANSMISSION

TMC Company
P.O. Box 423, Wayne, PA 19087-0423
Tel: 610-964-8862 Fax: 610-254-0186

DATE:	March 17, 2005	REF:	
TO:	Graham Hoare, Director, PowerTrain, Ford Motor Co., Dearborn, MI		
FAX:	313-337-3502	TEL:	313-322-5953
FROM:	S. L. Hou, President, TMC Co.		
RE:	TMC Fuel Injection Fuel System (Document: #TMC-FIJ-005 6 Figures)		

MESSAGE:

Dear Mr. Hoare:

Attached is the other portion of Document No.: #TMC-FIJ-005 on Technical Discussions. Please attach it to the text portion of the document sent by e-mail to ghoare2@Ford.com.

Regards,

S. L. Hou

Enclosures: Charts -- 6 Figures. 3 pages

Total Number of Pages (including this page) 4 pages

TMC Co. Document Number: #TMC-FIS-005 - 3/16/2005

Technical Discussion: Fuel Injection Fuel System Developed at TMC

On September 24, 2004, the California Air Resources Board imposed a much tighter fuel exhaust emission regulation that requires all auto manufacturers to reduce auto exhaust by 25% (SUV by 18%) effective in 2009. The government requirement will tighten to 30% in 2016. A hybrid car can easily out perform those requirements in city driving with an estimated minimum expense of $3,000.00 to buyers, and eventually the cost to replace the 42V battery plus the expenses associated with battery disposal.

Internal combustion engine has been developed for more than 100 years. A 25 % improvement in engine efficiency requires a breakthrough in engine technology. Yet, a 25% reduction in fuel waste is certainly doable. With the unprecedented energy demand today, using energy wisely may be a good practice to prolong the life of the steady diminishing underground oil reserve. EPA has stated that transportation exhaust contributes about one third of greenhouse effect. Fuel waste reduction saves fuel in city driving and reduces auto exhaust that contributes the most to air pollution in metropolitan areas.

The fuel injection fuel delivery system developed at TMC addresses performance and fuel waste by increasing the fuel injection dynamic range. Fuel pump is running at a steady constant speed, and fuel flow paths are guided by way of tubing. A main fuel line connects from a fuel pump outlet to the injector(s), and one or more fuel by-pass lines with flow constraint connects from part of the main fuel line including the pump outlet back to the fuel tank. All but one of the by-pass lines must have fuel by-pass controls up to the pump outlet capable of instantaneously changing pressure state (from open to closed or vice versa). Thus, it creates multiple discrete pressure levels and greatly increases the fuel injection dynamic range.

The constant speed fuel pump provides for stability and predictability of performance by eliminating variables typically introduced by variable pump speeds in current fuel systems. The system developed at TMC creates discrete multiple pressure levels instantaneously and maintains constant fluid pressure at any selected pressure level in the entire fuel line without complicated feedback loop and regulatory systems. **No excess pressurized fuel** is being continuously pumped to fuel injectors.

When operating in the city-driving mode, fuel pressure is set at low-pressure mode. That saves fuel and reduces auto exhaust, which may fulfill the newly declared regulations by California Air Resources Board to automakers effective in 2009. At the same time, the system can also provide a burst of superpower by setting fuel at the highest-pressure mode instantly. That enables an engine to deliver superpower beyond the maximum engine rating for a short duration without hesitation, when the driver has urgent need for power.

The following technical discussions are the system developed at TMC (patent pending) in comparison to the conventional fuel injection fuel systems used in today's vehicles.

Conventional Fuel Injection Fuel Delivery Systems:

A typical fuel injection fuel delivery system consists of a fuel tank, a fuel pump, at least one filter, and a fuel line connecting from the outlet of fuel pump to fuel rail where pressurized fuel is in fluid communication with at least one fuel injector. Engine operating conditions from various sensors (including pressure, engine speed, torque, temperature, etc.), are fed to engine management control (EMC). EMC determines the amount of fuel needed per pulse for the engine requirement, and then gives commands to generate electronic pulses with proper pulse width and timing to fuel injector actuators, and to E.C.U. to control the driving speed of fuel pump for the load. A predetermined pulse of fuel mist is injected to the fuel/air intake port, or to each engine cylinder directly. However, when engine is running about 6,000 rpm, where more fuel is needed for heavy load, the maximum fuel in-take stroke lasts only 5 milliseconds; and the time needed to open and close the fuel injector valve takes about 1 millisecond. That sets the limit of the allowed minimum pulse width so that the mass-produced fuel injectors can deliver equal amount of minimum fuel pulses to all cylinders for idling. Engineers set a typical fuel injection pulse width between 2 - 10 milliseconds. That translates to a fuel delivery dynamic range of about 25 to 1 ratio. Engineers set maximum fuel pulse width for maximum engine power. As a result, when the gas pedal is released, more fuel is delivered than necessary just to keep engine alive and accessories running.

Manufacturers change fuel pressure to improve the fuel injection dynamic range. Each fuel injection event lasts only a few milliseconds. A fuel pump has much slower response time. More fuel than injection needs must be supplied for stable engine operation at maximum load.

When pressurized fuel supply is too much for fuel injection events, E.C.U. may slow down fuel pump drive until excess pressurized fuel supply is partially used up. Two methods are commonly used in current auto production. Each has its own drawback as discussed below:

A. Change the drive of fuel pump to vary the pump speed (pressure).

   a. Fuel pump has large inductive impedance and a heavy mass load. Changing fuel pump drive does not stabilize fuel pressure in 100 to 500 msec. That causes hesitation when vehicle needs instant power for acceleration from low speed driving.

   b. Fuel pump may run sluggishly at low drive resulting in erratic idling fuel injections to cylinders. That causes the engine to vibrate, even stall, if the minimum pulse width is too short.

B. Install pressure regulators at the fuel rail, or at the fuel injector:

   a. Pressure regulators typically use a flexible diaphragm, or a conical cavity with a plunger that changes volume under pressure. It is the change of volume that regulates the pressure. The change of volume also means a slower response to pressure changes. Therefore, the response to switching between pressure levels is inherently slower. And

   b. Fuel pressure regulator sets the pressure. Excess fuel bleeds through a fuel return passage back to fuel tank. Fuel rail and fuel injectors are in the immediate vicinity of the hot engine. Therefore, returning fuel is heated and carries with it the elevated temperature, which will raise temperature in the fuel tank in prolonged driving.

The Structure and Methods of the Fuel Delivery System Developed At TMC:

The Fuel Delivery System developed at TMC overcomes the problems stated above and improves the fuel injection dynamic ranges. The system install at least one fuel by-pass passage, which can be implemented to most fuel delivery systems currently in use for new vehicle production and for auto-mechanics to upgrade most of existing vehicles already on the road at minimum additional cost. The differences compared to conventional fuel delivery systems are discussed as follows:

A. Install at least one fuel by-pass passage from the fuel line including the outlet of fuel pump to fuel tank (including the inlet of fuel pump). The structure as shown in Fig. 1 has only one fuel by-pass line, and the structure in Fig. 2 has a fuel by-pass line and a fuel-return line. Both by-pass passages may be installed some distance away from engine to avoid returning of excess fuel being heated by hot engine. Fuel by-pass and fuel return lines may be installed in the fuel tank, in the fuel pump module, or may be integrated in the fuel pump design.

B. Fuel-Return line is normally open. It creates a normally open **fuel recirculation loop.** Thus, it stabilizes fuel pump operation and provides a stable fuel pressure at the main fuel line. Fuel injectors see plenty of fuel at a constant stable pressure **without continuously pumping excess pressurized fuel to the fuel injectors**. Thus, it minimizes the need to install a hot fuel return passage from the engine.

C. The control of the by-pass line(s) is **binary**. The amount of fuel flow in each line can be pre-selected and it is quick and much simpler to obtain the desired fuel pressure. The response time of pressure changes is **instantaneous**–an intrinsic property of hydraulics. For an engine running at 6,000 rpm, the word "instantaneously" means the effect of pressure switching can be realized to the entire fuel line in just a few strokes maximum.

D. Fuel pump is running at a **constant** pre-determined speed. Opening and closing the Fuel By-Pass creates two pressure states. The higher-pressure state is for normal and highway driving (speed faster than 25 ~ 30 MPH). The lower-pressure state is for idling and for city driving (speed less than 30 MPH). The overlapping region, which delivers the same amount of fuel injected per pulse between two pressure states, and the characteristics of quick changing over between pressure states make the transition smooth to drivers (like gear changes in automatic transmission).

E. Anytime the gas pedal is released in city driving (assuming minimum pulse width at 2 milliseconds), there is fuel saving of 20 ~ 25% per pulse as shown in Fig. 4. When the engine reaches equilibrium, the fuel consumption rate will be reduced by 35 ~ 45 %. (Note: $Q_i \sim q_i^2$). Vehicle seldom drives at a constant speed in the city for long. All of these added up to a significant fuel saving in city driving. The fuel saving can be quantified by measuring the idling speed. A reduction from 650 rpm today to about 500 rpm means a 40 % fuel saving when idling, or about 40% auto exhaust reduction. Implementing TMC modification structure and methods may achieve today what

California Air Resources Board would like to impose to automakers in 2009 at a minimum additional cost.

F. Fuel-Return may be closed on-demand for a short duration to create a 3rd highest-pressure state. For example, if the 3rd highest pressure is 40% higher than the normal high pressure, a 230 HP engine will deliver 320 HP power momentarily for a short duration. That will reduce the time (from zero to 60 MPH) from 8.0 sec to 6.8 sec. It is activated together with feeding maximum air supply from accessories, when the driver has urgent need to accelerate with extra power and if the engine is not overheating. A detailed flow chart is shown in Fig. 6.

G. Similarly, momentarily closing fuel-return will provide the highest fuel pressure and deliver extra amount of fuel per pulse needed to start a direct injection engine.

CONCLUSION

With the unprecedented demand of energy today, using energy wisely may be a good practice to prolong the life of the steady diminishing oil reserve underground. EPA has stated that transportation exhaust contributes about one third of the greenhouse effect. Effort in fuel waste reduction will save fuel in city driving and reduce auto exhaust, which helps to provide cleaner air in metropolitan areas.

The fuel system developed at TMC uses today's engine technology, but adds one or more fuel by-pass lines with connections from the main fuel line to the fuel tank. Fuel pump is running at a constant speed for stability and predictability. All but one of the by-pass lines must have fuel by-pass controls capable of essentially instantaneously changing pressure state (from open to closed or vice versa). Thus, it greatly increases the fuel injection dynamic range.

When the system operates in city driving mode, there is fuel saving of about 30 – 35 %. That improves city-driving mileage, and reduces auto exhaust by about 30 – 35 %, which may achieve today what California Air Resources Board would like to impose to automakers in 2009.

When the driver has urgent need of power, the system can instantly deliver a burst of high power for acceleration momentarily, (for example, a 230 HP engine is capable of delivering 320 HP power instantaneously for a short duration, if the system is switched to the 3rd highest pressure state). The feature of superpower on-demand instantaneously will attract performance oriented and younger generation auto buyers to increase the market share of the automaker.

TMC Co. Document No.: #TMC-FIS-005 Figures 1 – 6

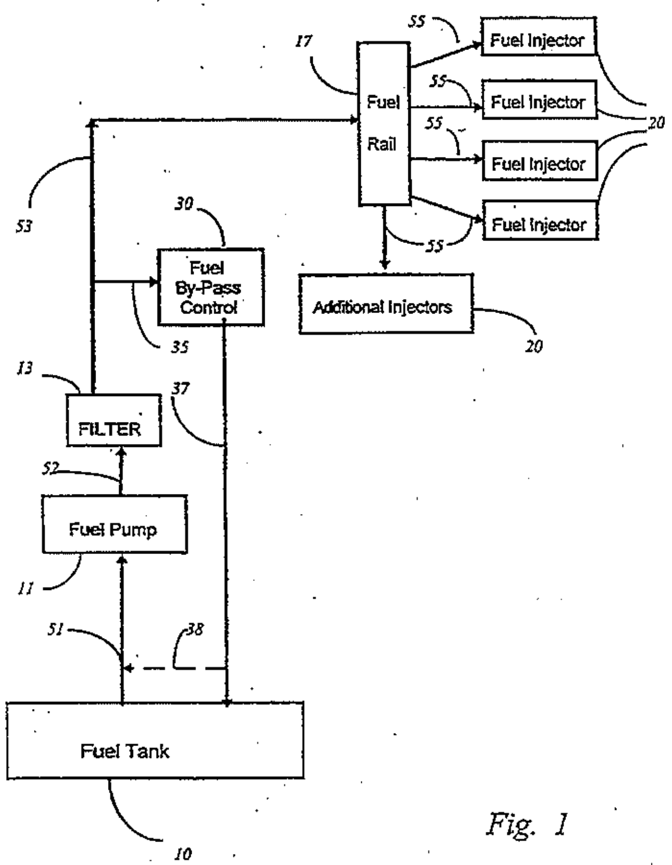


Fig. 1

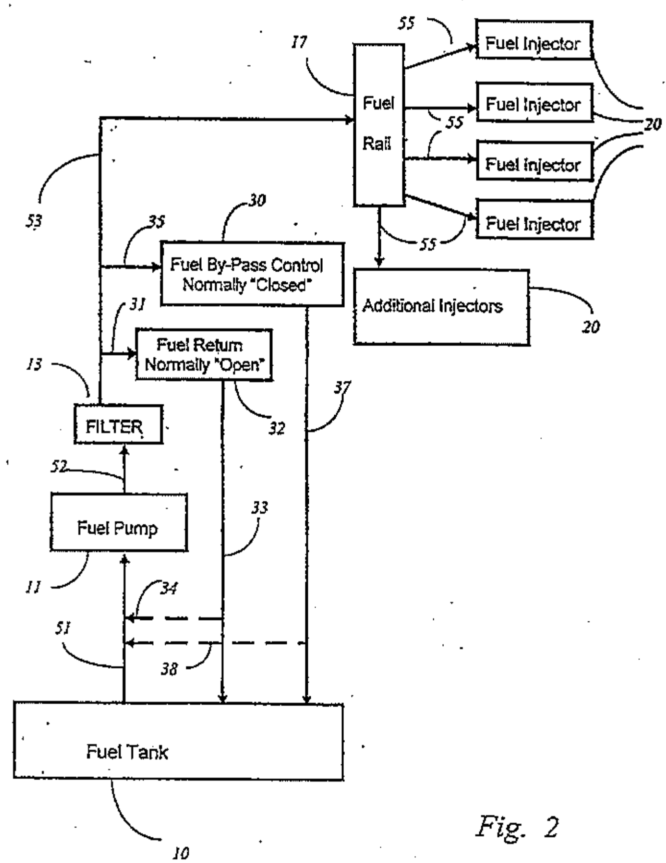


Fig. 2

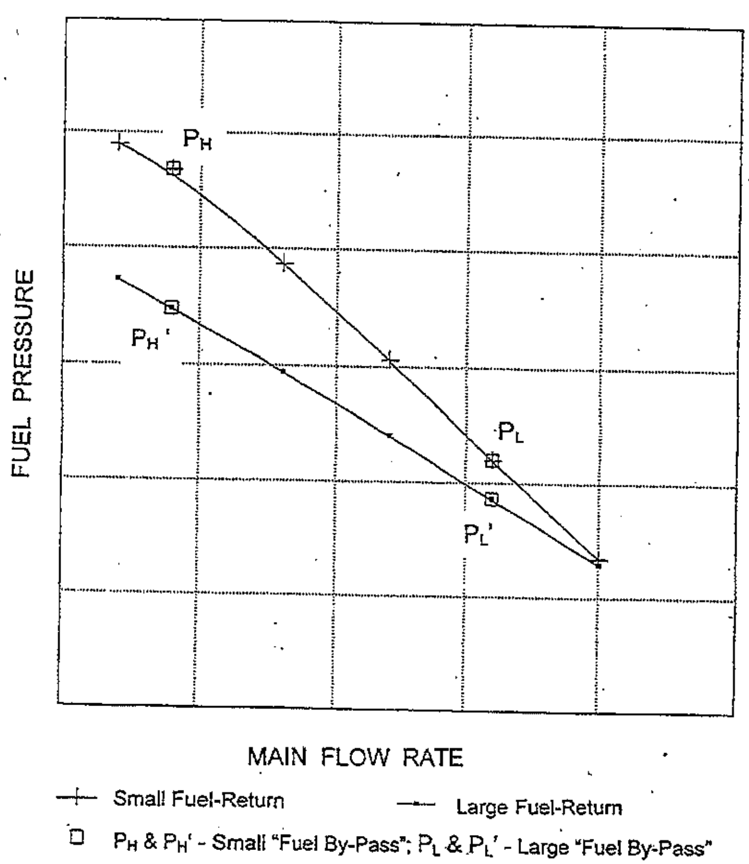
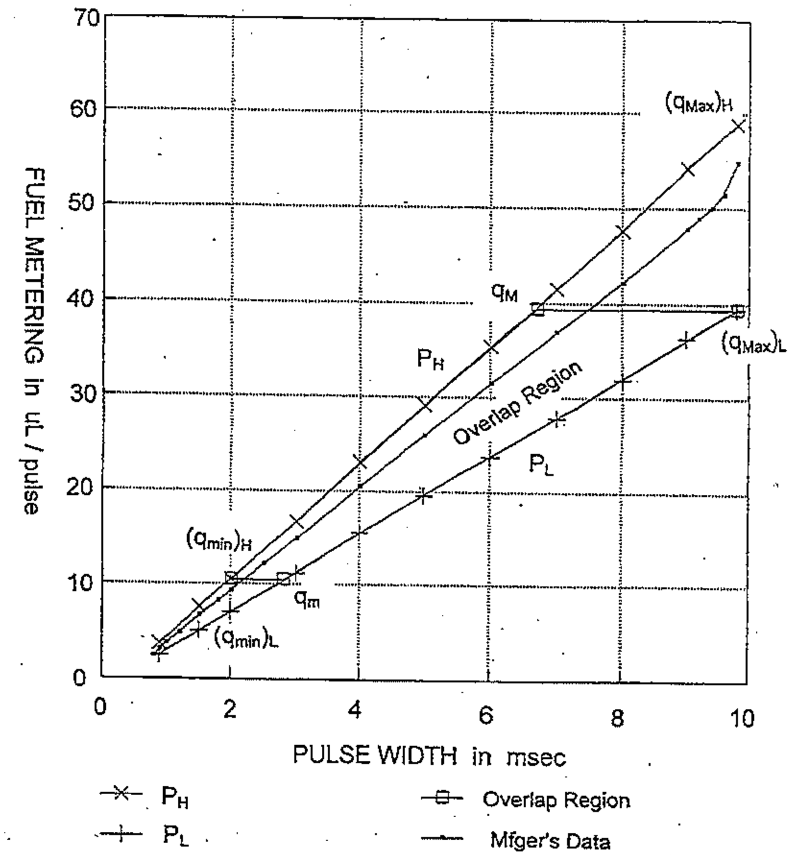
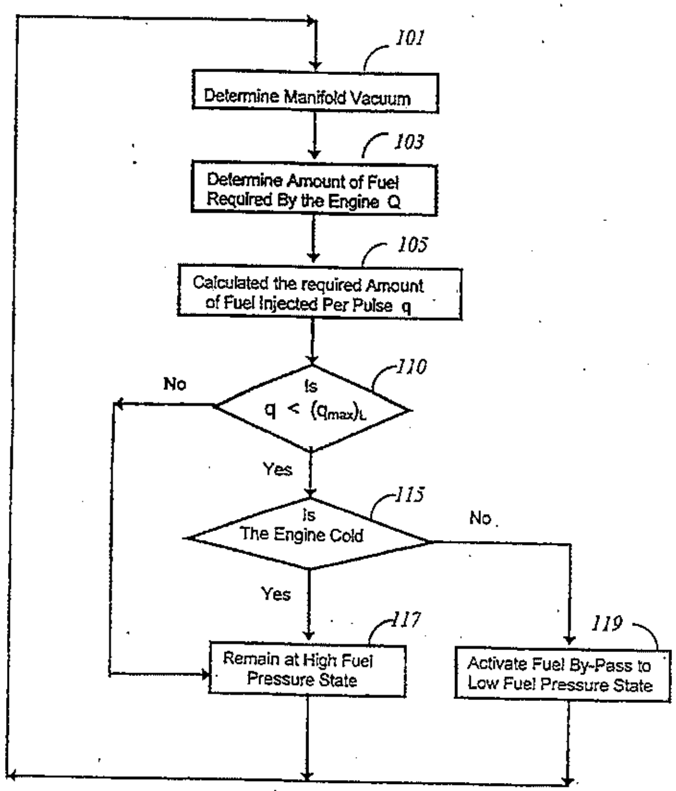


Fig. 3



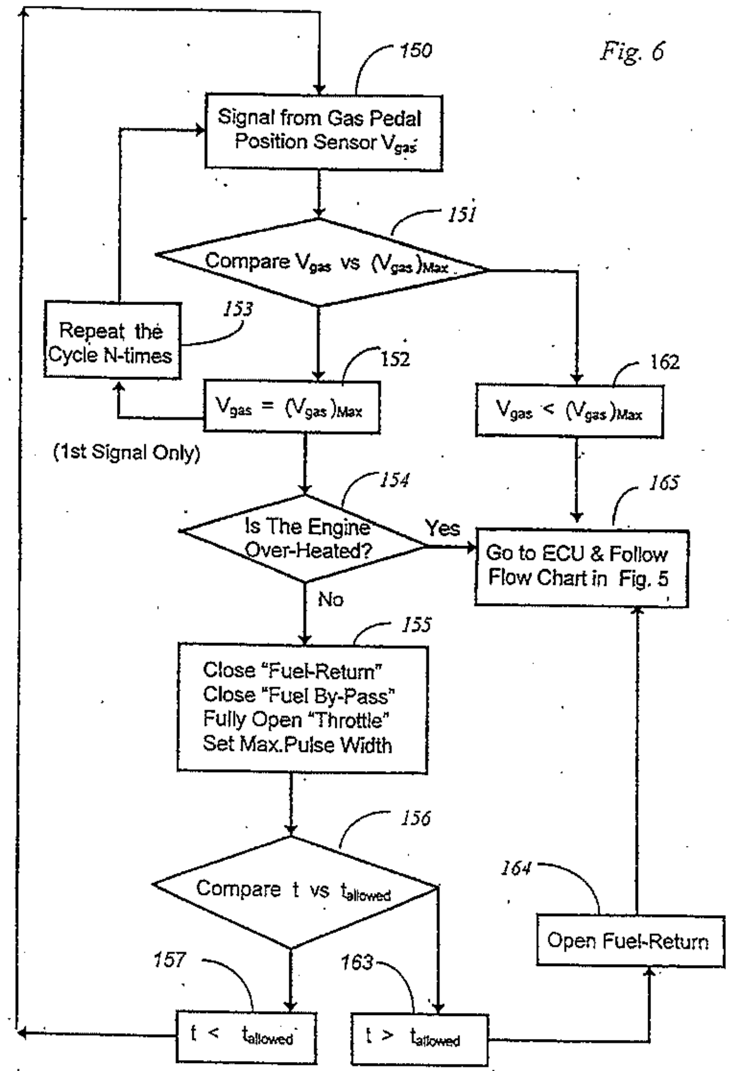
Data From An Injector Manufacturer

Fig. 4



101
Determine Manifold Vacuum
103
Determine Amount of Fuel Required By the Engine Q
105
Calculated the required Amount of Fuel Injected Per Pulse q
110
Is q < $(q_{max})_L$
No
Yes
115
Is The Engine Cold
No
Yes
117
Remain at High Fuel Pressure State
119
Activate Fuel By-Pass to Low Fuel Pressure State

Fig. 5



150
Signal from Gas Pedal Position Sensor V_{gas}
151
Compare V_{gas} vs $(V_{gas})_{Max}$
153
Repeat the Cycle N-times
152
V_{gas} = $(V_{gas})_{Max}$
162
V_{gas} < $(V_{gas})_{Max}$
(1st Signal Only)
154
Is The Engine Over-Heated?
Yes
No
165
Go to ECU & Follow Flow Chart in Fig. 5
155
Close "Fuel-Return"
Close "Fuel By-Pass"
Fully Open "Throttle"
Set Max.Pulse Width
156
Compare t vs $t_{allowed}$
164
Open Fuel-Return
157
163
t < $t_{allowed}$
t > $t_{allowed}$

Fig. 6

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Subject: Your e-mail to Mr. Graham Hoare dated March 17, 2005 regarding Fuel Injection Fuel System Developed at TMC (Document No.: #TMC-FIJ-005)

Date: Thu, 24 Mar 2005 15:24:13 -0500

From: "Bhavsar, Chinu (C.P.)" <cbhavsar@ford.com> View Contact Details Add Mobile Alert

To: tmccompany@yahoo.com

CC: "Popp, Jesse (J.)" <jpopp1@ford.com>, "Soltis, Mike (M.W.)" <msoltis@ford.com>, "Hoare, Graham (R.)" <ghoare2@ford.com>, "Mickel, Lori (L.L.)" <lmickel@ford.com>, "Cowley, Mike (M.D.)" <mcowley@ford.com>, "Gray, Chuck (C.E.)" <cgray5@ford.com>, "Hinds, Brett (B.)" <bhinds@ford.com>

Dear Mr. Hou,
Mr. Mike Soltis, Manager, Fuel Systems engineering is an expert in the fuel system control area and he can review/assess your proposal. As we discussed today, you must provide us a signed ford Confidential Disclosure Waiver (attached) before we can respond to your request.

<<waiver form.doc>>

You should follow the procedures outlines at:

Consumer Innovation Office
PO Box 6234
Dearborn, Michigan 48121-6234
Phone/Fax: 313/322-6814
Email: newideas@ford.com
Website: www.fordnewideas.com

Chinu Bhavsar
Sr. Staff Technical Specialist
Powertrain Research & Advanced Engineering
Ford Motor Company
760 Town Center Drive, FPCB, MD#32
Dearborn, Mi 48126-2720
U.S.A
Tel: 313-337-5214
Fax: 313-323-1568

,Brett, Chinu
.Can you pls look at and prepare a response

Thanks

Graham

-----Original Message-----
[mailto:tmccompany@yahoo.com] .From: S. L. Hou, TMC Co
Sent: Thursday, March 17, 2005 3:35 PM
(.To: Hoare, Graham (R
(Subject: Fuel Injection Fuel System Developed at TMC (Document No.: #TMC-FIJ-005

:Dear Mr. Hoare

Thank you for asking Lori to inform me to send the material by e-mail. I am attaching the Document No.: #TMC-FIJ-005 for your review. Six charts (or Figs. 1â€" 6) can not be sent by e-mail. Hence, the figures are sent by FAX to: 313-337-3502. The materials were basically the same as that discussed with Chris Woodring by phone on December 7, 2004.

TMC seeks licensing to an auto or OEM system/parts manufacturer. I will be in Detroit for the SAE 2005 World Congress from April 10 â€" 15, 2005. I would appreciate very much if we have a chance to meet. Please let me know the best time for us to get together.
Regards,

S. L. Hou, TMC Co.

Attachment: Document: #TMC-FIJ-005
(Text portion only 6 pages)
6 Figures to be sent by FAX to
313-337-3502

Attachments

Files:

waiver_form.doc (11k) [Preview] Scan and Save to Computer

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TMC Co.

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TMC Company
P.O. Box 423, Wayne, PA 19087-0423, USA
Tel: 610-964-8862 Fax: 610-254-0186

DATE:	March 25, 2005	REF:	
TO:	Chinu Bhavsar, Powertrain Research & Advanced Engineering, Ford Motor Company, 760 Town Center Drive, Dearborn, MI 48126-2720		
FAX:	313-323-1568	TEL:	313-337-5214
CC:	Graham Hoare, Director, Powertrain	FAX:	313-337-3502
FROM:	S. L. Hou, President, TMC Co.		
RE:	Confidential Disclosure Waiver		

MESSAGE:

Dear Mr. Bhavsar:

Thank you for your e-mail and the attached Confidential Disclosure Waiver. I have discussed with my attorney and agreed to sign the Waiver document, which is attached in this FAX letter.

Per your introduction, I will be glad to talk with Mr. Mike Soltis, Manager of Fuel Systems Engineering on technical matters, and look forward to a meeting with Mr. Hoare on potential licensing arrangement. Best regards,

Sincerely yours,

S. L. Hou

S. L. Hou, President
TMC Company

Attachment:	Confidential Disclosure Waiver	1	page
Total Number of Pages (including this page):		2	pages

CONFIDENTIAL DISCLOSURE WAIVER

The undersigned represents that he/she now has certain suggestions, inventions and/or ideas and may in the future have other suggestions, inventions and/or ideas (hereinafter referred to as "suggestions") and desires to interest Ford Motor Company and its subsidiaries in the merits of such suggestions. The undersigned acknowledges that Ford Motor Company and its subsidiaries cannot receive such suggestions in confidence and will consent to the disclosure thereof to their representatives only under the conditions hereinafter set forth, and not otherwise.

FIRST: All rights and remedies of the undersigned (and principals, if any, of the undersigned) arising out of the disclosure of such suggestions to, or the use thereof by Ford Motor Company, its subsidiaries or any of their representatives, shall be limited to such rights and remedies as may now or in the future be accorded under United States or foreign patents, trademarks, or copyrights.

SECOND: All other claims of any nature whatever arising out of any disclosure of the undersigned to Ford Motor Company and its subsidiaries are hereby waived.

Signature: S. L. Hou

Name: Shou L. Hou

Address: TMC Co., P.O. Box 423
Wayne, PA 19087-0423

Witnessed: Catherine Tung

Date: March 25, 2005

Authorized Representative: S. L. Hou, President, TMC Co.
(Company Name)

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Subject:	RE: Unable to send Waiver Document By FAX
Date:	Thu, 31 Mar 2005 08:53:13 -0500
From:	"Bhavsar, Chinu (C.P.)" <cbhavsar@ford.com> View Contact Details
To:	"S. L. Hou, TMC Co." <tmccompany@yahoo.com>
CC:	"Mickel, Lori (L.L.)" <lmickel@ford.com>

Thanks. Your inquiry has been forwarded to our fuel system expert Mr. Mike Soltis. He will advise you of his assessment of the TMC fuel system concept.

Mike Soltis, Mgr.
Fuel Systems Engineering.
(313-322-5477)
-337-
MSoltis@Ford.com.

Chinu Bhavsar
Sr. Staff Technical Specialist
Powertrain Research & Advanced Engineering
Ford Motor Company
760 Town Center Drive, FPCB, MD #32
Dearborn, Mi 48126-2720
U.S.A
Tel: 313-337-5214
Fax: 313-323-1568

-----Original Message-----
From: S. L. Hou, TMC Co. [mailto:tmccompany@yahoo.com]
Sent: Wednesday, March 30, 2005 5:20 PM
To: Bhavsar, Chinu (C.P.)
Subject: RE: Unable to send Waiver Document By FAX

Dear Mr. Bhavsar:

Document already sent by FAX to Mr. Graham Hoare at 313-337-3502. Please get a copy from Mr. Hoare's Administrative Assistance, unless you want me to re-send the document again. Regards,

S. L. Hou, TMC Co.

--- "Bhavsar, Chinu (C.P.)" <cbhavsar@ford.com> wrote:

> Please try 1-313-248-8015 My fax machnine is out of
> order at this time.
> Jesse,
> I will send you a copy of the CDW
> Chinu Bhavsar
> Sr. Staff Technical Specialist
> Powertran Research & Advanced Engineering
> Ford Motor Company
> 760 Town Center Drive, FPCB, MD#32
> Dearborn, Mi 48126-2720
> U.S.A
> Tel: 313-337-5214
> Fax: 313-323-1568
>
>
> -----Original Message-----
> From: S. L. Hou, TMC Co.
> [mailto:tmccompany@yahoo.com]
> Sent: Tuesday, March 29, 2005 12:04 PM
> To: Bhavsar, Chinu (C.P.)
> Cc: Hoare, Graham (R.)
> Subject: Unable to send Waiver Document By FAX
>
>
> Dear Mr. Bhavsar:
>
> It was my pleasure talking with you by phone on
> 3/24/05. However, I was unable to send the Waiver
> Form
> by FAX to 313-323-1568 as stated in your e-mail
> since
> last Friday (3/25/05). The document is finally sent
> by
> FAX to Mr. Graham Hoare @ 313-337-3502 this morning.

>
> Please check into this matter and forward the
> document
> to those at Ford Motor Company who need to know.
> Best
> regards,
>
> S. L. Hou, President, TMC Co.
>
>
>

→ Chiu
Can you please work directly with Mr Hou to close this out
Thky
Carl
Pls cl by 7/31

TMC Co. **VIA FAX TO: 313-337-3502**

July 20, 2005

Mr. Graham Hoare, Director of Powertrain
Global Core Engineering
Ford Motor Company
760 Town Center Drive
Dearborn, Michigan 48126

Dear Mr. Hoare:

It was my pleasure talking with you by phone on June 14, 2005. Thanks for confirming some of the features of TMC proposed improvement system through your test, which included quick response time and eliminating at least one of the pressure regulators. You promised to send me the evaluation comment by your engineering expert and a discussion by phone before sending me any proposal. The evaluation comment will be useful because your expert and I may overlook and misinterpret some features.

Thky
C

The technical document (#TMC-FIS-005 patent pending) was sent to you by e-mail and six figures by FAX on March 17, 2005. The document stated that almost any fuel system can be improved by creating fuel by-passes from main fuel line, away from fuel rail including outlet of fuel pump, to fuel tank. Using binary controlled valve on at least one Fuel-By-Pass paths allows quick response, increases fuel injection dynamic range, and solves problems typically related to insufficient fuel supply to fuel injectors when the driver has a need for a quick response.

The upgrade can improve Ford fuel injection system without changing your basic design. The cost of electromagnetic valves is offset by the cost of eliminating at least one pressure regulator. The up-graded system will have the following features:

- Reduce auto exhaust by 30% ~ 40% in city driving which may fulfill the regulations CA Air Resources Board will impose in 2009 at practically little additional cost.
- Enter superhighway from on-ramp at low speed with no hesitation. And
- Instantaneously deliver extra maximum power on-demand to improve its performance. That will attract performance oriented auto buyers to expand your market share.

For your information, at least five system/parts manufacturers including Robert Bosch GmbH and TI Automotive have signed Confidential Agreement prepared by TMC. TMC would like to license the invention to Ford Motor Company. I look forward to a meeting with you.

Sincerely yours,

S. L. Hou

S. L. Hou, President
TMC Company

TMC Company, P.O. Box 423, Wayne, PA 19087-0423 Tel: 610-964-8862 Fax: 610-254-0186

Ford Motor Company

Powertrain Research & Advanced Engineering
760 Town Center Drive, MD #32
Dearborn, Michigan 48216

July 28, 2005

TMC Company
P. O. Box 423
Wayne, PA 19087-0423
Attn: Dr. S. I. Hou

Subject: TMC fuel system document no. TMC-FIJ-005

Dear Dr. Hou,

This letter is in response to your July 20th letter to Mr. Graham Hoare.

Our fuel supply system expert Mr. Mike Soltis has reviewed the TMC concept and concluded that Ford Motor Company is not interested in pursuing it.

We wish you the best in your discussions with the suppliers you mentioned in your letter. I think it is a good idea to have a well established fuel system supplier do a business case study, before presenting a new concept to an OEM.

Regardless of our response, we appreciate your input and your enthusiasm for Ford Motor Company and our products.

Thank you.

Sincerely,

Chinu Bhavsar

Chinu Bhavsar
Sr. Staff Technical Specialist
Powertrain Research & Advanced Engineering
Ford Motor Company
Tel: 313-337-5214
Fax: 313-~~323-1568~~ 248-8015

Attachment: TMC Letter dated July 20, 2005

cc: Graham Hoare
Mike Soltis

TMC Co.

March 10, 2008

Barb Samardzich
Vice President, PowerTrain
Product Development Center
Ford Motor Company
21175 Oakwood Boulevard
Dearborn, MI 48124

RE: Improved Fuel Injection System Developed at TMC

Dear Barb Samardzich:

TMC appreciates an opportunity if Ford Motor Company will license the improved fuel injection fuel delivery system developed at TMC. US Patent 7,318,414 has just been granted to TMC on January 15, 2008. The system has at least one fuel by-pass to control fuel pressure off-line with a quick response. Using the system allows most vehicles to achieve high performance in a cost effective manner without redesigning its engine.

For example, a vehicle with a 230 HP engine for highway driving may perform like a 75 HP to save fuel in city driving. That will close the gap by 1/3 between city driving and highway driving mileages to save fuel in city driving. The vehicle can return to its full power instantly as needed for highway driving without feeling the pressure switching and for quick acceleration.

If the driver desperately needs power, the same engine with air accessories may delivery a burst of super power at 320HP for a sport-car-like performance without hesitation. Combined with stylish model design and electronic control already done, such a vehicle will attract many performance oriented car buyers who may also appreciate a better city driving mileage. That may improve Ford market share against competitions.

Supporting materials are enclosed for your review. Please forward copies as you see fit to related Ford operations for consideration. I look forward to a positive response from Ford.

Sincerely yours,

S. L. Hou

Shou L. Hou, President

Attachments: US Patent 7,318,414
Remarks of US Patent 7,318,414
Biography

cc: Dan Kapp, Director of PowerTrain Research

TMC COMPANY, P.O.BOX 423, WAYNE, PA 19087-0423
TEL: (610) 964-8862 FAX: (610) 254-0186

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Barb Samardzich, VP PowerTrain
(Please Print Clearly)
Ford Motor Co., 21175 Oakwood Blvd
Blvd, Dearborn, MI 48124

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PS Form 152, May 2002 (See Reverse)

March 10, 2008

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Subject: RE: Improved Fuel Injection System Developed At TMC

Date: Fri, 25 Apr 2008 13:31:28 -0400

From: "Samardzich, Barb (B.J.)" <bsamardz@ford.com> View Contact Details Add Mobile Alert

To: "S. Hou" <slhou@tmc-co.us>

CC: "Kapp, Dan (D.R.)" <dkapp1@ford.com>

Thanks, I forwarded your information to our advanced group - Dan Kapp. He would be the right one to follow up with.

Regards,

Barb Samardzich
Vice President, Powertrain Product Development
PDC-DC, MD 504, Phone: 313.62.16000
Assistant: Linda Isakson, 313-62-16222

From: S. Hou [mailto:slhou@tmc-co.us]
Sent: Friday, April 25, 2008 1:23 PM
To: Samardzich, Barb (B.J.)
Subject: Improved Fuel Injection System Developed At TMC

Dear Dr. Samardzich:

I trust that you enjoyed your recent trip to UK and the exceptional progress of 1Q2008 sales at Ford.

It has been over a month since you received materials from TMC. May I offer any help to further our discussion? Please let me know the best time for me to contact you by phone. Regards,

S. L. Hou, President, TMC Co.
E-Mail: slhou@tmc-co.us
Tel: 610-964-8862
Fax: 610-254-0186

Subject: RE: Improved Fuel Injection System Developed At TMC
Date: Tue, 29 Apr 2008 14:49:05 -0400
From: "Kapp, Dan (D.R.)" <dkapp1@ford.com> View Contact Details Add Mobile Alert
To: "S. Hou" <slhou@tmc-co.us>
CC: "Samardzich, Barb (B.J.)" <bsamardz@ford.com>, "Krause, Edward (E.K.)" <ekrause3@ford.com>

Thank you for your interest in Ford. I have the material you submitted to Barb Samardzich. Typically, our process for receiving new ideas from the outside is to refer submitters to the website below to provide a non-confidential description of the idea for our technical assessment and ultimately a signed non-disclosure agreement. From the information you have already provided, I will have my technical experts do an assessment and give you some feedback relative to our interest to save you that step but any further discussion would require the signed NDA.

http://fordnewideas.com/main/home.html

Dan Kapp
Director, PTRA
Phone: 313-337-6554 / Fax 313-337-3502

From: S. Hou [mailto:slhou@tmc-co.us]
Sent: Monday, April 28, 2008 2:04 PM
To: Kapp, Dan (D.R.)
Cc: Samardzich, Barb (B.J.)
Subject: Improved Fuel Injection System Developed At TMC

Dear Mr. Kapp:

Barb Samardzich has indicated in her e-mail that she has forwarded my information to you for consideration.

It has been over a month since Ford has received materials from TMC. May I offer any help to further our discussion? Please let me know the best time for me to contact you by phone. Regards,

S. L. Hou, President, TMC Co.
E-Mail: slhou@tmc-co.us
Tel: 610-964-8862
Fax: 610-254-0186

Powertrain Research and Advanced
2101 Village Road
Dearborn, MI 48121

June 10, 2008

To: S.L. Hou, Ph.D., President
TMC Co.

Cc: Barb Samardzich, Vice President Powertrain Engineering
Ed Krause, External Alliances Manager

Subject: Constant-Speed Multi-Pressure Fuel Injection System for Internal Combustion Engine

I have had the Constant-Speed Multi-Pressure Fuel Injection System for Internal Combustion Engine material that you sent to Ford Motor Company reviewed by our fuel system technical specialist and have concluded that Ford Motor Company is not interested in participating in a program to develop the system. Our conclusion is that a fuel system of this concept would not achieve efficiencies greater than our existing engines.

Specific to the fuel system patent, items of concern to us include the following:

- The "claim" states that operating at low pressure state is capable of 30% fuel savings in city driving when the gas pedal is released including idle. So, in reality, this 30% reduction in fuel consumption is only realized at tip out or idle only conditions and not during any other drive cycle. The question is how much does the fuel consumed at idle contribute to the over fuel consumption. The answer is: a fraction of the overall consumption providing the "claim" works as described in the patent. I could find no reference to an actual vehicle that has been modified with this system and proven to provide the actual benefits of this "claim".

- The author fails to recognize that the latest generation of fuel injector function has a greater dynamic range than their predecessors and that injector pulse width (PW) can be adjusted within milliseconds to provide stable operation at idle conditions. This is confirmed during engine mapping and development as idle operation must run at Stoich air/fuel thereby ensuring the proper fuel mass is delivered. This is improved further via strategy and controls by simply reducing the voltage to the pump if lower system pressure is desired and basically accomplishes the same results as the "claim" provided one accepts the results offered in the patent.

In response to your May 29, 2008 letter to me suggesting the installation of smaller engines capable of a "burst of super power as large as that of the larger engine", the ability to deliver the additional fuel flow through your concept means nothing without the corresponding means (pressure charging) to deliver the additional airflow which is the bigger challenge. However, it is conceptually very similar to Ford's well publicized technical strategy called "EcoBoost" which will employ significantly "downsized" engines with equal or better performance through combining turbocharging with gasoline direct injection.

Again, thank you for your interest in Ford.

Dan Kapp

Dan Kapp, Director,
Powertrain Research & Advanced

TMC Co.

July 8, 2008

Mr. Dan Kapp, Director
Powertrain Research & Advanced
Ford Motor Company
2101 Village Road
Dearborn, MI 48121

cc: Barb Samardizch, V.P., Powertrain Product Development
Ed Krause, External Alliances Manager

RE: Response to Your Letter Dated June 10, 2008 on U.S. Patent 7,318,414

Dear Mr. Kapp:

Thank you for your letter dated June 10, 2008 (mailed on 6/16/2008). The letter includes the feedback by your fuel system specialist on TMC documents sent to Ford Motor Company. The following are remarks in regards to specific items of your concerns, which may have been overlooked:

- **Improved Fuel Economy & Reduced Emissions in City Driving:** In city driving, speed limit is only 35 MPH and stop-and-go is frequent. Driver usually releases the gas pedal and let the vehicle coasting after a short acceleration. Typical city driving mileage is about 30% less than highway driving mileage even using today's improved injectors. The difference (or gap) is caused by the minute injected fuel pulses at minimum pulse width after releasing gas pedal (including idle) just to keep engine running.

  The claimed system (configurations 2, 3, & 4) opens the normally closed binary valve in fuel by-pass path with flow restraint in city driving mode. That instantly sets fuel pressure at P_L. When gas pedal is released, the minute injected fuel pulses at the same minimum pulse width $(q_i)_L$ can be 25% smaller than $(q_i)_H$ under higher pressure P_H . Engine speed ω will be reduced to its new slower idle speed faster because the torque is smaller. Fuel consumption rate during coasting $(Q_i)_L$ is proportional to $(q_i)_L\omega$. Thus immediately after releasing gas pedal, coasting fuel consumption rate $(Q_i)_L$ will be 25% less, and approaches 42% less when engine reaches idle speed. On the average, the system is capable of reducing the gap by 1/3 between city driving mileage and highway driving mileage. *That is 10% overall improved fuel economy in city driving and 10% reduced emissions in metropolitan areas.* All claims under configurations 2, 3, & 4 stated that when pressure is set at P_L , there is improved fuel economy and reduced emissions in city driving when *gas pedal is released including idle* (Claims 26, 28, 31, 34, and 44).

- **Rapid pressure switching** is one of the key features of this patent that allows the vehicle to operate using pulse width modulation under different assigned pressure states, and allows instant pressure switching to widen fuel injection dynamic ranges. Because fuel pump has a large inductive load and big rotor inertia, changing applied voltage to fuel pump does not stabilize fuel pressure for at least large fractions of a second. That will cause hesitation when driver has urgent need of extra power from stand still (column 3, lines 32 – 50).

Facts About The Speed of Responses: The internal clock in the embedded micro-controller is operating at 10^7 to 10^8 Hz. However, executing a line of instruction in program language takes about 1 microsecond. Opening and closing a fuel injector takes a little more than 1 millisecond. Engine stroke lasts about 5 milliseconds at 6,000 rpm. The effect of pressure change using binary control valve is about a few milliseconds, and the effect caused by pressure spike and multi-reflections of pressure waves will die off in just a few revolutions at 3,000 rpm. By adjusting pulse width during pressure switching, driver can have a smooth ride. Because fuel pump has a large inductive load and big rotor inertia, changing applied voltage to fuel pump does not stabilize fuel pressure for at least large fractions of a second.

- **Using Recirculating Loop to Stabilize Fuel Pressure:** All claims in configuration 1, 3 & 4 use at least one fuel recirculation loop to stabilize fuel pressure. In particular, claims 38, 40, 41, 42 (configuration 1) can be used to upgrade fuel systems currently in use and for new fuel system design to stabilize fuel pressure at low cost. The system can be produced consistently and cost effective in mass production environment.

- **Using Multi-Pressure Levels to Improve Fuel Economy & Reduce Emissions:** Claim 9 (configuration 3) is capable of instantly creating three stable fuel pressures, namely P_{H2} , P_{H1} , P_L , where $(P_{H2} > P_{H1} > P_L)$. Engine control module controls the opening of throttle valves and coordinates the operation of air accessories, like turbo charger, super charger, to supply adequate air in response to engine fuel demand and run at Stoich air/fuel. If the engine is designed for P_{H1} for better fuel economy, the system is still able to produce much higher power quickly at P_{H2} for performance during by-pass and speeding for a limited time period. In comparison with engines designed for P_{H2}, the system has the potential of 4% ~ 6% improved fuel economy and reduced emissions. Attached is a partial list of Ford light vehicles equipped with different engine sizes in the same model. The list (Model Year 2008 – "Fuel Economy Guide" published by EPA) reflects the statement above.

In conclusion, U.S. Patent 7,318,414 has disclosed several key features by adjusting fuel pressure in fuel system, which include improved fuel economy and reduced emissions to both highway driving and city driving, and more power on-demand with quick response at low cost. The features are unique to address the challenges facing auto industry today. TMC is not capable of supplying developed products as a tier one OEM supplier, but willing to license the patent to carmakers (including technical consultation if needed) so that the features can be incorporated into the design of fuel injection system for your engine against competitions. Several automakers in Japan have used brute force approach for improved fuel economy and reduced emissions in city driving with some success. Ford is the technology leader in automotive industry. I will be appreciative and greatly honored if Ford will license the technology and incorporate some features into your smart "EcoBoost" engine design. That will attract many car buyers and move closer to fulfill Government emissions and fuel economy requirements.

I look forward to hearing your positive reply.

Sincerely yours,

S. L. Hou. President, TMC Co.

Enclosure: A partial list of Ford light vehicles with different engine sizes in the same model.

FORD MOTOR COMPANY

Model	Transmission - Speed	Engine Size / Cylinder	City / Highway (MPG)
* Ranger Pickup 2WD	A - 5	2.3 L / 4	19 / 24
	A - 5	3.0 L / 6	15 / 20
	A - 5	4.0 L / 6	15 / 20
* Ranger Pickup 4WD	A - 5	3.0 L / 6	14 / 19
	A - 5	4.0 L / 6	14 / 17
* F-150 Pickup 2WD	A - 4	4.2 L / 6	14 / 19
	A - 4	4.6 L / 8	14 / 19
	A - 4	5.4 L / 8	13 / 17
* F-150 STX SE 2WD	A - 4	5.4 L / 8	14 / 19
* Fusion	A - 5	2.3 L / 4	20 / 28
	A - 6	3.0 L / 6	17 / 25
* Milan (Mercury)	A - 5	2.3 L / 4	20 / 28
	A - 6	3.0 L / 6	18 / 26
* Escape	A - 4	2.3 L / 4	20 / 26
	A - 4	3.0 L / 6	18 / 24
* Mustang	A - 5	4.0 L / 6	16 / 24
	A - 5	4.6 L / 8	15 / 22

References: Model Year 2008 "Fuel Economy Guide" published by EPA.

Powertrain Research and Advanced
2101 Village Road
Dearborn, MI 48121

August 20, 2008

To: S.L. Hou, Ph.D., President
TMC Co.

cc: Barb Samardzich, Vice President Powertrain Engineering
Ed Krause, External Alliances Manager

Subject: Response to your letter dated July 8, 2008

Dear Mr. Hou;

Thank you again for your interest in Ford. I am not going to debate the technical merits of your invention. Rather, I would challenge the basic premise upon which you build your fuel economy claims. The differences between city and highway fuel economy have virtually nothing to do with control of fuel, but rather are attributable to the fundamental physics of engine efficiency and the vehicle speed and load regimes of the respective cycles. Fueling errors would inhibit our ability to meet strict tailpipe emission standards long before they translated to a significant loss in fuel economy. Analytically, we can eliminate all fuel flow at decel and idle conditions to determine that represents about 7% of the total fuel consumed on the city cycle, so a 10% improvement claim by managing fuel delivery pressure does not seem credible. In addition, let's consider where Ford, and the rest of the industry, are headed with respect to engine technology and control enablers for improving fuel economy to consider the compatibility of your system:

- We already employ aggressive fuel shut-off at decel conditions which addresses a similar area of opportunity.
- As we move to direct injection, fuel pressure is varied and closely controlled but by the high pressure on-engine pump. Fuel delivery provides only a low pressure lift function.
- Longer term, and with direct injection as an enabler, engine-off at idle will be another trend.

Given the strategic technical direction that will address FE improvement opportunities in the same areas that your proposal targets and the concerns sighted above as to the potential benefit, there is no interest from our side to pursue. Again, thank you for your follow-up, but we have given this a thorough assessment.

Dan Kapp, Director,
Powertrain Research & Advanced