An approach to design and develop a Gasoline Direct injection system (GDI) to meet *Bharat Stage 6/Euro 6* emission norms and customer performance requirement. : A Case Study

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***Abstract*--As demand for mobility continues to grow across the globe, so too does the market for cars and trucks. The general demand in the market today is for vehicles with excellent fuel economy, superb power performance and cleaner & greener emissions. But the actual situation is somewhat contrary in the sense that the generally bought by the public have characteristics which include very high levels of pollution caused by scavenging losses, un-economical operation because of fresh charge losses, less scope for lean operation and no control on the engine once the valves have closed. Therefore the goal of this paper is to discuss a design of an optimised injection system to achieve optimum emission values and noise levels. In addition this paper looks at improving fuel consumption, lowering NOx emission and drivability independent of the operating point.**

***Keywords*—Downsizing, ECU, EURO Emission norms, GDI, NEDC, Positive ignition, Scavenging, Stoichiometric, Stratified charge, Turbocharging, Ultra-lean burn.**

I. INTRODUCTION

Fuel injection is the introduction of fuel in an internal combustion engine, most commonly automotive engines. First Carburettor technology was used to atomize fuel by creating suction in intake, air accelerated through the manifold draw s the fuel into the airstream through Venturi tubeof carburettor. Fuel injection replaced carburettor from the 1980s onward be-cause of controlled regulations successfully implemented by means of emission norms. Fuel injection reduced the emission level considerably meeting upto Bharat Stage 4(BS 4) emission norms. Next level of emission norms-Bharat Stage 6 (BS 6) is proposed to be implemented by April 2020. Gasoline Direct Injection system is being innovated to meet BS 4 norms.

Gasoline Direct Injection (GDI) is certainly not new. The first known application of this technology was introduced in 1925 in a Hesselman engine for airplanes. Cars starting using it in the 50's with the Mercedes Benz Gullwing (1953) having this technology.[1] It was then innovated into today's form. In today's market, the high majority of the current OEM manufacturers have at least one and in most cases, many GDI equipped engines in their product line. Most experts agree that GDI will soon replace the conventional Carburettor and port fuel injection systems that we have been familiar with for years because of their less scope of operation in lean air-fuel mixture, poor fuel economy. It certainly isn't a perfect technology and there is work presently going on to correct some issues, but the advantages seem to far outweigh any disadvantages and the benefits of having this technology are impressive.

This paper mainly discuss about the GDI system and how its functioning can meet BS 6/Euro 6 emission norms as well as customer requirement for better fuel economy for the longer runs.

II. EMISSION NORMS

Euro Emission Norms- European Union emission regulations for new vehicles were once specified in Directive 70/220/EEC with a number of amendments adopted through 2004. In 2007, this Directive has been repealed and replaced by Regulation 715/2007 (Euro 5/6) [2899]. Some of the important regulatory steps implementing emission standard for light-duty vehicles were:

Euro 1 standards (EC 93): Directives 91/441/EEC (passenger cars only) or 93/59/EEC(passenger cars and light trucks).

Euro 2 standards (EC 96): Directives 94/12/EC or 96/69/EC.

Euro 3/4 standards (2000/2005): Directive 98/69/EC, further amendments in 2002/80/EC.

Euro 5/6 standards (2009/2014): Regulation 715/2007 ("political" legislation) [2899] and several comitology regulations.

Emission standards for light-duty vehicles are applicable to all vehicles with a reference mass not exceeding 2610 kg (Euro 5/6). EU regulations introduce different emission limits for compression ignition (diesel) and positive ignition (gasoline, NG, LPG, ethanol, etc) vehicles. Positive ignition vehicles were exempted from PM standards through the Euro 4 stage.Emissions are tested over the NEDC (ECE 15 + EUDC) chassis dynamometer procedure. Effective year 2000 (Euro 3), that test procedure was modified to eliminate the 40 sec. engine warm-up period before the be-ginning of emission sampling. This modified cold start test is referred to as the New European Driving Cycle

(NEDC) or as the MVEG-B test. All emissions are expressed in g/km.

EU emission standards are summarised in the following table. All dates listed in the table refer to new type approvals.

Tier	Date	CO	THC	NMHC	NOx	$HC+NO_x$	PM	PN
Petrol (Gasoline)								
Euro 1†	Jul-92	2.72 (3.16)	-	-	-	0.97 (1.13)	-	-
Euro 2	Jan-96	2.2	-	-	-	0.5	-	-
Euro 3	Jan-00	2.3	0.2	-	0.15	-	-	-
Euro 4	Jan-05	1	0.1	-	0.08	-	-	-
Euro 5	Sep-09	1	0.1	0.068	0.06	-	0.005**	-
Euro 6	Sep-14	1	0.1	0.068	0.06	-	0.005**	-
* Before Euro 5, passenger vehicles > 2500 kg were type approved as light commercial vehicles N1-I								
** Applies only to vehicles with direct injection engines								
*** A number standard is to be defined as soon as possible and at the latest upon entry into force of Euro 6								
† Values in brackets are conformity of production (COP) limits								

Fig: EU Emission Standards for Passenger Cars

Standard	Reference	YEAR
India 2000	Euro 1	2000
Bharat Stage II	Euro 2	2001
		2003.04
		2005.04
Bharat Stage III	Euro 3	2005.04
		2010.04
Bharat Stage IV	Euro 4	2010.04
Bharat Stage V	Euro 5	(to be skipped)
Bharat Stage VI	Euro 6	2020.04 (proposed)[11]

Fig: Co-Relation of Bharat Stage and Euro emission norms for 4 wheelers.

III. GDI SYSTEM OVERVIEW

An early use of indirect gasoline injection dates back to 1902, when French aviation engineer Leon Levasseur pioneered it on his Antoinette 8V aircraft powerplant. Another early use of gasoline direct injection was on the Hesselman engine invented by Swedish engineer Jonas Hesselman in 1925. Hesselman engines use the ultra-lean burn principle; fuel is injected toward the end of the compression stroke, then ignited with a spark plug.

The first commercial electronic fuel injection (EFI) system was the ELECTROJECTOR developed by Bendix Corporation in 1957. Chrysler offered Electrojector on the 1958 Chrysler 300D, DeSoto Adventurer, Dodge D-500 and Plymouth Fury, arguably the first series-production cars equipped with an EFI system. It was jointly engineered by Chrysler and Bendix. Bosch developed an electronic fuel injection system, called D-Jetronic (D for Druck, German for "pressure"), which was first used on the VW 1600TL/E in 1967. Bosch superseded the D-Jetronic system with the K-Jetronic and L-Jetronic systems for 1974, though some cars (such as the Volvo 164) continued using D-Jetronic for the following several years.

A. GASOLINE DIRECT INJECTION SYSTEM

Gasoline Direct Injection system uses a common rail and gasoline high pressure injectors deliver fuel directly into the combustion chamber, sometimes on the intake stroke and sometimes on the compression stroke.

The GDI engine management system continually chooses among three combustion modes:

- Ultra-lean burn
- Stoichiometric
- full power output.

Each mode is characterised 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 40:1 (or even higher in some engines, for very limited periods). These mixtures are much leaner than in a conventional engine and reduce fuel consumption considerably. The fuel, which is injected in the intake stoke, evaporates in the cylinder at high pressure of 120 bars. The evaporation of the fuel cools the intake charge. The cooling effect permits higher compression ratios and increasing of the volumetric efficiency and thus higher torque is obtained.

GDI engine coupled with Turbocharging can be downsized, this concepts actually helps to meet BS 6/Euro 6 emission norms.

B. THE MIXTURE FORMATION

The air-fuel mixture in the gasoline engines is prepared in-cylinder. During the induction stroke, only the air flows from the open intake valve and it enters into the cylinder. This ensures better control of the injection process and particularly provides the injection of fuel late during the compression stroke, when the intake valves are closed. As the lack of time to fuel vaporize in GDI engines, the fuel is injected into the cylinder at a very high pressure to help the atomization and vaporization process.

The duration for injection timing is little; advanced injection timing causes piston wetting and retarded injection timing decrease sufficient time for fuel-air mixing. In the PFI engine, a liquid film is formed in the intake valve area of the port, which causes delayed fuel vaporization. Especially during cold start, it is necessary to increase fuel amount than the ideal stoichiometric mixture. This "over fueling" leads to increasing HC emissions during cold start. Alternatively, injecting the fuel directly into the combustion chamber avoids the problems such as increasing HC and giving the excess fuel to engine.

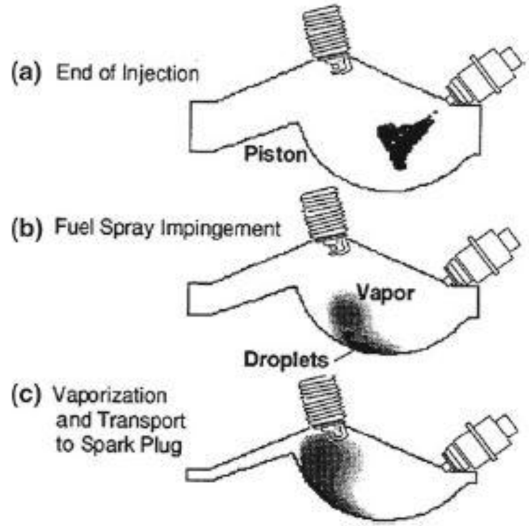
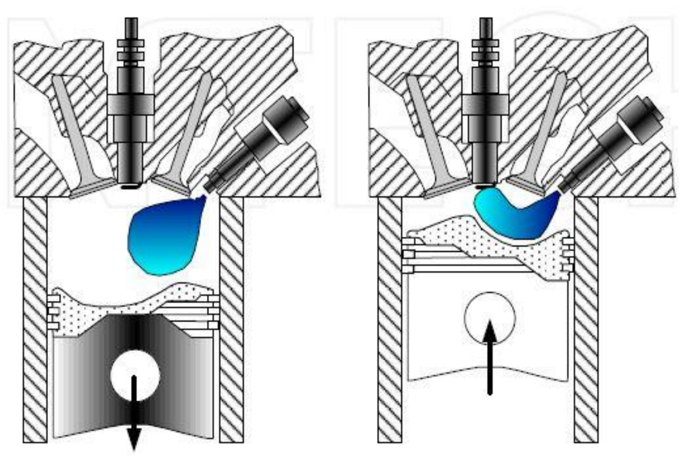


Fig: operation at ultra-lean mode

The GDI engines implements the two basic charge modes, Stratified charge mode and Homogeneous charge mode. At the partial load conditions, stratified charge (late injection) is used, that is, fuel is injected during the compression stroke to supply the stratified charge. The engine can be operated at an air-fuel ratio exceeding 100 and fully un-throttled operation is possible, but the engine is throttled slightly in this zone and the air-fuel ratio is controlled to range from 30 to 40 in order to introduce a large quantity of Exhaust Gas Recirculation (EGR) and to supply the vacuum for the brake system. A homogeneous charge (early injection) is preferred for the higher load conditions, that is, fuel is injected during the intake stroke so as to provide a homogeneous mixture. In most of this mode, the engine is operated under stoichiometric or a slightly rich condition at full load. In the lowest load conditions in this mode, the engine is operated at homogeneous lean conditions with air-fuel ratio of from 20 to 25 for further improvement of fuel economy.



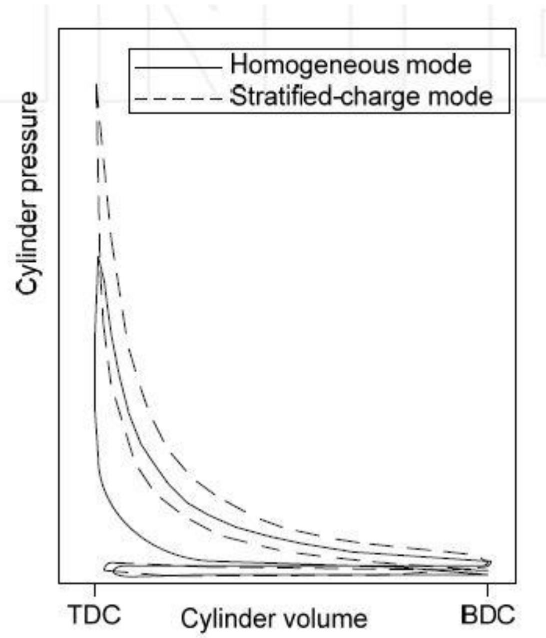
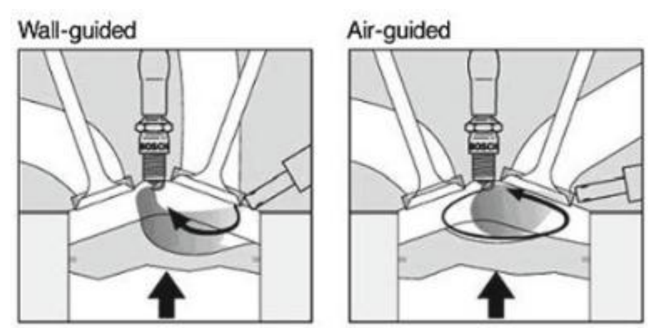


Fig: Plot shows the comparison between the two mode

VW direct injection combustion system is a combination of two systems– wall guided and air guided –by tumble flow. This system is less sensitive against the cyclic variations of airflow. This combustion system shows advantages as well in the stratified and in the homogenous mode. Injector is intake-side placed, The fuel is injected to the piston under given angle. The piston has two bowls. The fuel bowl is on the intake-side; the air-bowl is on exhaust-side. Tumble flow is obtained by special



shaped intake port. The fuel is guided simultaneously via air and fuel bowl to the spark plug.

C. SUITS BEST FOR DOWNSIZING CONCEPTS WITH TURBOCHARGING

Gasoline direct injection is a process whereby fuel is injected straight into the combustion chamber at high pressure. This is an effective means of reducing fuel consumption and emissions. Combined with turbocharging, the engine can be downsized resulting reductions in fuel consumption and CO_2 emissions can be delivered in the region of 15 percent keeping power output the same.

D. REDUCE TURBO LAG

Turbochargers are able to reach their set boost pressure only beyond a certain engine speed. At low engine speeds, the exhaust gas flow inside the turbine is too weak, with the result that the air cannot be compressed well enough. This produces a turbo lag.

"*Scavenging*" system approach developed by Bosch solves this problem by briefly opening the intake and exhaust valves simultaneously, creating a dynamic head between the in- take and exhaust sides of the engine and increasing the supply of fresh air in the combustion chamber. This generates up to 50 percent higher torque at low engine speeds. Scavenging leverages the synergies from gasoline direct injection, variable camshaft adjustment, and turbocharging and supplies improved responsiveness on a par with that of high capacity engines.

F. ENGINE MANAGEMENT SYSTEM

Engine management system consists of electronic control unit(ECU), sensors and actuators. The engine control unit continually chooses the one among operating modes depending on engine operating point and sensor's data. The ECU controls the actuators to input signals sent by sensors. All actuators of the engine is controlled by the ECU, which regulates fuel injection functions and ignition timing, idle operating, electric fuel pump and operating of the other systems. Adding this function to the ECU requires significant enrichment of its processing and memory as the engine management system must have very precise algorithms for good performance and drive ability.

Inputs (sensors): Mass air flow sensor, intake air temperature sensor, engine temperature sensor, intake manifold pressure sensor, crankshaft position sensor, camshaft position sensor, throttle position sensor, accelerator pedal position sensor, rail fuel pressure sensor, knock sensor, lambda sensor upstream of primary catalytic converter, lambda sensor downstream of primary catalytic converter, exhaust gas temperature sensor.

Outputs (actuators): Fuel injectors, ignition coils, throttle valve positioned, electric fuel pump, fuel pressure control valve.

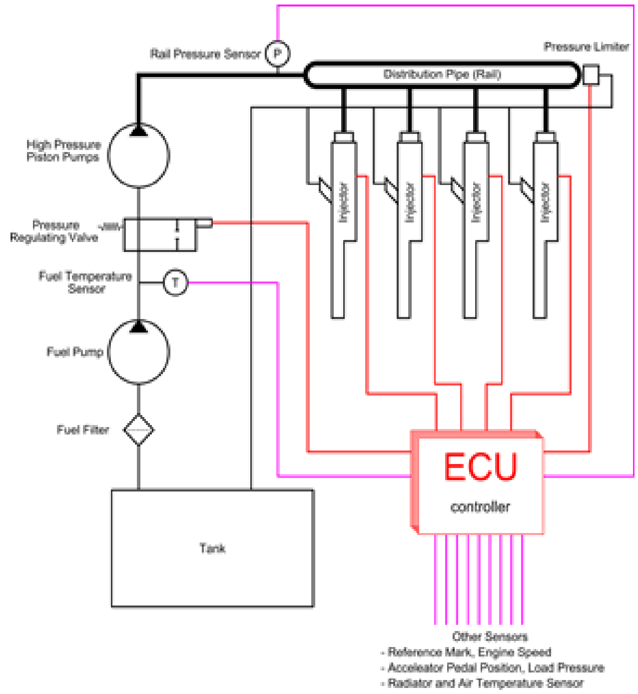


Fig: Schematic diagram of Engine Electronics.

IV. CURRENT TRENDS AND FUTURE CHALLENGES

At the present day, in the some gasoline engines are used port fuel injection system. This technique has achieved a high development point. As these engines operate with stoichiometric mixture, fuel economy and emissions of these engines cannot be improved further. However, GDI engines have been popular since these engines have potential for reduction of NOx, CO_2 emissions and fuel consumption to comply with stringent Environmental Protection government standards. To attain this potential, it is required that use of the GDI engines with turbocharging. The GDI engines with turbo charger enable downsizing of engines, higher fuel efficiency, lower emission and higher power. The GDI engines also help eliminate the disadvantages conventional turbocharged engines to provide viable engine solutions.

The primary drawback of direct injection engines is theirs cost. Direct injection systems are more expensive because their components must be well-made. In these engines, the high cost high-pressure fuel injection system and engine management components are required. The cost of the GDI engines is high at the present day, but GDI engines with turbocharger that have more fuel economy are expected to be cheaper than diesel or hybrid engines in future.

In multiple injection during each power stroke, a series of injections takes place. This improves mixture formation, combustion and fuel consumption.The injectors used in DI system have nozzles which open outwards to create an annular gap just a few microns wide. The peak fuel pressure in this system is up to 200 bar - around 50 times the fuel pressure in a conventional petrol injection system. The firms such as Bosch, Delphi and Siemens have developed a fuel injection system for gasoline engines to automakers. The aim is to improve the performance of the direct injection systems.

V. CONCLUSION

Implementation of Gasoline Direct Injection (GDI) in light commercial vehicle is proving very advantageous because of its downsized turbocharged engines, with reduced NOx levels thereby meeting to the government regulations and fulfilling customer’s fuel economy requirement for longer runs.

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