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A Review of Stratified Charged SI Engines

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Abstract- Growing demand of energy efficient engines and ever-increasing awareness about emission has forced the engine manufactures to develop the engines, which are energy efficient and at the same time should create minimum emission. The both objectives can be fulfilled only if the engine can ensure the complete combustion and operate with as minimum specific fuel consumption as possible. This has led the development of principle in which, the SI engine uses very lean air-fuel charge and high compression ratio for best possible economy. The leanness also ensures the complete combustion. However, the design of such engine is rather a challenge because a sustainable flame has to be maintained with such lean air fuel charge. This paper explains the concept of lean combustion and reviews different aspects about design considerations, performance and limitations of engines employing lean combustion.

Index Terms- SI Engine; stratified charge engines; lean combustion.

1. INTRODUCTION

Spark Ignition and Compression Ignition are two well-established methods in IC Engines to obtain combustion. The engines using both the theories are working presently. However, both the engines have their own advantages and dis-advantages. The SI engines give good performance on full load. Such as good air utilization, effective combustion and high speed, however, their performance on part load is rather poor. On the other hand, Diesel engines offer good performance at part load (up to 80% load) but their full load performance is limited by objectionable smoke due to excessive local richening of air fuel mixture during full load operation (high rate of diesel injection). This has primarily led the Engine developers to think of some means to combine the advantages of both CI and SI engines. This led towards the development of stratified charge engines. The stratification means arranging into layers. In stratified charged engines, the charge near spark plug is essentially rich enough to initiate the combustion but as we go away from spark plug in combustion chamber, the mixture becomes leaner and leaner so that, the overall A/F ratio in combustion chamber is lean. Thus, the charge is stratified into rich (near spark plug) and lean layers. But, what are the consequences of this stratification?

1.1 PHILOSOPHY OF LEAN BURNING

With the use of leaner mixture and slightly higher compression ratio, In SI Engine a high performance level approaching the diesel engine can be achieved [1].

Consider the Air standard efficiency of an Otto cycle engine for a carbureted engine the value of γ is 1.28 to 1.3 approximately. As the mixture becomes leaner, this value of γ approaches the value of γ for air i.e. (γ=1.4) thus it is clear that with the use of leaner mixture, there is a direct gain in thermodynamic efficiency due to increased value of γ for mixture [2]. Further, in a lean mixture, the effect of dissociation is very small due to lower peak cycle temperature. This also results into gain in efficiency. Low cycle temperature due to leaner overall A/F ratio will also reduce the effect of variable specific heat thus finally resulting into reduction of specific fuel consumption. As we know, the gasoline engines are quantitatively governed [3]. The closing of throttle results into reduced quantity of charge intake resulting into less cylinder pressure but as the A/F ratio remains more or less constant; the peak cylinder temperature remains almost same. This directly results into increased losses to the coolant and hence high BSFC at part load operation (30 to 60 % throttle opening). This also implies that there is considerable effect of dissociation during Part load operation. Also during idling, the SI engine is subjected to charge dilution due to residual exhaust gases left over in previous cycle. The quantity of residual gases increases with the increase in clearance volume i.e. reduction in compression ratio for same cylinder dimensions. Thus, it is clear from above discussion that, if we use higher compression ratio, with over all lean A/F ratio, it can result into gain in part load as well as full load efficiency. This is further explained below in this section. In addition, the higher compression ratio can ensure faster flame propagation in lean A/F ratio due to increased charge density and increased reaction and transportation rate in burning charge. As we know, for same compression ratio, efficiency of otto cycle is greater than that of diesel cycle. It implies that, for higher compression ratio in SI engines, efficiency comparable to that of diesel cycle can be achieved. Hence, by keeping the compression ratio of an otto engine slightly less than that of diesel engine, and incorporating over all lean A/F ratios in combustion chamber, most of the advantages of diesel engines such as high thermal efficiency can be achieved. At the same time, certain disadvantages of compression ignition can be eliminated. Such as compulsory use of very high compression ratio for self igniting a heterogeneous mixture. The use of Spark plug for ignition in stratified charged SI engine gives a direct control over the combustion thus, eliminating the requirement of low ignition lag of fuel as demanded by diesel engine. The stratified charged engines employ direct injection of gasoline into combustion chamber like diesel engines. This enables an SI engine to be governed like CI engine and hence eliminates certain disadvantages of quantity governing (employed in SI Engine) like low manifold pressure during part load, poor air utilization at part load, High cycle temperature and increased pumping losses in manifold during part load. Use of dedicated injection system can improve fuel injection and hence can shorten the physical delay in the process of combustion. Thus, stratified charged engines are usually fuel tolerant and will operate with wide range of liquid fuels [4]

As the engine uses overall lean A/F ratio, the combustion ensures low NOx due to lower peak cycle temperature. In addition, the fuel injection eliminates disadvantages of non-exhaust type HC emissions from carburetor body. Also the presence of excess air in combustion chamber ensures lowest CO emission and HC emission from Engine exhaust. Stratified charged SI engines do not cause particulate pollution due to presence of homogeneous charge. The stratified charged engines offer smooth combustion (good rate of flame propagation) and inherent resistance to knock. This can be explained from figure 1

Fig shows the plan of stratified charged combustion chamber. The figure only shows the location of 'Spark Plug' with respect to walls of combustion chamber. This may not be always same in all engines but for the sake of understanding the effect of stratification, it is shown in this fashion. The charge strata that is in the vicinity of spark plug is rich in concentration and gives minimum ignition lag. This ensures instantaneous pre-flame reactions and hence effective burning of charge near the spark plug at all speeds and loads. As the flame advances towards the combustion chamber walls, it compresses the charge ahead of it

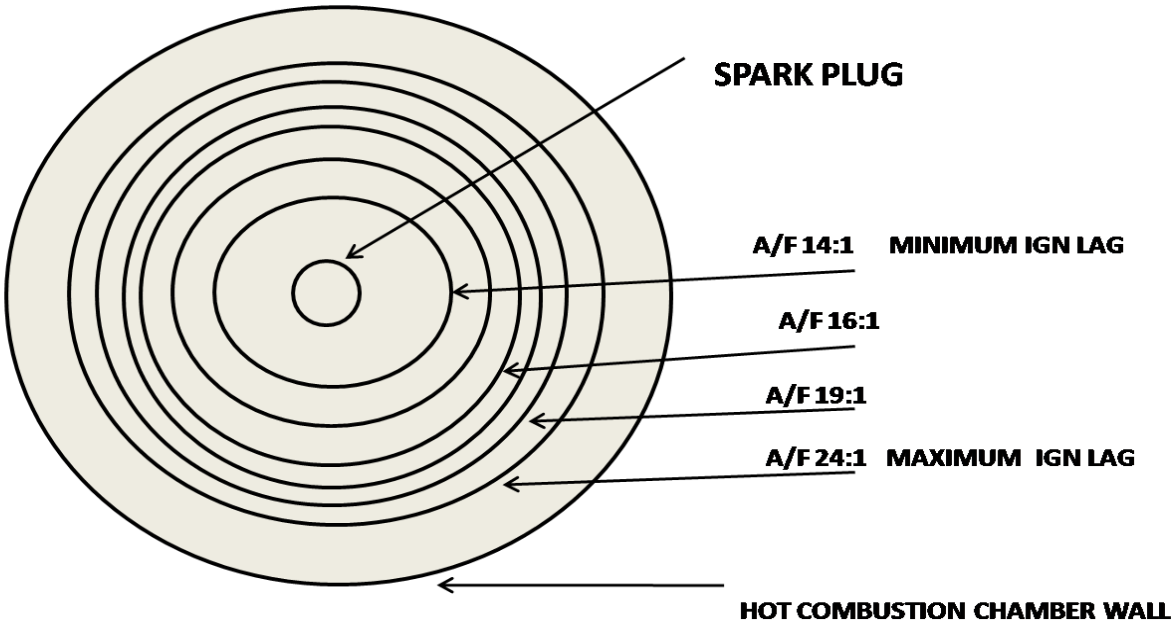

Figure 1 Charge stratification in Combustion chamber

but since the charge in contact with hot walls of combustion chamber is leaner, it is consumed by the flame before it can auto ignite due to its maximum (longer) ignition lag. This introduces an inherent resistance to detonation and hence promotes the use of low MON(Motor octane Number) fuel for use.

2. VARIOUS ASPECTS

In this section, we will see the various aspects regarding the charge stratification process and Effects uniquely associated with it. As we know, the combustion is a complex phenomenon and there are various aspects associated with this phenomenon. Here we will summarize some of the interesting aspects related with lean burn combustion.

The combustion studies suggest that the ignition cannot be defined as only a chemistry-based phenomenon and physical mixing should be included in the prediction of ignition delay in case of lean burning [5]. This implies that, the physical mixing of charge in lean combustion chamber has significant impact on combustion process. The main challenge for lean burn technology is that, under lean operating conditions, the conventional three-way catalyst TWC system is no longer effective in reducing NOx pollutants. A special TWC with NOx trapping and conversion capabilities, known as Lean NOx Trap LNT, has to be used downstream of the conventional TWC. This LNT requires proper control of storage and purge cycles to get good fuel economy and controlled NOx emission in case of lean burn gasoline engine. [6]

Also researches has reported that higher peak temperatures can increase the pollutant emission level of a stratified lean-charge engine much more as compared to a homogeneous lean-charge engine [7] Further, the NOx storage capacity of the LNT, one of the most critical parameters for its control strategies, varies dynamically. This is because the trap is susceptible to sulphur poisoning. As sulphates build up in the trap, the effective LNT trapping capacity is reduced [8]. This restricts the use of high Sulphur % in gasoline. A vast work has been carried out on hydrogen direct injection for stratified charged engines mainly due to following reasons.

1. In case of Direct hydrogen injection stratified charged engines, It is found that, NOx emissions and engine efficiency are strongly dependent on the equivalence ratio, which can be easily modulated with electronic fuel injection system.

2. DI operation is capable of achieving higher efficiencies and lower NOx emissions [9]

3. Hydrogen has an extremely higher burning velocity and wider flammable limits compared with hydrocarbon fuels. Hydrogen addition to methane has been reported to be effective to promote combustion at lean operation [10]

4. Direct injection in spite of its high cost, is still widely used in case of stratified charged engines. Bronislaw Sendyka and Mariusz Cygnar [11] reported that the increase in the total efficiency of GDI engine determined on the basis of test bed investigations varies considerably (10 to 17%) depending upon on the rotational speed and load of the engine.

There are various advances in Stratified charge engine technology the two of which are mentioned below.

A. The system producing effective Rich mixture in Spark plug zone e.g In PSC system, a passage is drilled in the metal cladding of the spark plug to accommodate a small section of capillary tubing, which is used to introduce the pilot fuel. [12]

B. The system with better combustion and achieving a sustainable flame front in over all lean mixture by implementing high heat release rates in the vicinity of Spark plug as in case of MITSUBISHI® lean burn gas engines. In this case, they adopted pilot liquid fuel injection in place of spark plug. The pilot fuel is very small in quantity but has powerful ignition energy 8000 times that of a spark plug, so that combustion is stable and efficiency is improved. Moreover, owing to the potent ignition energy, there is no need to prepare a high-concentration air-fuel mixture in the pre-combustion chamber as required in spark ignition engines; hence, production of NOx in the pre-combustion engine is lowered [13]. Like stratified SI engines, Stratified diesel engines are also getting popularity. The main reason is that. Certain modification in Diesel-like stratified charge engines makes it possible to avoid unwanted pollutions in the exhaust gas and building cheap engines without Oxi-cat and soot filters. [14]

3. CHALLENGES IN DESIGN

The charge stratification can be done with the help of generating swirl and using Spark ignition. This requires open combustion chambers. Some of the examples of this are.

1 TCP (Texaco combustion process)
2 FCP (Ford® combustion process)
3 'Witzkey Swirl Combustion Process'
4 AD Process
5 PROCO (Developed by Ford®)

Also, the stratification can be produced by parting combustion chamber as in case of Broderson method. In this case, the load control is achieved by variation in injection timing i.e. injecting during compression stroke or Suction stroke. However, parting the combustion chamber can lead to over richening of charge at high load and poor scavenging of pre-chamber.
To achieve combustion in stratified combustion chamber, the rate and most important the timing of fuel injection has to be precisely controlled. E.g., Broderson method of stratification works on proper timing of fuel injection [1]. Even a small error in injection timing can worsen the performance of engine leading to poor power output and efficiency or even misfire. In addition to this, the design of intake port and over- all design of combustion chamber is rather difficult task for charge stratification. Especially in swirl stratified charged engines. In these engines, the stratification is obtained by high degree of swirl (As in case of 'Texaco combustion process' and 'Witzkey Swirl Combustion Process'). For proper charge stratification, it is utmost important that a swirl of very high degree has to be generated inside the combustion chamber. This is possible only when the intake manifold, intake port, shape of combustion chamber are properly designed. In addition to this, location of Spark plug plays a vital role in initiation of combustion (e.g. in TCP) and placement of fuel injector at appropriate location ensures proper breaking of jet which is necessary for effective stratification. Thus the design cost of Stratified engines is much more than that of conventional SI and CI engines.

4 SUMMERY AND CONCLUSION

The engines employing charge stratification offers good part as well as full load efficiency. In addition, they exhibit an inherent resistance to knocking. Hence are suitable to use a wide range of liquid fuels. There is a scope of supercharging in stratified charged SI engines, provided that, the swirl should be properly generated inside the combustion chamber. An un-throttled SI engine is free from pumping losses and is good in volumetric efficiency. Also they tend to emit less NOx as well as less CO. Parting the combustion chamber for charge stratification as in case of Broderson method can lead to over richening of fuel at high load and poor scavenging of pre-chamber resulting in poor full load performance. As far as EMS (Engine Management System) is concerned, it should be precise to control load variations. The design of the Stratified combustion chamber is rather complex and requires advanced techniques like CFD to validate the required charge motion inside the combustion chamber. Their power to weight ratio is somewhat less due to employment of high compression ratio and induction of less heating value charge (lean mixture) per working cycle.

REFERENCES

[1] M.L Mathur, R.P. Sharma, Internal Combustion Engine, pp 778-798, Eight edition, Dhanpat Rai publication (P) Ltd. ISBN 978-81-89928-46-9
[2] Yunus A. Çengel, Michael A. Boles, Thermodynamics – An Engineering Approach, pp 494- 498, Fifth edition McGraw Hill Education
[3] V Ganesan, Internal Combustion Engines, pp 189-200, fourth edition, McGraw Hill Education (India) Pvt. Ltd ISBN 1-25-900619-0
[4] John B. Heywood, Internal Combustion Engine Fundamentals chapter 1, McGraw Hill,Inc
[5] S. HONG, M. S. WOOLDRIDGE and D. N. ASSANIS; Modeling of Chemical And Mixing Effects on Methane Auto Ignition Under Direct Injection, Stratified Charged Conditions; Proceedings of the Combustion Institute, Volume 29, 2002/pp. 711–718
[6] Feng Zhang, Karolos M. Grigoriadis, Matthew A. Franchek, Imad H. Makki; Linear Parameter-Varying Lean Burn Air-Fuel Ratio Control for a Spark Ignition Engine, Transactions of the ASME, Vol. 129, July 2007, 404-414
[7] C. Jimènez, D. Haworth, T. Poinsot, B. Cuenot And R. Blint; Numerical simulations of combustion in a lean stratified propane-air mixture, Center for Turbulence Research, Proceedings of the Summer Program 2000, pp 133-144
[8] Jing Sun, Yong Wha Kim and Leyi Wang; Aftertreatment control and adaptation for automotive lean burn engines with HEGO sensors, Int. J. Adapt. Control Signal Process. 2004; 18,145–166
[9] Vahid FATHI, Arash NEMATI, Samad JAFARMADAR ,Shahram KHALILARYA; Influence of initial charge conditions on engine performance and emission of a DISI Hydrogen-fueled engine under various injection timings, Turkish J. Eng. Env. Sci. 35 (2011) , 159 – 171

[10] Toshio Shudo, Koichiro Tsuga, Yasuo Nakajima; Analysis of Direct Injection Spark Ignition Combustion in Hydrogen Lean Mixture, Seoul 2000 FISITA World Automotive Congress ,June 12-15, 2000, Seoul, Korea

[11] Bronislaw Sendyka and Mariusz Cygnar; Stratified Charge Combustion in a Spark-Ignition Engine With Direct Injection System, http://dx.doi.org/10.5772/53971

[12] Danaiah P., Ravi Kumar P,Vinay Kumar D; Lean Combustion Technology for Internal Combustion Engines: a Review, Science and Technology 2012, 2(1): 47-50

[13] Akira Tsunoda, Hiromi Shimoda, Tatsuo Takaishi; MITSUBISHI Lean-burn Gas Engine with World's Highest Thermal Efficiency, Mitsubishi Heavy Industries, Ltd. Technical Review Vol.40 No.4 (Aug. 2003)

[14] H. Heitland, Prof. Dr.-Ing, G. Rinne, Prof. Dr.-Ing; New Concepts To Avoid Unwanted Pollutants From D.I. Diesel Engines In Passenger Cars, Journal of KONES Internal Combustion Engines 2003, vol. 10, No 1-2