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A REVIEW ON GASOLINE DIRECT INJECTION SYSTEM

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Abstract

Gasoline direct injection system is a type of fuel supply system used in current trend of automobiles .One of the important worldwide initiative of the automotive industry is to develop a direct-injection gasoline engines. The need for fuel economy and stringent exhaust emission norms has led to the transition of fuel supply system from carburettor to Port Injection and Port Injection to direct injection. There are four technical features that make up the foundation technologies in direct injection systems i.e. [i] Upright Straight Intake Port that supplies optimal airflow into the cylinder, [ii] Curved-top Piston that controls combustion by helping shape the air-fuel mixture, [iii] High Pressure Fuel Pump that supplies the high pressure needed for direct in-cylinder injection, [iv] High Pressure Swirl Injector that controls the vaporization and dispersion of the fuel spray. Fuel economy can be obtained by adjusting air fuel ratio to the acting load. At lower loads charge stratification is needed for stable ignition and combustion. Depending on the modality of stratification attainment, different combustion systems can be considered. Injector housing and orientation with respect to the combustion chamber has to be carefully chosen. In this paper advantages of direct injection systems over other fuel supply systems, selection of combustion systems needed for charge stratification and positioning of injectors with respect to spark plug is reviewed.

Keywords: Gasoline direct injection(GDI), charge stratification, Port Injection, carburettor

1. Introduction

The basic goals of the automotive industry is to obtain a high power, low specific fuel consumption, low emissions, low noise and better drive comfort vehicles. With the increase in air pollution due to significant increase in automobile, the environment protection agencies have drawn down the emission limits annually. With the depletion of fuels and increase in fuel price, there is need to develop efficient engines. To increase engine efficiency there is a need to develop fuel supply systems which would lead to the complete fuel combustion in engine cylinder producing maximum power. This has led to the transition of fuel supply system from carburettor to Port Injection and Port Injection to direct injection. In carburettor the fuel from the fuel chamber is sucked in by the pressure variation caused due to the incoming air. The fuel then mixes with the air and reaches the cylinder through the inlet manifold. Where as in a port injection system the fuel to the cylinder

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is supplied by a separate fuel injector placed near the inlet valve of the cylinder. And in a direct injection system the fuel to the cylinder is supplied by a fuel injector placed inside the cylinder. Fuel injection system development was Because of operating difficulties of carburettor such as Ice formation, Vapour Lock and Back Firing and failing of port fuel injection systems to satisfy emission norms. In fuel injection systems, induced air can be metered precisely and the fuel is injected in the manifold to air amount.

If port fuel injection system is compared with carburettor system, it is seen that has some advantages:

1. Lower emission of exhaust gases
2. The carburettor venture prevents air and, in turn, volumetric efficiency decreases. But in port injection there is increase in volumetric efficiency and therefore increased output power and torque.
3. Low specific fuel consumption.
4. The fuel injection eliminates several intake manifold distribution problems as seen in carburettor.

Though the port fuel injection system has some advantages, it cannot meet continuously increasing demands regarding performance, emission legislation and fuel economy at the present day. Gasoline Direct Injection (GDI) engines offers various benefits over port injected engines It avoids fuel wall film in the manifold, improves accuracy of air/fuel ratio during dynamics, reduces throttling losses of the gas exchange by stratified and homogeneous lean operation, higher thermal efficiency by stratified operation and increases compression ratio, decreases the fuel consumption and CO2 emissions, lower heat losses, increased performance and volumetric efficiency due to cooling of air charge, better cold start performance and better the drive comfort.

In the following sections requirements, performance, emission control, mixture formation, charge formation, combustion systems and operating modes of GDI is discussed.

2. Requirements of GDI

The concept of GDI is derived from compression ignition engines injection systems. But a direct conversion of diesel engine systems to direct injection spark ignition engines is not possible because of the basic differences in the combustion process. While in diesel engines combustion is spontaneously initiated by compression in several zones of the chamber, in spark ignition engines combustion has to be triggered in a precise point corresponding to spark gap. Both a spatial and temporal optimization of the interaction between air and injected fuel is required if charge stratification is done. Another demanding requirement is the capability of performing both early and late injection with proper atomization: early injection aimed at a homogeneous charge needing a more dispersed fuel spray while late injection aimed at stratification requiring a narrower fuel spray. The injector is an important element of the whole system which plays a key role in the mixture preparation process. Position b/w spark gap and injector has to be optimised by using CFD modelling.

3. Performance

The parameters that has a huge influence on engine efficiency are compression ratio and air/fuel ratio. A higher compression ratio increases the power output and reduces the fuel consumption. The maximum efficiency (or minimum specific fuel consumption) need not always occur with a stoichiometric mixture [1].It depends on load. For example part load or start of engine (throttled) it is better to have lean mixture. Lean mixture is a mixture having low quantity of fuel. But for large load condition and high speed, it is better to have a stoichiometric mixture or fuel rich mixture. [2]

In these engines, the compression ratio is about 9:1 or 10:1. To prevent the knock, the compression ratio cannot be increased more. For the same engine volume, the increasing volumetric efficiency also raises the engine power output. Engines run usually at part loads (low and medium loads) in urban driving.

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Volumetric efficiency is lower at part loads, so engine effective compression ratio decreases (e.g. from 8/1 to 3/1-4/1), engine efficiency decreases and fuel consumption increases. The urban driving fuel economy of the vehicles is very high [1]. So the owners of the vehicles prefer the vehicles of which the urban driving fuel economy is low. At full load, as the GDI engine operate with throttle, only a small reduction of fuel consumption can be obtained to the PFI engine. There is the more fuel economy potential at part load. At compression stroke, since air is given the cylinders without throttle for stratified charge mode, pumping losses of the GDI engine is minimum at part loads [3]. The improvements in thermal efficiency have been obtained as a result of reduced pumping losses, higher compression ratios and further extension of the lean operating limit under stratified combustion conditions at low engine loads [4].

In the table 1, it is given specifications of the two different engines. One uses port injection to supply fuel and other uses GDI. From table it is clear that urban driving fuel economy in GDI engine is 18% lower than that of PFI engine. CO2 emission is 12% lower than that of PFI engine. Although GDI engine swept volume is lower than PFI engine, power and torque is higher by 20% and 35%, respectively. As engine torque is maximum at interval 1500-4000 1/min, shifting is not necessary at the acceleration and thus drive comfort increase [5].

Engine Type	Swept volume	Max. Power	Max. Torque	Mixture formation system	Fuel economy (urban driving) L/100km	Fuel economy (highway driving) L/100km	CO_2 emission g/km
Gasoline engine	1.6 L	75 kW 5600 1/min	148 Nm 3800 1/min	PFI (port fuel injection)	10,5	6,0	179
TSI gasoline engine	1.4 L	90 kW 5000 - 5500 1/min	200 Nm 1500 - 4000 1/min	GDI (Gasoline direct injection)	8,6	5,5	157

(Table 1 Comparison Between GDI and PFI engines)

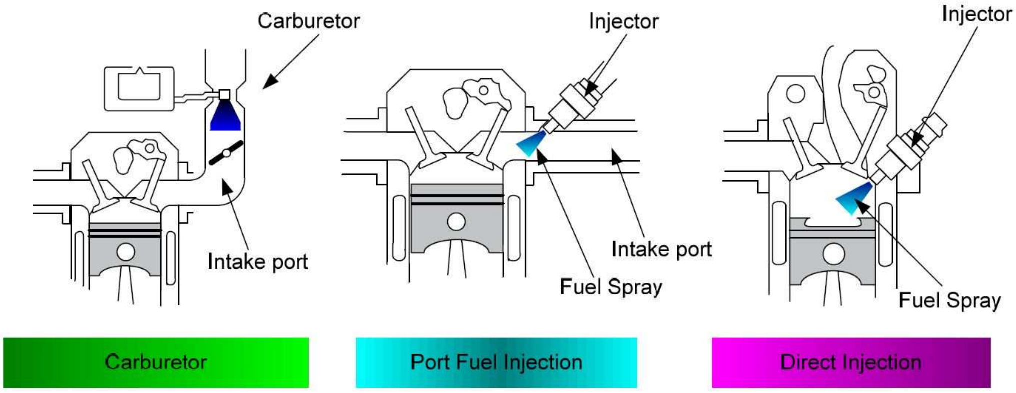
4. Emission control

CO emission is very low in GDI engine. CO varies depending on air /fuel ratio. CO is high at rich mixtures. Since GDI engines operate with lean mixture at part loads and stoichiometric mixture at full load, CO is not a problem for these engines. In GDI engine, due to the wetting of the piston and the cylinder walls with liquid fuel, HC emission can increase. Hydrocarbon (HC) emissions are a function of engine temperature and, therefore it can rise during cold start. The cold starts characteristics vary depending on the fuel distribution characteristics, the in-cylinder air motion, fuel vaporization, and fuel-air mixing [6]. Soot emission can occur at very rich mixtures. However, the GDI engines emit soot at stratified-charge operation, as in–cylinder can be areas with very rich mixtures. In addition, in GDI engine, if mixture formation do not realize at full loads due to rich mixture, the soot emission can increase.

In order to satisfy emission norms three-way catalytic converter to convert the CO, HC and NO_x in the engines in used. But, NO_x cannot be completely converted to harmless gases at lean mixture operation. Therefore, engines with lean mixture also require a NOx storage type catalytic converter to convert the NO_x. Therefore an exhaust gas recirculation system is used for NO_x. Using rich mixture CO gas is formed. It releases the NO_x by reacting with the components such as Ba and Ca and then reacts with NOx to form CO_2 and N_2.Thus converting NO_x to harmless N_2 gas.

5. Mixture formation

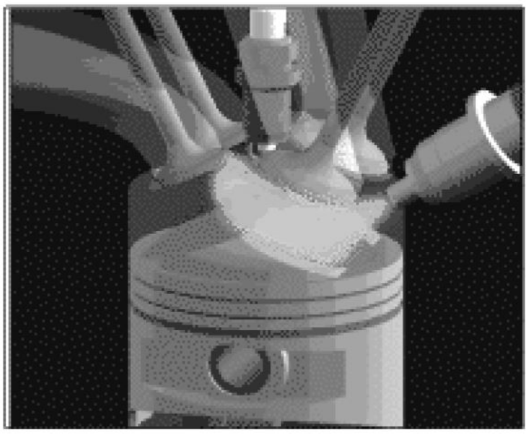
The air-fuel mixture in the gasoline engines is prepared in-cylinder and out-cylinder. While the mixture in the engine with carburettor (Fig 1) and port fuel injection is prepared out-cylinder, mixture in the gasoline direct injection engines is prepared in-cylinder. In place of PFI (Fig 1) engines where the fuel is injected through the port, in GDI engines (Fig 1), the fuel is injected directly into cylinders at a high pressure



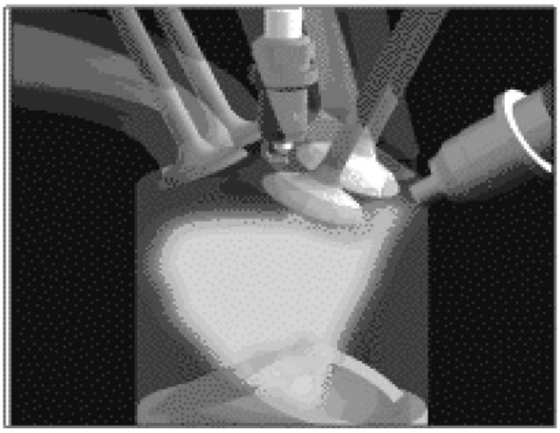
(Fig.1 Mixture formation in different fuel supply systems)

6. Charge formation

Two basic charge modes, stratified and homogeneous charges are implemented in GDI.



(Figure.2 Stratified mode)



(Figure.3 Homogeneous mode)

A Stratified charge is used at partial load conditions. To supply Stratified charge, fuel is injected during the compression stroke. The engine can be operated at an air-fuel ratio exceeding 100 and fully 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) .Figure.2 shows the injection of stratified charge in engine cylinder.
A homogeneous charge (early injection) is preferred for the higher load conditions during operation with stratified charge the engine runs with un-throttled conditions and engine load is adjusted by fuel/air-equivalence ratio.A homogeneous charge is used at full load conditions. To supply homogeneous charge, fuel is injected during the intake stroke. During operation with homogeneous charge the adjustment of engine load is done by throttling. Figure.3 shows the injection of homogeneous charge in engine cylinder.

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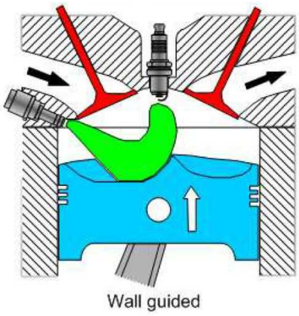
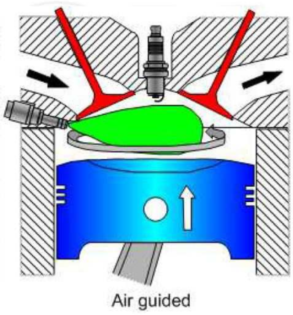
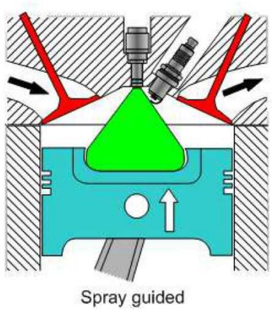
7. GDI combustion systems

Mainly three combustion systems can be used for for charge stratification[7]. These are wall-guided, air-guided and spray-guided combustion systems. Fig.6, Fig.7 and Fig.8 shows wall-guided, air-guided and spray-guided combustion systems respectively. In the following subsection the three combustion systems and also latest development in combustion systems is discussed.







(Figure.4 Wall guided) (Figure.5 Air guided) (Figure.6 Spray guided)

7.1 *Wall guided combustion systems*

The interaction between the fuel spray and the surface of a proper cavity on the top of piston leads to stratification process. This system is easy to manufacture compared to other systems. Some amount of fuel does not evaporate from piston surface leading to emissions of HC and CO and also fuel consumption increases. Therefore this system alone is not efficient. In the wall guided combustion systems the injector is placed remote to the spark plug.

7.2 *Air guided systems*

The interaction between the fuel spray and the motion of the air charge inducted in the cylinder leads to stratification process. In the air-guided combustion systems the injector is placed remote to the spark plug. Air speed is controlled by the air baffles in the manifold and also it has inlet ports with special shape.

7.3 *Spray guided systems*

The features of the spray and its dynamics, as regard to the fuel atomization, droplet distribution, and overall geometry influences stratification process. In the spray-guided technique fuel is injected near spark plug where it also evaporates. This technique has following advantages: increased stratified operation region, reduced wall wetting, less sensitive to in-cylinder air flow, less sensitive to cylinder to cylinder variation and reduced HC emissions. It achieves better fuel efficiency compared to other two combustion systems.

7.4 *Latest trends in Combustion systems*

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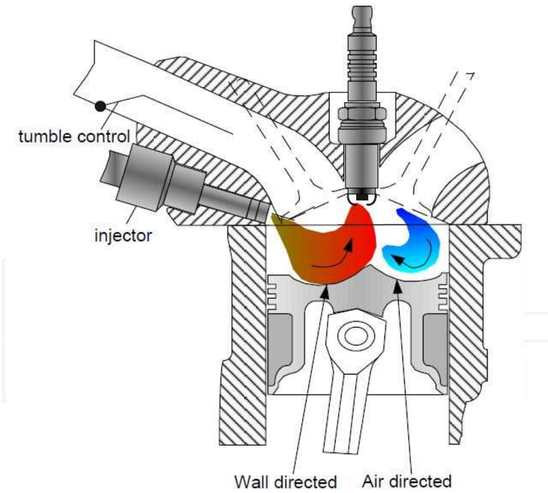
Stratified-Charged Gasoline Injection and Air-wall guided combustion system is thought to be future of combustion systems. Stratified-Charged Gasoline Injection (CGI) system with Piezo injection technology is a type of Spray-Guided combustion system. It runs with high excess air and thus excellent fuel efficiency is provided. Multiple injections extend this lean-burn operating mode to higher rpm and load ranges. During each compression stroke, a series of injections is made spaced just fractions of a second apart. This allows the better mixture formation, combustion and lower fuel consumption [8].

Air-wall guided combustion system is a combination of air and wall combustion system. 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. 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 [9]. The fuel is guided simultaneously via air and fuel bowl to the spark plug.



(Figure.7 Air-wall guided combustion system)

8. Operating modes

GDI engine operates at different operating modes depending on load and engine speed for a stable and efficient engine operation. These engines have three basic operating modes, stratified with an overall lean mixture, homogeneous with lean mixtures and homogeneous with stoichiometric mixtures. The engine is operated with the stratified, homogeneous lean and homogeneous stoichiometric modes; at low load and speed, at medium load and speed and at high load and speed respectively.

ECU (electronic control unit) choses the mode depending on the condition. Air fuel ratio determines each mode. The stoichiometric air-fuel ratio for petrol (gasoline) is 14.7:1 by weight

Ultra lean mode (stratified-charge) involves ratios as high as 65:1. These mixtures are much leaner than conventional mixtures and reduce fuel consumption. Stratified-charge mode is used for light-load running conditions, at constant or low speeds, where no acceleration is required. The fuel has to be injected shortly before the ignition, so that the small amount of air-fuel mixture is optimally placed near the spark plug. This technique enables the usage of ultra-lean mixtures with very high air-fuel ratio which is impossible with traditional carburettors or even port fuel injection. In this mode NO_x emission is high so an EGR is used. At high load, the mixture in the stratified mode can be too rich, and thus soot can form. At high speed, it is impossible to provide sufficient stratification due to high turbulence in the cylinder.

Homogeneous mode is used for higher load and speed range. It obtains low emissions and high torque the air-fuel mixture is homogenous and the ratio is stoichiometric or slightly richer than stoichiometric. As the fuel is

injected during the intake stroke, there is sufficient time for air-fuel mixture formation. In this mode NO_x emission is very low so EGR is not used.
Transition from stratified mode to homogeneous mode takes place in two stage injection (double injection) process .The primary injection is performed at intake stroke and majority of fuel is injected. The remaining fuel is injected at secondary injection and compression stroke. Double injection is made to reduce soot emissions and to decrease fuel consumption at low Engine speeds.

9. Conclusion

It is clear that GDI fuel supply systems has superiority over other systems due to their versatility. These systems have become popular due to their potential to reduce toxic,CO_2 emission and fuel consumption to comply with environmental protection norms. The amount of fuel injection can be precisely metered and monitored. So that desired air-fuel ratio is obtained for different cylinders.The GDI engine has a high compression ratio and a highly efficient air intake system which results in improved volumetric efficiency. A combination of different combustion system or an improvement of existing combustion system as discussed in previous section is preferred for better charge stratification.

One of the major drawback of direct injection engines is cost. This is because their components must be well-made. Cost can be reduced by large scale production of these systems.

References

1. Çelik M. B "Performance Improvement and Emission Reduction in Small Engine with Low Efficiency", *Journal of the Energy Institute*, pp 80, 2007.
2. Spicher U., Kölmel A., Kubach H. and Töpfer G., "Combustion in Spark Ignition Engines with Direct Injection", *SAE Paper* 2000-01-0649.
3. Baumgarten C., "Mixture Formation in Internal Combustion Engines", *Springer Verlag*, Germany, 2006.
4. Fan L., Li G., Han Z. and Reitz R. D., "Modeling Fuel Preparation and Stratified Combustion in a Gasoline Direct Injection Engine", *SAE Paper* 1999-01-0175.
5. Anon, Volkswagen AG, Bosch Motronic MED7 "Gasoline Direct Injection" *Volkswagen Self- Study Program 253*, 2002, Wolfsburg.
6. Gandhi A. H., Weaver C. E., Curtis E. W., Alger T. F., Anderson C. L., Abata D. L., "Spray Characterization in a DISI Engine During Cold Start",*Imaging Investigation*, *SAE Paper* 2006-01-1004.
7. Spicher U., Kölmel A., Kubach H. and Töpfer G., "Combustion in Spark Ignition Engines with Direct Injection", *SAE Paper* 2000-01-0649.
8. http://www.greencarcongress.com/2006/02/mercedesbenz_pr.html,(17.04.2010).
9. Stefan S., "Optical Diagnostics on FSI Transparent Engine", *FISITA World Automotive Congress*, Barcelona 23-27 May, Barcelona Spain, 2004
10. Küsell M., Moser W. and Philipp M., "Motronic MED7 for Gasoline Direct Injection Engines: Engine Management System and Calibration Procedures", *SAE Paper* 1999-01-1284.
11. Mustafa Bahattin Çelik and Bulent Ozdalyan (2010). "Gasoline Direct Injection", *Daniela Siano* (Ed.), ISBN: 978-953-307-116-9, InTech,

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