

Experimental investigation on a direct gasoline fuel injection (DGI) system with high turbulence fuel-air mixing and enhanced engine security measures

Md. Syed Ali Molla¹, Md. Shafiq Sayid², Md. Muhaiminul Hassan³ & Md. Al, Mamun³

¹ Dept. of M. E., Khulna University of Engineering & Technology (KUET), Bangladesh

² Motor Walla Ltd, USA

³ Ahsanullah University of Engineering and Technology

⁴ M.Sc. Eng student, BUET, Bangladesh

Email: mmsali03@yahoo.com, & pmsali@me.kuet.ac.bd , s.sayid@gmail.com, muhaiminul7@gmail.com

ABSTRACT

A Direct Gasoline Fuel (GDI) engine can provide fuel economy and higher engine efficiency. Harmful emissions levels can also be controlled accurately with the GDI system. These gains can be achieved by the precise control over the amount of fuel injection, proper fuel air mixing and injection timings which can be varied according to engine load and operating conditions. In addition, there are no throttling losses in some GDI engines, when compared to a conventional fuel injection system, which greatly improves efficiency, and reduces 'pumping losses' in engines without a throttle plate. The Direct Gasoline Injection (DGI) technologies have the advantages over manifold fuel injection system and port fuel injection system for maximum fuel economy, and thereby it can minimize environmental pollution at an accessible price by harnessing the DGI's inherent advantages. DGI-technologies deliver a 10~30 % improvement in fuel economy over a current other model engine, along with enhanced drivability. Though in the present model DGI system vehicles, fuel is injected at the end of compression stroke where fuel-air mixture get less opportunities of homogeneous mixing rather it burns like heterogeneous mixture like diesel engine when the tendency of formation pollution increases. Moreover high pressure injection system is required to inject gasoline fuel in compression stroke which increases the cost of fuel injection kits. But in this present research work, a different idea of direct gasoline fuel injection is used where fuel is injected in suction stroke inside the cylinder when low pressure and high turbulence prevail in air-fuel mixing. The fuel air mixture gets more opportunity of homogeneous mixing in suction and compression stroke unlike the presently used direct gasoline fuel injection system in SI engine. Thus pollution reduction potentials increases and low cost fuel injection can be used. Even TBI and PFI fuel injection kit can also be used with little or no modification. More over high coolant temperature and low oil pressure are the main causes of major failures in IC engine. This fuel injection system is designed and programmed with additional security measure to prevent engine from oil starvation and high engine coolant temperature. Thus this fuel injection system can not only reduce pollution reduction potentials and cost of fuel injection system but also it increases engine security measures.

Keywords: Direct gasoline fuel injection system (DGI), microcontroller, high turbulence, low pressure fuel injector.

1. Introduction

The construction of the carburetor is relatively simple and it has been used almost exclusively on gasoline engines in the past. However, in response to recent demands for cleaner exhaust emissions, more economical fuel consumption, and improved drivability, the carburetor now must be equipped with various compensating devices and it makes carburetor more complex. In place of carburetor, therefore, the injection system is used, assuring the proper air-fuel ratio to the cylinder by using electronic controlling devices in accordance with various driving conditions. Compared with throttle body (TBI) and port fuel injection (PFI) systems, direct gasoline injection system (DGI) is more difficult and expensive. But the payback for the added complexity is higher torque, dramatically reduced emissions and increased engine efficiency. This is possible as fuel can be injected in the exact quantity, time and location that it's demand by the engine.

Engines generate their worst emissions-just after cold-start. During warm-up of a DGI engine, a small shot of fuel is injected just before the exhaust valve opens. There's still enough heat and oxygen in the chamber for this charge to ignite, and the heat from that after burn gets the catalyst up to operating temperature just seconds after cold-start. The injectors are either open or closed, and pulsed as in a port-injection system (PFI). Since the fuel flows directly into the combustion chamber instead of impinging on the intake valve, the nozzle can be designed to form a "cloud" of fuel with a specific size and shape [1]. The DGI-technologies can deliver a 10~30 % improvement in fuel economy over a current EFI-engine, along with enhanced drivability [1]. The engine management system continually chooses among three combustion modes: ultra lean burn, stoichiometric and full power output. Each mode is characterized by the air fuel ratio. The stoichiometric air-fuel ratio for gasoline is 14.7:1 by weight (mass), but ultra lean mode can involve ratios as high as 25:1 (or even higher in some engines, for very limited periods). These mixtures are much leaner than in a

* Corresponding author. Tel.: +88-01714087350

E-mail address: mmsali03@yahoo.com : pmsali@me.kuet.ac.bd

conventional engine and reduce fuel consumption considerably [2].

The 1955 Mercedes-Benz 300SL, the first production sports car to use fuel injection, used direct injection. The Bosch fuel injectors were placed into the bores on the cylinder wall used by the spark plugs in other Mercedes-Benz six-cylinder engines (the spark plugs were relocated to the cylinder head). Later, more mainstream applications of fuel injection favored the less-expensive indirect injection methods. Toyota's D4 direct injection system first appeared on various Japanese market vehicles equipped with the SZ and NY engines [3-5]. Toyota later introduced its D4 system to European markets with the *IAZ-FSE* engine found in the 2001 Avenir [6] and US markets in 2005 with the *3GRE-FSE* engine found in the *Lexus GS 300*. Toyota's *2GR-FSE* V6 first found in the *Lexus IS 350* uses a more advanced direct injection system, which combines both direct and indirect injection using two fuel injectors per cylinder, a traditional port fuel injector (low pressure) and a direct fuel injector (high pressure) in a system known as D4-S [6].

Renault introduced the 2.0 IDE (Injection Directe Essence) [7], first on the Megane. Rather than following the lean burn approach in 1999. Renault's design uses high ratios of exhaust gas recirculation to improve economy at low engine loads, with direct injection allowing the fuel to be concentrated around the spark [8]. Later gasoline direct injection engines have been tuned and marketed for their high performance as well as increased fuel efficiency. PSA Peugeot Citroen, Hyundai, and Volvo entered into a development agreements and licensed Mitsubishi's GDI technology in 1999 [9-13]. The Mitsubishi engines were also produced in the NetCar factory and used in the 1.8 L Carisma and the GDI-powered Volvo S40/V40 models [14-15]. In 2002, the *Alfa Romeo 156* with a direct-injection engine, the *JTS* (Jet Thrust Stoichiometric) went on sale[16] and today the technology is used on almost every Alfa Romeo engine. Infiniti produced the M56 which includes DI. Motus Motorcycles is developing, with Katech Engines, a direct-injected V4 engine named the KMV4 as the powertrain for their MST Motorcycle. In 2011 the Hyundai Sonata 2011 model 1 came with GDI engines, including a turbo-charged 2.0-litre that produces 274 hp. Hyundai's Theta I-4 engine family is a proprietary design, engineered in Namyang, Korea and currently in production for applications all over the world [17]

M.M. Syed Ali et al. carried out experimental investigation in on direct fuel injection system in 2010 and found that fuel injection quantity can be varied with engine speed and load [18]. M. M. Syed Ali et al. also took research investigations [19-20] on single cylinder EFI System and 4 cylinder Port Fuel Injection System where fuel could be controlled according to engine demands.

M.M. Syed Ali also investigated with a different model for a low pressure DGI System instead of existing high

pressure DGI model considering several advantages. Instead of high pressure fuel injection system Low Pressure DGI System was modeled for a 4 cylinder SI engine where air fuel mixing gets high turbulence and long duration for air fuel mixing [5]. This can provide better fuel air mixing before combustion. The experimental investigation [21] showed fuel air ratio at different operating condition can be maintained to achieve high fuel economy and less pollution formation specially carbon monoxide (CO) and hydrocarbon (HC) pollutants.

2. Layout and components of a DGI system

The fuel delivery system incorporates the following components:

- (i) Fuel tank, (ii) Fuel pump (iii) Fuel filter (iv) Fuel delivery pipe (rail) (v) Pulsation damper (in many engines) (vi) Fuel injectors (vii) Cold start injectors (most engines) (viii) Fuel pressure regulator etc.

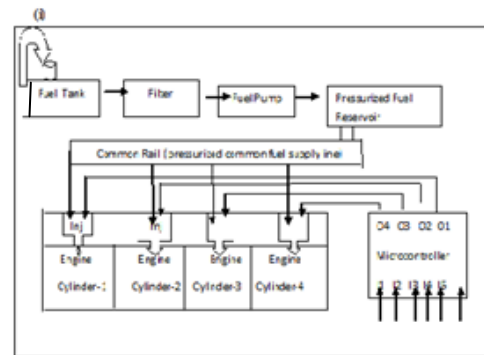
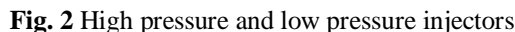


Fig. 1 Layout of the experimental setup

Usually fuel injection pressure in DGI system is nearly 40 times higher than the fuel injection pressure in EFI system. Fuel injection at low pressure is preferred considering several advantages in system. There are two types of electric fuel pump used in the EFI systems. The early conventional EFI system used an externally mounted in-line pump. These roller cells pumps incorporate an integral pressure pulse damper or silencer designed to smooth out pressure pulses and provide quiet operation. Later model engines utilize an in-tank pump integrated with the fuel sender unit. These turbine pumps operate with less discharge pulsation and run quieter than the in-line variety. In-tank pumps can be serviced by removing the fuel sender unit from the tank. In this case intake turbine pump has been selected and used.

Injector

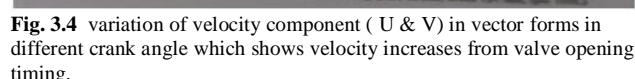
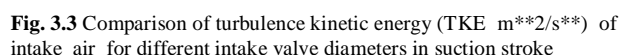
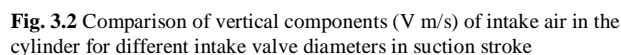
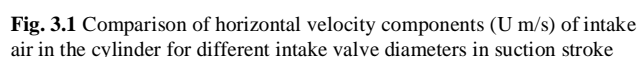
In a direct fuel injection engine, the fuel must be injected in a short period of time and at pressures at least 40 times higher than in port fuel injection [4].



In this investigation low pressure fuel injectors are taken considering fuel injection at low pressure inside the cylinder and availing high turbulence air-fuel mixing. This can enhance homogeneous air fuel mixture and can reduce CO and HC pollutions. More over the cost of fuel pump and injectors will be reduced considerably.

In this present design following additional considerations are taken unlike present DGI system.

In the presently used DGI fuel injection system, fuel is injected at the end of compression stroke using high pressure fuel pump and injectors. Cylinder air velocity, swirl, turbulent kinetic energy increases and decreases at different crank angles [5] and follows the different fluctuating patterns as shown in Figure 3.1 to Figure 3.5 as shown below .



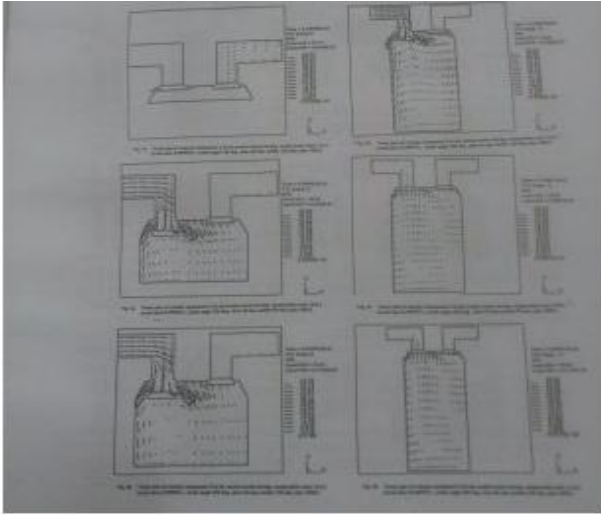


Fig. 3.4 variation of velocity component (U & V) in vector forms in different crank angle where velocity components (U&V) increases gradually from valve opening timing 180° (TDC) to 270° and then decreases till valve closing timing 360° (BDC) .

These variations of air velocity, swirl, turbulent kinetic energy does not help in air fuel mixing in the presently used DGI system. But these fluctuations help in better fuel air mixing and complete combustion in the model under investigations reducing the potential of the formation of CO, HC pollutants. But in the present DGI system, it get less time for fuel air mixing and provide heterogeneous mixture like diesel fuel injection. More over low pressure fuel injector and pump like TBI and PFI can be used. This reduces the cost of fuel injection system. Thus cost of fuel injection system, fuel economy and emission reduction potential will be improved.

3.2. Design considerations and program for microcontroller

A microcontroller has been built with an ATmega 8 IC for controlling device as depicted in figure 4. DGI system was designed for variable speed and variable load and other operating conditions of a real engine. The engine management system usually continually chooses among three combustion modes: ultra lean burn, stoichiometric, and full power output. Each mode is characterized by the air-fuel ratio. The stoichiometric air-fuel ratio for petrol (gasoline) is 14.7 to 1 by weight, but ultra lean mode can involve ratios as high as 25:1. These leaner mixtures of DGI system is much leaner than in a conventional engine, reduce fuel consumption [4].

In this design instead of three mode six modes of engine operation with specially, starting (choke circuit) idle circuit, slow speed circuit, medium speed circuit, high-speed circuit, acceleration circuit. In each running condition there is provision of extra fuel supply for high load and low load operation so that wide varying of fuel air ratio can be supplied keeping in conformity of engine operating conditions. Various types of sensors, ICs and transistors

are used to sense the speed and suction pressure and engine operating conditions

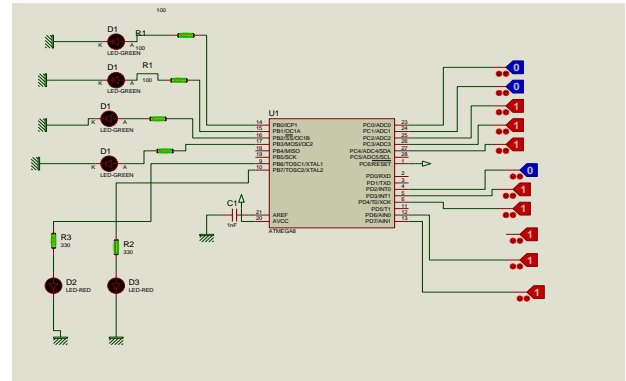


Fig. 4: Microcontroller IC and input output diagram.

An engine demand various quantity of air depending on load and speed. The intake air flow and air pressure represents the variation of load. The distributor of EFI and DGI systems have built in signaling system for engine rpm and crank angle position. Ne – signal and Ge-signal give engine rpm and crank angle position. Oxygen signal fitted in Catalytic converter give presence of oxygen in exhaust gas which in term give information to the engine that it is running with lean or rich or with optimum fuel air ratio. The program was made on the logics required for operating conditions of the engine. The air velocity and pressure in the intake manifold can determine the loading position in each mode. The Oxygen sensor gives the level of fuel air ratio.

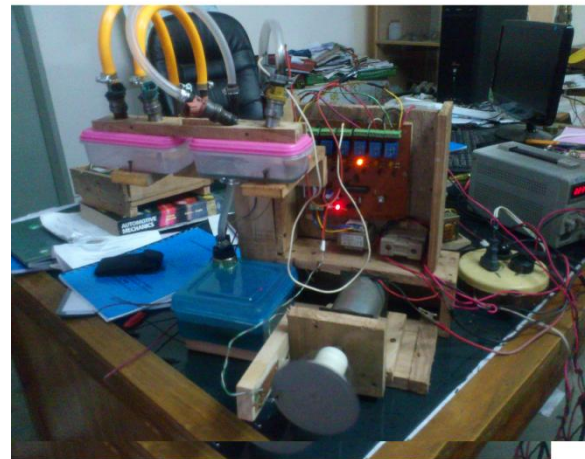


Fig. 5 Experimental setup for high turbulence DGI fuel injection system

All these parameter are set to the program to get required output signal for fuel flow injector. Before programming on a microcontroller based DGI system, the fuel air ratio required in all engine operating conditions like starting system (choke system), idle system, slow speed, medium speed, high speed system, acceleration system with variable engine load are considered accordingly the

required input are set to microcontroller. The output of microcontroller controls the injectors, where the fuel injection quantity varies depending on engine operating conditions.

4. Results & discussion

After completion of the experimental set-up (Fig. 5) of the fuel injection system, the performance of the direct gasoline fuel injection system was tested. The fuel injection quantity can be varied to any required quantity depending upon engine load and speed. Moreover the fuel injection is found to be stopped as soon as it receive signals from high coolant temperature and low oil pressure during engine operation. This will immediately stop the engine avoiding major damage of crankshaft, crankshaft bearing, piston and piston-rings etc. This module can be used in other model like EFI or Port Fuel Injection system vehicle with small modification. Carburetor vehicle with electronic distributor has the facility to give engine speed (rpm), crank angle position. In other word carburetor mounted vehicle with electronic distributor can be modified to this system where the amount of fuel to be supplied from injector to engine cylinder in all engine operation modes can be controlled by this microcontroller.

5. Conclusion

At the end, it may be concluded that

- (i) The microcontroller based Low pressure high turbulent direct fuel injection system is found to work properly.
- (ii) The model test showed that variable fuel injection quantity at different speed and load can be maintained.
- (iii) There more opportunity of homogeneous air-fuel inside the cylinder during high turbulence phase in suction and compression stroke. This can help to reduce the formation of carbon monoxide (CO) and hydrocarbon (HC) pollution during combustion of fuel- air mixture..
- (iv) The emission reduction potential is very high as fuel injection can be controlled depending upon the engine running condition.
- (v) Fuel delivery cost of module of DGI system is nearly 1500-2000 USD in US market but this microcontroller based module will be reduced
- (vi) The introduction of low pressure high turbulent direct gasoline fuel injection system will also reduce the cost of presently used high pressure direct fuel injection system.
- (vii) Introduction of oil pressure signal and temperature signal can give primary signals (alarm or red light) for low engine oil pressure ($P < 2$ bar) and high coolant temperature ($t > 85^{\circ}\text{C}$). At the predetermined low engine oil pressure ($P < 1.5$ bar) and coolant temperature ($t > 90^{\circ}\text{C}$) control signal will stop fuel injection to avoid major engine damages. Thus it can enhanced engine security significantly

Nomenclature

CO	Carbon monoxide pollutants
DGI	Direct gasoline fuel injection
EFI	Electronic fuel injection
HC	Hydrocarbon emissions
IC	Integrated circuit
LPHT	Low pressure high turbulence
PFI	Port fuel injection
TBI	Throttle body injection

References

- [1] W. H. Crouse and D. L. Anglin, "Automotive Mechanics", 10th revision/McGraw-Hill Book Company, USA
- [2] Fuel Systems at Sears® | *Sears.com*
- [3] 30_39-Jfl/"Y,,v" (PDF). Retrieved 2009-07-17.
- [4] www.Sears.com/Fuel-System- services
- [5] M.M. Syed Ali, M. Sapuan Salit, M. M. H. Megat Ahmad, W. Asrar, " Effects of intake valve diameter on suction air pressure and volumetric efficiency in a four stroke internal combustion engine" Suranaree Journal of Science and Technology, July-Sept. 2004,Thiland
- [6] "Improving the Environmental Performance of Internal Combustion Engines". *Toyota*.1999-02-22. Retrieved 2009-08-21.
- [7] Crouch, Jonathan. "Renault Megane Cabriolet 1997-2003". *uk.cars.yahoo.com*. Archived from the original on 2011-07-18. Retrieved 2012-06-21.
- [8] Wan, Mark (2000). "Lean Burn Engine". Autozine Technical School. Retrieved 2010-11-14.
- [9] Yamaguchi, Jack (2000-02-01). "Mitsubishi's new GDI applications". *Automotive Engineering International (highbeam)*. Retrieved 2013-09-09.
- [10] Beecham, Matthew (2007-12-07)."Research Analysis: a review of gasoline direct injection systems". *Just-Auto*. Retrieved 2013-09-09.
- [11] "Mitsubishi Motors and PSA Peugeot Citroen Reach Agreement on GDI Engine Technical Cooperation" (Press release). *Mitsubishi Motors*. 1999-01-12. Archived from the original on 2009-01-12. Retrieved 2013-09-08.
- [12] "Mitsubishi Motors Supplies Hyundai Motor Co. with GDI Technology for New V8 GDI Engine" (Press release). *Mitsubishi Motors*. 1999-04-28. Archived from the original on 2009-01-12. Retrieved 2013-09-08.
- [13] Motor Business Japan. Economist Intelligence Unit. 1997. p. 128. Retrieved 2013-09-09. "Hyundai is second only to Volvo among companies borrowing the technology from Mitsubishi."
- [14] Japan Quarterly 46. Asahi Shimbun. 1999. p. 22. Retrieved 2013-09-09.
- [15] "Not so nuts" (98). *AutoSpeed*. 2000-09-19. Retrieved 2013-09-09.

- [16] "News 2002". *italiaspeed.com*. Retrieved 2007-10-24.
- [17] Abuelsamid Sam (2009-11-13). "New Hyundai 2.4-liter GDI four cylinder makes 200 hp in 2011Sonata". *AOL Inc*. Retrieved 2010-11-14.
- [18] M. M. Syed Ali, Husnay Mobarok and Md. Mominul Haque " Experimental study on aprogram controlled direct gasoline fuel injection (DGI) system in SI engine for variable speed and load", *Undergraduate project thesis 2010*, Department of Mechanical Engineering , KUET, Khulna, Bangladesh.
- [19] M. M. Syed Ali, Rubel Shikder, Md. Jahirul Islam, "Development of a Microcontroller based EFI System for a Single Cylinder Four SI Engine," *Undergraduate project thesis*, Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh, 2012-2013.