A Review on Electronically Assisted Gasoline Direct Injection 4-Stroke Single Cylinder Engine System

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Abstract: ***An in-cylinder gasoline direct injection (GDI) engine, incorporating novel combustion technologies, has been developed. Such innovative technologies consist of the upright straight ports to generate tumble motion, the electromagnetic swirl injector to realize optimized spray dispersion and atomization and the compact piston cavity to maintain charge stratification, and in addition other highly advanced technologies to achieve desirable engine management. This new GDI engine is thus available with ultra lean stratified combustion for higher thermal efficiency under partial loads as well as homogenous combustion to realize higher performance under full load.***

Keywords: Four stroke, Gasoline, Direct injection, Spark ignition Engine & ECU.

1. Introduction

In internal combustion engines, Gasoline Direct Injection (GDI), sometimes known as Fuel Stratified Injection (FSI), is an increasingly popular type of fuel injection system employed in modern four and two-stroke petrol engines. The petrol/gasoline is highly pressurized, and injected by high voltage driven injectors via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional single or multi-point fuel injection that happens in the intake manifold tract, or cylinder port. In some applications, gasoline direct injection enables stratified fuel charge (ultra lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load

The major advantages of a GDI engine are lower emission levels, increased fuel efficiency and higher engine power output. In addition, the cooling effect of the injected fuel and the more evenly dispersed combustion mixtures and temperatures allow for improved ignition timing settings which are an equally important system requirement.

Emissions levels can be more accurately controlled with the GDI system. The lower levels are achieved by the precise control over the amount of fuel, air and ignition settings which are varied according to the engine load conditions and ambient air temperature.

In addition, there are no throttling losses in some GDI designed engines, when compared to a conventional fuel injected or carbureted engine, which greatly improves efficiency and reduces ‘pumping losses’ in engines without a throttle plate. Engine speed is controlled by the engine management system which regulates fuel injection and ignition timing parameters, instead of having a throttle plate which restricts the incoming air supply. Adding this function to the engine management system requires considerable enhancement of its processing and memory, as direct injection plus other engine management systems must have very precise mapping for good performance and drivability.
The engine management system continually chooses among three combustion cycles: ultra lean burn, stoichiometric, and full power output. Each cycle is characterized by the air-fuel ratio. The stoichiometric air-fuel ratio for petrol (gasoline) engines is 14.7:1 by weight, but the ultra lean cycle can involve ratios as high as 35:1 (or even higher in some engines, for very limited periods). These mixtures are much leaner than in a conventional fuel injected engine and reduce fuel consumption and certain levels of exhaust emissions considerably.

Ultra lean burn cycle is used for light-load running conditions, at constant or reducing road speeds, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke, so that the small amount of air-fuel mixture is optimally placed near the spark plug. This stratified charge is surrounded mostly by air which keeps the fuel and the flame away from the cylinder walls for low emissions and heat losses. The combustion of the fuel takes place in a to roidal (donut-shaped) cavity on the piston’s surface designed to improve air swirl and delivered by a specially designed injector nozzle. This allows successful ignition without misfire, even when the air/fuel mixture is very lean

Stoichiometric cycle is used for moderate load conditions. Fuel is injected during the intake stroke, creating a homogenous fuel-air mixture in the cylinder. From the stoichiometric ratio, an optimum burn results in a clean exhaust emission, further cleaned by the catalytic converter.

Full power cycle is used for rapid acceleration and heavy loads (as when climbing a hill). The air-fuel mixture is homogenous and the ratio is slightly richer than stoichiometric, which helps prevent knock (pinging). The fuel is injected during the intake stroke.

Direct injection is supported by other engine management systems such as variable valve timing (VVT) with variable length intake manifold (VLIM) or acoustic controlled intake system (ACIS). A high performance exhaust gas recirculation valve (EGR) will almost certainly be required to reduce the high nitrogen oxides (NOx) emissions which will result from burning ultra lean mixtures.

Conventional fuel injection engines could inject fuel throughout the 4 stroke sequence, as the injector injects fuel onto the back of a closed valve. Earlier direct injection engines, where the injector injects fuel directly into the cylinder, were limited to the induction stroke of the piston. As the RPM increases, the time available to inject fuel decreases. Newer GDI systems have sufficient fuel pressure to inject more than once during a single cycle. Fuel injection takes place in two phases. During the intake stroke, some amount of fuel is "pre-injected" into the combustion chamber which cools the incoming air, thus improving volumetric efficiency and ensuring an even fuel/air mixture within the combustion chamber. Main injection takes place as the piston approaches top dead centre on the compression stroke, shortly before ignition.

1.1 Gasoline Direct Injection Engine Performance

The key areas of the theoretical potential and the current research and development status of the spark-ignition, four stroke, direct-gasoline-injection engine have been discussed in detail in each of the sections of this treatise. It is quite evident from the technical literature worldwide that significant incremental gains in engine performance and emission parameters are indeed indicated and, to some degree, have been achieved. Specific technical issues related to BSFC, UBHC, NOx, particulate matter and fuel sprays in GDI combustion systems have been addressed and discussed, which has clearly accentuated the numerous practical considerations that will have to be addressed if the GDI engine is to realize its full potential and become a major future automotive power plant. These key considerations are:² Can a sufficient enhancement in operating BSFC be achieved in a stratified-charge GDI to offset the increased system complexity as compared to a PFI engine?² Can the applicable US, European and Japanese emission standards that are applicable in the 2000–2012 timeframe be achieved and maintained for the required durability intervals?² Can a production-feasible compromise be obtained between the required system complexity and overall system reliability, considering that the required GDI hardware may incorporate multi-stage injection, variable swirl-and-tumble control hardware and variable fuel pressure? Can injector fouling due to deposit formation be minimized for the wide range of fuel quality and composition in the field such that reasonable service intervals can be achieved? Can control-system strategies and algorithms be developed and implemented such that sufficiently smooth transitions from stratified-charge, late-injection operation to mid-range to homogeneous-charge, early-injection operation may be obtained, thus yielding drive ability levels that are comparable to current sequential PFI systems In determining which GDI system configuration delivers the most advantages, much work remains to be done. The field experiences of the production Mitsubishi, Toyota, Nissan and Renault GDI systems are being accumulated, and will be analyzed and discussed by engineers in the GDI field. The delivered emission indices and brake specific fuel consumption are being critically evaluated for each mode of the operating map, and are being compared to those obtained with other GDI configurations and strategies. In addition, the relative merits of spray-wall and spray-flow control strategies using both tumble and swirl are being determined. This will permit a more knowledgeable evaluation of the relative merits of each system. Even when the merits of each of these production and prototype GDI engines are fairly well established, much research and development will still be required for system optimization in order to develop production configurations. For very nearly the same reasons that port fuel injection gradually replaced the carburetor and the throttle-body injector, and that sequential PFI gradually displaced simultaneous-fire PFI, GDI combustion configuration that is an enhancement of one of the systems discussed in this treatise will emerge as the GDI system of choice, and will gradually displace the sequential PFI applications.

Studies were conducted on the stratified mixture formation and combustion characteristics in a new concept direct injection gasoline engine. A photo graphic system-equipped engine that runs at high speed was developed to observe fuel spray behavior and flame behavior, measure local mixture concentration and flame propagation. It was observed that the newly developed system achieves stable stratified combustion in the high-speed region due to the optimized piston cavity shape and fuel spray characteristics, especially suitable spray penetration with high injection pressure (13MPa) which provides the following benefits at higher speed:

1. ensuring the mixture formation to be ''robust'' against air flow, which increases in velocity at higher speed;
2. improving the stability of mixture concentration around the spark plug to prevent increased fluctuation of combustion;
3. accelerating mixture diffusion in the cavity;
4. inhibiting over-rich mixture region to minimize generation of incomplete-combustion products;
5. maintaining continuous mixture concentration distribution in the cavity to prevent insufficient flame propagation and combustion efficiency reduction.

This GDI technology was successfully implemented in a 2 wheeler 4 stroke engines. The newly developed housing results in the reduction of weight and regulation of injector pressure. The high pressure fuel pump was designed and characterized for various performance parameters. Through this, the problem of overflow was controlled – thus making it possible to run the engine smoothly, continuously and economically. This improved the load bearing capacity and operational reliability.

The efficiency of the engine could be improved by using a suitable piston head that would concentrate the entire mass of incoming air in a given region of the cylinder. Also a suitable swirl type injector with appropriate flow characteristics should be used. The injector design should also be based on the size of the engine and the viscosity and density of the fuel. The injector should be used to take combustion heat. Further, the position of the spark plug and injector should be optimized in such a way that they get more close to the cylinder head and spark plug doesn't get wet with fuel spray. We would also have to deal with the demands of the exhaust gas treatment in stratified and lean operation. Observing the data from the several cycles of the test run, we concluded that we would have to minimize the cyclic variations in pressure of the engine. This would help in lowering the maximum cylinder pressures and increasing the efficiency and the detonation limit. For this to happen we would have to minimize cycle to cycle variations in combustion and/or maximize combustion rates.

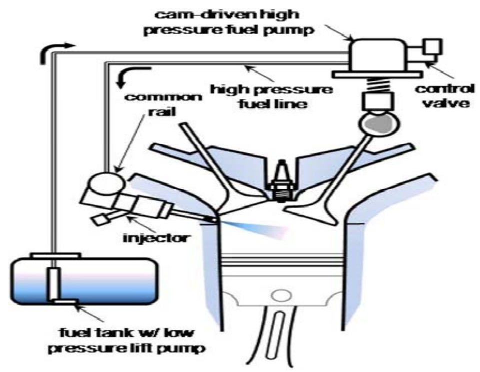

Figure 1: Main components of Gasoline Direct Injection system.

2. Discussion

The major advantages of a GDI engine are increased fuel efficiency and high power output. Emissions levels can also be more accurately controlled with the GDI system. In addition, there are no throttling losses in some GDI engines, when compared to a conventional fuel-injected or carbureted engine, which greatly improves efficiency, and reduces 'pumping losses' in engines without a throttle plate. 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, but ultra lean mode can involve ratios as high as 6.5:1 (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.

Ultra lean burn mode is used for light-load running conditions, at constant or reducing road speeds, where no acceleration is required. The fuel is not injected at the intake stroke but rather at the latter stages of the compression stroke, so that the small amount of air-fuel mixture is optimally placed near the spark plug. This stratified charge is surrounded mostly by air, which keeps the fuel and the flame away from the cylinder walls for lowest emissions and heat losses. The combustion takes place in a toroidal (donut-shaped) cavity on the piston's surface. The cavity is displaced to one side of the piston, the side that has the fuel injector. This technique enables the use of ultra-lean mixtures that would be impossible with carburetors or conventional fuel injection.

Full power mode is used for rapid acceleration and heavy loads (as when climbing a hill). The air-fuel mixture is homogenous and the ratio is slightly richer than stoichiometric, which helps prevent knock (pinging). The fuel is injected during the intake stroke.

Direct injection may also be accompanied by other engine technologies such as variable valve timing and tuned/multi path or variable length intake manifolding. Water injection or (more commonly) exhaust gas recirculation may help reduce the high nitrogen oxides (NOx) emissions that can result from burning ultra lean mixtures.

It is also possible to inject more than once during a single cycle. After the first fuel charge has been ignited, it is possible to add fuel as the piston descends. The benefits are more power and economy, but certain octane fuels have been seen to cause exhaust valve erosion. For this reason, most companies have ceased to use the Fuel Stratified Injection (FSI) operation during normal running.

Newer FSI systems that have sufficient fuel pressure to inject even late in compression phase do not suffer to the same extent; however, they still do not inject during the exhaust cycle (they could but it would just waste fuel). Hence, all other factors being equal, an FSI engine needs higher-capacity injectors to achieve the same power as a conventional engine. Some engines overcome this limitation by using both direct injection and multiport fuel injection.

3. Future scope

The major advantages of a GDI engine are increased fuel efficiency and high power output. Emissions levels can also be more accurately controlled with the GDI system. In addition, there are no throttling losses in some GDI engines, when compared to a conventional carbureted engine. Engine speed is controlled by the engine control unit/engine management system (EMS), which regulates fuel injection function and ignition timing, instead of having a throttle plate which restricts the incoming air supply. The fuel injection eliminates several intake manifold distribution problems. One of the most difficult problems in a carbureted system is to get the same amount and richness of air-fuel mixture to each cylinder. Fuel injection has no choke, but sprays atomized fuel directly into the engine. This eliminates most of the cold start problems associated with carburetors. With fuel injection, fuel mixture requires no extra heating during warm up. No manifold heat control valve or heated air system is required. Throttle response is faster because the fuel is under pressure at the injection valves at all times. An electric fuel pump supplies the pressure. The carburetor will depend on differences in air pressure as the force that causes the fuel to feed into the air passing through. Delivers a more evenly distributed mixture of air and fuel to each of the engine's cylinders, which improves power and performance.

4. Conclusion

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system is optimized. There are several competing objectives such as;

- Power output
- Fuel efficiency
- Reliability
- Drivability and smooth operation
- Initial cost
- Maintenance cost
- Engine tuning
- Emissions performance

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