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A Brief Study on Homogeneous Charge Compression Ignition Engine

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Abstract: HCCI (Homogeneous Charge Compression Ignition Engine) is a new mode of combustion which leads to the development of ICE. HCCI engine is an alternative to the present day diesel engine with higher thermal efficiency. To reduce the effect of pollutants, the development of engines by improving the technology and by friendly combustion process, the engines are able to achieve/meet the future emission standards. The recent advancement in HCCI engine, has meet these standards by reducing the NOx and soot emissions up to 85-90% and also by increasing its thermal efficiency 10-15% more than the present day gasoline and diesel engine. HCCI engines are operated upon gasoline, diesel, natural and most other alternate fuels. HCCI engines incorporated with the best features of both spark ignition (SI) and compression ignition (CI) engines. However, HC and CO emissions are slightly higher as compared to CI engines. So, the usage of methods like EGR (Exhaust Gas Recirculation), variable fuel ratio, and by variation of induced gas temperature. The paper looks in to the ignition timing of the HCCI engine and the factors effecting (or) depending to increase efficiency. Also the methods to required characteristics of HCCI engine.

Keywords: HCCI engine, EGR (Exhaust Gas Recirculation), spark ignition (SI), compression ignition (CI).

I. INTRODUCTION

1979, Onishi et al, discovered HCCI as on alternative combustion mode for two stroke IC engine and succeeded in combustion with high level of residuals and high initial temperature at light initial temperature at light load conditions. This technology was named as Active Thermo-Atmospheric Combustion. In the same year; Noguchi et al conducted a spectroscopic analysis on two stroke opposed piston engine of HCCI, they measured high levels of CHO, HO2 and O radicals with on the cylinder. 1983, Najt and Foster, experimented successfully on a four stroke HCCI engine with blends of paraffinic and aromatic fuels like Iso-octane and Heptane. Over different speeds and different dilution levels. And came with a result that low level of internal residuals are produced in four stroke engine. 1996, Thomas, Ryan et al used diesel in four stroke HCCI engine for a wide range of compression ratio from 7.5:1 to 17:1. In 1998, Christensen, proved that fuel stratification can extend to the low and high load limit of HCCI, by the usage of super charging in HCCI with three different fuels (iso-octane, ethanol and CNG).In 2005, the operating range is modified as, when the engine operates in HCCI mode at low, medium and crushing loads, when the engine is to operate at Hybrid mode.

II. WORKING

In HCCI combustion, the fuel and air are premixed to form a homogeneous (lean) mixture before the combustion happen at correct temperature and pressure. The self-ignition is controlled by chemical kinetics of the mixture without the influence of spark plug. The self-ignition temperature and pressure for HCCI is low when compared with diesel engine but the temperature attained is higher than the conventional gasoline engine. As the mixture is auto ignited, there will be difficulty in controlling mixture and the heat release rate at high load operation. The difficulties achieved in the engine are high load operations, cold start, knock control. High compression ratio in HCCI engine leads to fast combustion. HCCI raises the density and temperature by increasing compression until the entire mixture reacts spontaneously.

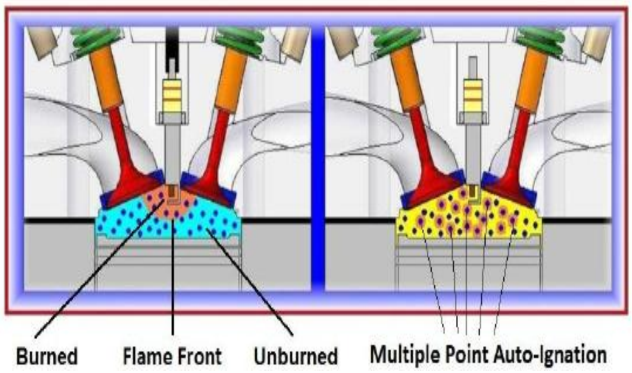

Fig: 2.1 HCCI Combustion Chamber

The ignition phases inside the SI, CI combustion chamber and the HCCI combustion is shown in fig: 2.1 in which the auto ignition takes place at multiple positions inside the combustion chamber unlike in SI and CI engines. HCCI achieves gasoline engine like emissions with diesel engine like efficiency.

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Major problem is knocking which is due to combustion where ignition happens before the piston reaching top dead center. Knocking reduces engine reliability due to high vibrate effects. To reduce Knocking, an intake air charge, varying the compression ratio and exhaust gas recirculation have produced a controlled combustion and reduced knocking. To overcome the major problems in SI and CI engines,

a large amount of alternate searches have been started by researchers by taking in consideration of both homogeneous combustion of SI engines and heterogeneous combustion of CI engine. HCCI combustion is the combination of SI and CI. HCCI engine produces ultra-low emissions of nitrogen (NOx) with exhaust gas recirculation and low particulate matter emissions. Engine manufacturers are facing many challenges to deliver conventional vehicles that unable to tolerate by the regulations of emission norms. The engine can operate, using premixed charge that burns volumetrically and homogeneously inside the cylinder is compressed by piston. High compression ratio in HCCI engine, ignite the mixture at idle (or) near idle conditions. The Intake charge is preheated to nearly 200degreeC, by keeping the compression ratio value between 6 to 8.1, in order to avoid advanced combustion. The delay of ignition is lead to NOx and pH formations. If the equivalence ratio decreases the spark assistance is also decreases. Through spark assistance the inlet air temperature and compression ratio can be decreased. The basic design of the combustion chamber of HCCI looks as follows as shown in Fig:2.2.

Fig: 2.2 Basic Design of the Combustion Chamber of HCCI

The fuel and air are preheated before entering the combustion chamber. Later the air is entered in one inlet and the fuel from the second inlet. The exhaust after the exhaust stroke is sent from the outlet or exhaust valve is shown in fig:2.2 designed in solid works. At cold start, idle and higher loads the engine switches in to spark ignition mode. Due to the homogeneous lean mixture the raising of inlet gas temperatures are neglected. The air intake is controlled by the throttle plate losses. As we know that, the HCCI engine operates at higher loads the method “DOWNSIZING” is used to maintain higher efficiency with less fuel consumption.

2.1) GASOLINE HCCI ENGINE

This was introduced to solve the problem of unwanted auto ignition/knocking which are frequently occurs in spark ignition. The HCCI engine has a potential to overcome the issues like propagating the flame with in the cylinder attaining a temperature of 2500k which leads to the emissions of NOx oxides. It is employed with self-ignited combustion. The ignition happens at various points, which extends rapidly in all directions, which reduces the overall combustion temperatures. Negative valve overlap is one of the technique that contributes to the ultra-low formation of NOx. The presence of unburned gases through EGR from negative valve overlap reduces the overall combustion temperatures. By changing the EGR level and fueling at constant air flow we can achieve higher efficiency.

2.2) DIESEL HCCI ENGINE

HCCI diesel engine was not important than the HCCI petrol engine. It is used to bring the NOx and pH to very low values. It also reduces the soot formations.

III. CHALLENGES

Challenges Faced in HCCI engine:

i) Knocking
ii) Emission reduction through EGR
iii) Cold start

3.1) KNOCKING

As the HCCI engines run on different fuels, knocking place a major role in engine performance and for attaining higher efficiencies. The knocking percentages varies for different fuels used. Knocking is burning of the fuel (air-fuel mixture) before the compression state. As the fuel mixture concentration in HCCI engines is mostly controlled through chemical kinetics, as the spark plug is not generated in HCCI it is very difficult to avoid knocking in these engines. So the engine purely depend upon the lean mixture used. Guo.et.al states that the amount of hydrogen content in hydrogen-diesel HCCI engine should not be more than 16%. To attain stable combustion it is necessary to maintain hydrogen content of 15% and also to avoid deterioration for the performance of the engine and to avoid engine damage. If the natural gas like di methyl ether used to run HCCI engine the in cylinder pressure must be maintained under 9MPA to avoid knocking and also in natural HCCI gas engines knocking depends upon equivalence ratio which should be less than 0.45 by having inlet temperature of 380k.

3.2) EXHAUST GAS RECIRCULATION (EGR)

EGR is the most preferable method followed to produce low emissions. The exhaust gas is trapped in the combustion chamber by closing the exhaust valve early than the usual closing time. The tapped gas mixes with the fresh charge by attaining auto-ignition temperature.

The gas is circulated homogeneously throughout the chamber so that the auto-ignition takes place at different locations simultaneously by performing homogeneous combustion. The emitting levels of emissions depends upon the EGR ratio circulated for auto ignition inside the chamber. NOx emissions are completely avoided in EGR process. With the increase of EGR percentage HC emissions increases periodically. The main purpose of EGR is to dilute the lean mixture for the controlled combustion rate. The trapping of EGR process is done through two methods internal EGR and external EGR.

3.2.1) INTERNAL EGR

It is a recompression or exhaust gas retention strategy. This strategy uses NVO method in which exhaust gas is trapped inside the cylinder by closing the exhaust valve early than the usual closing time after the exhaust stroke

3.2.2) EXTERNAL EGR

It is a re-induction strategy method, in this some amount of exhaust gas is re-admitted inside the cylinder through an external inlet valve.

Main purpose of these strategies is to dilute charge so as to attain control combustion rate for stable combustion. Through these strategies some EGR effects are produced and are classified as thermal energy effects and chemical species effects. Thermal energy effects are essential for initiation of combustion, while the release rate of heat and ignition timing is affected by chemical species in EGR.

3.3) COLD START

Cold start is one of the major problems in HCCI combustion at high and low loads. To avoid this cold start in engines different methods like SPCCI engines. But it effects the fuels used so to avoid cold start a new design possessing method is introduced by the name "NAUTILUS".

Unlike the conventional pistons, nautilus design has two pistons namely primary and secondary pistons. The secondary piston has the same dimensions as that of the conventional one but the main change in it is the primary piston is mounted on the secondary piston. As shown below in Fig: 3.1

Fig: 3.1 The Primary Piston is Mounted on the Secondary Piston

The various challenges of HCCI are rectified through dynamic multiphasic combustion. This multi phasic combustion technology allows addition of different fuels (lean mixture fuels) with in primary and secondary chambers. Incorporation of spark plug or turbo chargers or fuel injectors are used based upon the requirement. The fuel injectors, spark plugs, turbo chargers are mounted on the primary chamber and the auto-ignition firstly takes place inside the primary chamber. The piston design looks as shown below in fig 3.2

Fig: 3.2 Piston Design

The Primary chamber is also known as symmetrically controlled chamber. The nautilus cycle is protected from torching action by coating the chamber and through oil cooling. The shape of the primary piston looks like concave when viewed from top view. Coming to the cycle of the nautilus engine. It runs upon the Atkinson cycle. The cycle comprises with shorter compression strokes and larger expansion strokes.

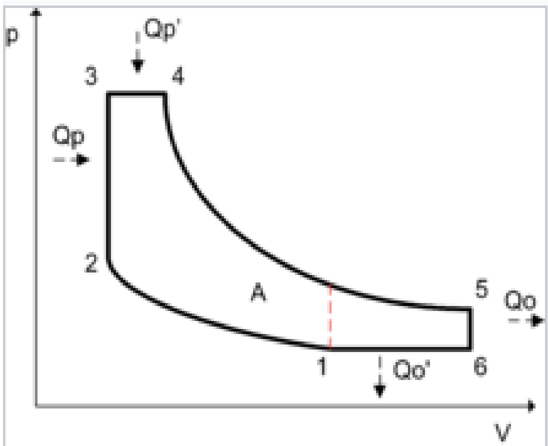

Fig: 3.3 Atkinson cycle P-V Diagram

Through this nautilus engineering the cold start problem is completely avoided by improved fuel atomization and vaporization before the piston reaches the combustion chamber through EGR and Fuel Injection.

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IV. CONCLUSION

HCCI combustion is the new mode of combustion phenomena. The combustion is controlled by chemical kinetics and through EGR by valve timing. This engine shows the capability of producing higher efficiencies like petrol engines and also lower emissions like diesel engines. However, the challenge like cold start is completely avoided through the new engineering concept of "NAUTILUS".

It must also see through the usage of fuels as the engine must be operated according to the requirement of the fuel used for combustion.

FUTURE SCOPE

The major challenges like Knocking, Emissions and cold start are seen and suitable solutions are represented in the paper. As the stable combustion is achieved in the HCCI and as well as the NAUTILUS HCCI, but the avoidance of HC and CO emissions is mainly depending upon the fuel properties we use.

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