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REVIEW ON GASOLINE DIRECT INJECTION

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ABSTRACT

Gasoline direct-injection engines generate the air/fuel mixture in the combustion chamber. During the induction stroke, only the combustion air flows through the open intake valve. The fuel is injected directly into the combustion chamber by special fuel injectors.Direct injection gasoline engines promise the highest potential to minimize fuel consumption. The first gasoline direct injection engines of the 'second generation' with spray-guided combustion systems were introduced to the market in 2006. The thermodynamic potential of such engines for significantly enhanced fuel economy, transient responsehas led to a large number of research and development projects. These engines are able to operate in lean operation mode throughout a wide operating range. Fuel savings of 10–20% can be achieved compared to conventional gasoline engines with port fuel injection.

Keywords

Direct injection, induction stroke, spray-guided combustion, lean operation mode.

1. INTRODUCTION

The basic goals of the automotive industry; a high power, low specific fuel consumption, low emissions, low noise and better drive comfort. With increasing the vehicle number, the role of the vehicles in air pollution has been increasing significantly day by day. The environment protection agencies have drawn down the emission limits annually. Furthermore, continuously increasing price of the fuel necessitates improving the engine efficiency.

2. MIXTURE FORMATION

The various mixture formation techniques have been used. The air-fuel mixture in the gasoline engines is prepared in-cylinder and out-cylinder. While the mixture in the engine with carburetor and port fuel injection is prepared out-cylinder, mixture in the gasoline direct injection engines is prepared in-cylinder.

2.1 Carburetors

Since the engines with carburetor do not hold the air fuel ratio close to the stoichiometric at different working conditions, catalytic converter cannot be used in theseengines. Therefore these engines have high emission values and low efficiency.

2.2 Port Fuel Injection

In fuel injection systems, induced air can be metered precisely and the fuel is injected in the manifold to air amount. By using the lambda sensor in exhaust system, air/fuel ratio is held of stable value.

Advantages of MPFI over carburetors

- Lower exhaust emissions.
- Increased volumetric efficiency and therefore increased output power and torque. As the carburetor venturi prevents air and, in turn, volumetric efficiency decrease.
- Low specific fuel consumption.
- The more rapid engine response to changes in throttle position. This increases the drive comfort.

Though the port fuel injection system has some advantages, it cannot be meet continuously increased the demands about performance, emission legislation and fuel economy, at the present day. The electronic controlled gasoline direct injection systems were started to be used instead of port fuel injection system.

2.3 Gasoline Direct Injection

In place of PFI engines where the fuel is injected through the port, in GDI engines, the fuel is injected directly into cylinders at a high pressure. 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 .The Gasoline Direct Injection (GDI) engines give anumber of features, which could not be realized with port injected engines:

- Avoiding fuel wall film in the manifold,
- improved accuracy of air/fuel ratio during dynamics,
- Reducing throttling losses of the gas exchange by stratified and homogeneous lean operation,
- Higher thermal efficiency by stratified operation and increased compression ratio,
- Decreasing the fuel consumption and CO_2 emissions, lower heat losses.
- Increased performance and volumetric efficiency due to cooling of air charge.

3. ENGINE EFFICIENCY

The parameters that have the greatest influence on engine efficiency are

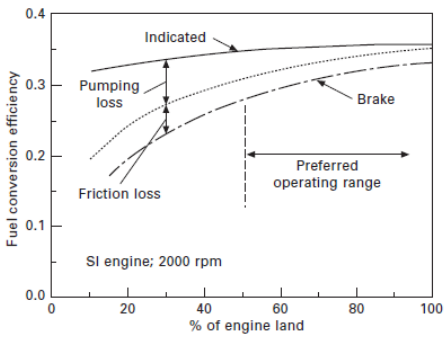

Fig.1:Parameters affecting engine Efficiency

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3.1 Compression Ratio

The effect of raising compression ratio is to increase the power output and to reduce the fuel consumption. In these engines, the compression ratio is about 9/1-10/1. Since knocking combustion occurs at full load operations, engines can be made to operate at a higher compression ratio at part load conditions and at a reduced compression ratio at full load by designing them to be capable of variable compression ratios. Unfortunately, owing to the additional complexity and cost as well as performance issues, no variable compression ratio engines are currently in production. The use of high octane fuel is another effective way to allow the gasoline engine to operate with higher compression ratios, such as alcohol fuels.

3.2 Air/Fuel ratio

The maximum efficiency (or minimum specific fuel consumption) occurs with a mixture that is weaker than stoichiometric because the port fuel injection engines work at stoichiometric air/fuel ratio, it is impossible to see more improvement in the fuel economy.

3.3 Volumetric Efficiency

For the same engine volume, the increasing volumetric efficiency also raises the engine power output. In engines with throttle plate, flow is restricted and hence the volumetric efficiency decreases and hence engine has to do work for intake and exhaust process leading to loss of efficiency.

3.4 Frictional Losses

More the frictional losses less will be the engine efficiency. Frictional loss can be reduced by adopting low friction mechanical devices, improved surface treatment and lubrication management. As the rubbing loss is proportional to the surface area, a smaller displacement engine will suffer less friction. In addition, smaller displacement engines reduce the weight. The most important attribute of replacing a large engine with a smaller displacement one is its potential for significant fuel economy benefit by shifting the engine operation from the least efficient part load operation conditions to wide open throttle operations. This is commonly referred to as engine downsizing.Through downsizing, the smaller engine will be operated more often at higher load and wide open throttle conditions, avoiding the less efficient part load conditions. However, the downsized engine needs to be boosted to meet the maximum power and maximum torque requirement. The maximum pressure charging of spark ignition gasoline engines is, however, limited by knocking combustion.

4. HOW GDI IMPROVES ENGINE EFFICIENCY

4.1 Higher Compression Ratio is employed without knocking.

Since knocking combustion is most sensitive to the compression temperature of the fuel/air mixture, it can be minimized by reducing the charge temperature in the cylinder. Direct injection of liquid fuel in the cylinder permits the fuel evaporation to take heat from the surrounding air and causes the air temperature to drop. At full load conditions, the charge cooling effect is large enough to allow the engine's geometric compression ratio to be increased by a couple of ratios without causing knocking combustion. Knocking does not occur because only air is compressed at low and medium loads. At full load, since fuel is injected into cylinder, the charge air cool and this, in turn, decreases knock tendency.

4.2 It works on lean air fuel mixture at part load.

Since GDI works on lean mixture at part load, hence engine efficiency is increased at part load. Direct injection technology can extend the overall in-cylinder air to fuel ratio to 100:1 by stratified charge combustion, where the near-stoichiometric mixture is located near the spark plug, while the excess air is mainly distributed in the rest of the combustion chamber.

4.3 Higher Volumetric Efficiency

As GDI engines are unthrottled at part load hence the engine efficiency increase at part load and it is slightly throttled at full load.

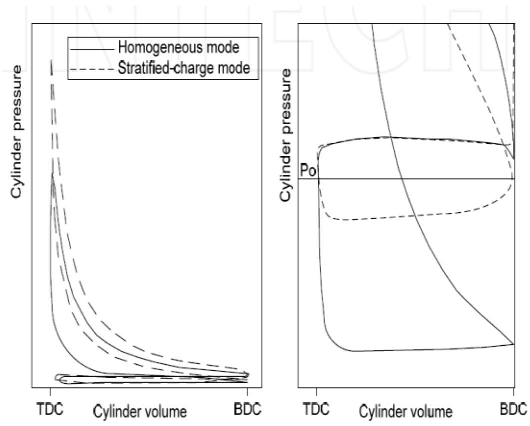

Fig2: Reduction In throttle losses in Stratified Mode

4.4 Engine downsizing with GDI reduces frictional losses.

With the charge cooling effect of direct injection, higher boost pressure can be employed in downsized engines without the risk of knocking combustion toallow a naturally aspirated engine to be replaced with a smaller boosted engine.

5. REASONS FOR INCREASE IN GDI THERMAL EFFICIENCY

The benefits of direct fuel injection in gasoline engines in terms of efficiency can be demonstrated by considering the Otto cycle (constant-volume process) – the assumed ideal process for a gasoline engine. In simplified form, with the assumption of ideal gas as a working fluid, the thermal efficiency of the constant-volume process follows this equation.

$$\eta_{f,i} = 1 - \frac{1}{r_c^{\kappa-1}}$$

The efficiency is only affected by the compression ratio rc of the engine and the isentropic exponent k. The highest possible efficiency is therefore produced by a high compression ratio and a large isentropic exponent, which in turn depends on the mixture composition and temperature.With direct fuel injection, sensible enthalpy is decreased in the combustion chamber due to the vaporization of fuel and the associated evaporative cooling. This decreases the temperature at the end of compression, which means that these engines are less prone to knock than engineswith port fuel injection. The improved

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knock resistance can be used to increase the compression to between roughly 1.5 and 2 units, which reduces fuel consumption by approximately 3%.

The greatest increase in efficiency is achieved by the implementation of unthrottled operation with lean charge stratification. A high isentropic exponent (k) is achieved by maximizing the leanness of the mixture. The leaner the mixture that can be successfully used to operate the engine, the closer the isentropic exponent will be to its maximum value of 1.4 (that of pure air). In the case of direct injection, thermal efficiency can be increased by influencing two decisive variables: the compression ratio and the isentropic exponent.

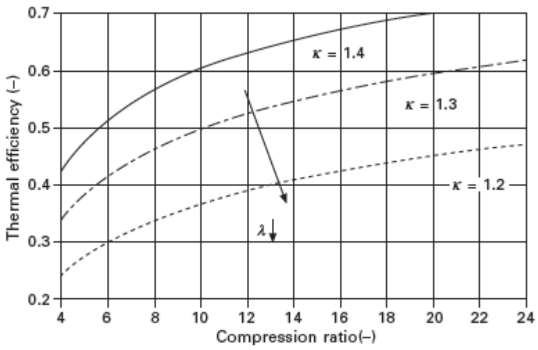

Fig3: Thermal Efficiency Of Constant Volume Process.

6. GDI OPERATION MODES

GDI engine operates at different operating modes depending on load and engine speed for a stable and efficient engine operation.

6.1 Lean mode

GDI engine operate with lean mixture and unthrottled at part loads, this operation provide significantly improvements in fuel economy.

Fuel is injected into cylinder before spark plug ignites at low and medium loads. At this condition, Air/Fuel (A/F) ratio in cylinder vary, that is, mixture in front of spark plug is rich, in other places is lean. In all cylinder A/F ratio is lean and A/F ratio can access until 40/1.

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. 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. The lean burn increases the NOx emissions. In this mode, EGR is actuated in order to decrease NOx.

6.2 Homogeneous mode

At full load, as the GDI engine operates with homogeneous charge and stoichiometric or slightly rich mixture, this engine gives a better power output and low emissions. In homogeneous operation, fuel starts injecting into cylinder at intake stroke at full loads. The fuel, which is injected in the intake stoke, evaporates in the cylinder. The evaporation of the fuel cools the intake charge. The cooling effect permits higher compression ratios and increasing of the volumetricefficiency and thus higher torque is obtained. At full load, as the GDI engine operate with throttle, only a small reductionof fuel consumption can be obtained to the PFI engine. In this mode, as engine operates with stoichiometric mixture, NOx emission decrease and therefore EGR is not activated.

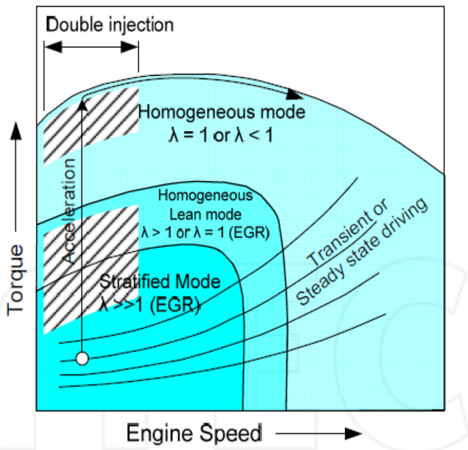

Fig.4: GDI operation Mode depending upon engine speed and load.

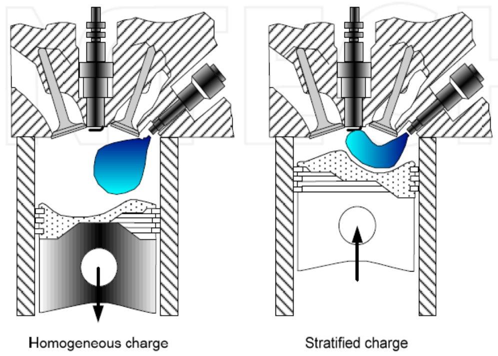

Fig5: Homogeneous An Stratified Charge Mode

7. MIXTURE FORMATION IN STRATIFIED MODE

In the stratified operation, three combustion systems are used to form an ignitable mixture near spark plug at the instant ignition. These are the wall-guided, air-guided and spray-guided combustion systems.

7.1 Wall-guided combustion systems

The fuel is transported to the spark plug by using a specially shaped piston surface. In most cases, the piston is shaped in such a way that the spray from the fuel injector is directed to the spark plug via the piston crown bowl. The mixture transportation during this process is normally supported by a swirl or tumble flow operation. As the fuel is injected on the piston surface, it cannot completely evaporate and, in turn, HC and CO emissions, and fuel consumption increase. To use this system alone is not efficient.

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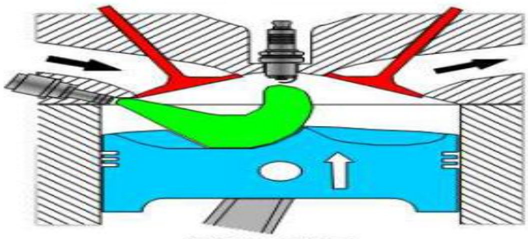
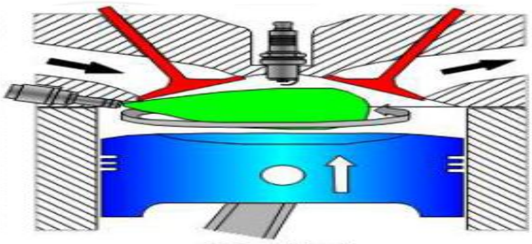


Wall guided

7.2 Air-Guided combustion system

In contrast to wall-guided systems, air-guided combustion systems aim to reduce the hydrocarbon emissions that are a by-product of wall-guided systems by preventing the fuel from coming into contact with the walls of the combustion chamber.

The fuel is injected into air flow, which moves the fuel spray near the spark plug. The air flow is obtained by inlet ports with special shape and air speed is controlled with air baffles in the manifold. Most of stratified-charge GDI engines use a large-scale air motion (swirl or tumble) as well as specially shaped piston a surface in order to keep the fuel spray compact and to move it to the spark plug.

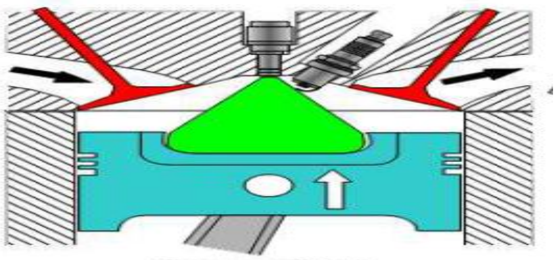


Air guided

7.3 Spray-Guided combustion system

An important feature of spray-guided combustion systems is the physical proximity of the spark plug to the fuel injector. It must be ensured, through optimum positioning of the spark plug in relation to the injection plume, that an ignitable mixture is present at the spark plug at the point of ignition for a wide range of operating conditions. When compared with wall/air-guided systems, fuel wetting on the pistons or combustion chamber walls is reduced to the point where it is essentially eliminated. This reduces the emissions of unburned hydrocarbons.

With wall/air-guided combustion systems, the swirl and/or tumble flow necessary to transport the mixture to the spark plug reduces the volumetric efficiency and therefore has disadvantages in terms of performance. In principle, this restriction does not apply to spray-guided systems. Hence, the spray-guided technique theoretically has the highest efficiency.



Spray guided

8. GDI EMISSIONS

Under homogeneous charge operation, the direct injection gasoline engine exhibits similar emission characteristics to that of the port fuel injection engine. The major difference lies in the part load stratified charged operation. In the case of direct injection stratified charge operation, the flame is subject to quenching in the extra lean region at the outer boundary of the stratified charge, resulting in a significant amount of unburned fuel mass in the cylinder. Over-rich regions near the piston due to wall wetting by the fuel spray also contribute to the unburned fuel left in the cylinder. Furthermore, an over-rich mixture in the inadequately prepared stratified charge region will lead to the formation of soot particles and subsequent particulate emissions. The lower in-cylinder temperature associated with the overall lean-burn operation reduces the post-flame oxidation effect more than that of homogeneous stoichiometric combustion. The overall unburned HC and soot/particulate emissions at part load stratified charge operation with direct injection are typically several times higher than those from homogeneous operations.

NOx emissions from part load stratified charge operation are higher than that from the homogeneous charge operation at the same load. Although the peak cycle cylinder average temperature is reduced due to the overall lean burn charge, combustion temperature in the stratified charge remains high and becomes higher than the homogeneous charge as combustion takes place at elevated pressure without throttle operation. Furthermore, NOx emission increases with advanced combustion timing, which is sometimes necessary to achieve stable stratified charge combustion by catching the near-stoichiometric mixture formed soon after the end of injection. Exhaust gas recirculation (EGR) is effective in reducing in-cylinder NOx formation by lowering the peak combustion temperature and acting as a diluent. However, a larger amount of EGR is required to reduce NOx emissions, since the exhaust gas of a lean-burn mixture contains less CO2 and water vapor.

Whilst the higher HC and CO emissions of stratified charge operation with direct injection can be accommodated by a more effective three-way catalyst, an additional after treatment system must be employed to reduce the level of exhaust NOx emission to meet the current emission legislation. Two types of lean-NOx after treatment systems have been implemented in production engines. The DeNOx catalyst or lean-NOx catalyst and NOx trap or NOx storage catalyst.

9. SUMMARY

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 toxic, CO2 emissions and fuel consumption to comply with stringent standards. To attain this potential, it is required that use of the GDI engines with supercharging and/or turbo charging. The GDI engines with turbo charger enable the production of smaller displacement engines, higher fuel efficiency, lower emission and higher power. The GDI engines also help eliminate the disadvantages conventional turbocharged engines (namely turbo lag, poorer fuel economy and narrowed emissions potential) 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 exhaust gas treatment 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. Thanks to mass production, if the prime cost of the GDI engines can be decreased.

Of the next-generation vehicles, only Hybrid Electric Vehicles (HEV) can be regarded as alternative energy vehicles. They have the potential to grade alongside conventional vehicles in terms of cost and convenience since their fuel costs are very low, although they cost more than conventional vehicles (Morita, 2003). It seems that large scale adoption of HEVs will not be realized unless their costs come down dramatically. GDI engine also doesn't force owner of motor vehicle to forgo luggage rack because of batteries, and doesn't make the car heavier. And it gives drivers lots of fun-to-drive torque very quickly.

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