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Laser Ignition System for I. C. Engines : Review

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ABSTRACT

Laser is a device, which emits electromagnetic radiation through optical amplification based on simulation emission of photons. "LASER" means Light Amplification by Simulated Emission of Radiation. Recent research in laser-induced ignition (LI) of air-fuel mixtures in internal combustion (IC) engines revealed that it has several advantages over conventional electrical spark ignition (SI). Spark plugs offer only limited possibilities for optimizing engine efficiency, due to their fixed position within a cylinder and the protrusion of electrodes which disturb the cylinder geometry and can quench the flame kernel. Laser radiation on the other hand is non-invasive and has greater flexibility in terms of the ignition position, allowing the possibility of multipoint ignition. Advantages of laser ignition include; reduced emissions, more stable combustion and lower idle speeds, when compared to conventional spark ignition. Current work reviews the key advances in Laser Ignition of internal combustion engines made by a number of research groups. The opportunities, challenges and prospects for future implementation of laser ignition in next generation internal combustion engines are also explored.

Keywords: IC (Internal Combustion), CI (Compression Ignition), SI (Spark Ignition), LI (Laser Ignition).

I. INTRODUCTION

IC engine will continue to be the important vehicle power plant over the next two decades, before significant displacement by alternative technologies takes place. Design of new engines are becoming more and more complex, with advanced combustion methodologies that burn an increasing variety of fuels to meet future goals on performance, fuel economy and emissions. Spark plug remained almost unchanged since its invention, yet its poor ability to ignite highly dilute air-fuel mixtures limits the potential for improving combustion efficiency. SI also restricts engine design, particularly in new GDI engines (Gasoline Direct Injection also known as Petrol Direct Injection, Direct Petrol Injection, Spark Ignited Direct Injection or Fuel Stratified Injection), since the spark position is fixed by the cylinder head location of the plug, and the protruding electrode disturbs the cylinder geometry and may quench the combustion flame kernel. In the recent past laser ignition of IC engines was examined by many researchers to know its potential to improve combustion efficiency and stability compared to SI by igniting highly dilute air-fuel mixtures with comparatively low ignition energies and to initiate ignition away from the (cold) walls of the combustion chamber. With recent advances made in laser technology, the range of Laser ignition control parameters now includes laser pulse energy, pulse duration, wavelength, plus optical techniques and pulse selection for spatial and temporal distribution of laser energy in either single or multiple ignition events [1].

II. BACKGROUND OF IGNITION IN IC ENGINES

Ignition is the process of starting radical reactions until a self-sustaining flame develops. We can distinguish between auto ignition, induced ignition and photo-ignition [2]. Photo-ignition is caused by photolytic generation of radicals and is out of scope in the current review.

2.1. Ignition Types in IC engines [2]:

a. Compression Ignition (CI) or Auto Ignition: At certain values of temperature and pressure a mixture will ignite spontaneously, this is known as the auto ignition or compression ignition.
b. Induced Ignition: A process where a mixture, which would not ignite by it, is ignited locally by an ignition source (i.e. Electric spark plug, pulsed laser, microwave ignition source) is called induced ignition. In induced ignition, energy is deposited, leading to a temperature rise in a small volume of the mixture, where auto ignition takes place or the energy is used for the generation of radicals. In both cases subsequent flame propagation occurs and sets the mixture on fire.

2.2. Disadvantages of conventional Ignition Systems [3]:

a. Spark plug position is not flexible as shielding of plug from immense heat and fuel spray is needed.
b. Optimal selection of Ignition location is not possible.
c. Spark plug electrodes can disturb the gas flow within the combustion chamber.
d. Carbon deposits on the spark plug needs to be cleaned on a timely manner.
e. Ratio between fuel and air has to be within the correct range to burn.
f. Higher turbulence levels are required.
g. Erosion of spark plug electrode.

2.3. Alternative Ignition Systems:

Protection of resources and the reduction of the CO_2 emissions with the aim to limit the greenhouse effect requires a lowering of the fuel consumption of motor vehicles. Great importance for the reduction lies upon the driving source. Equally important are the optimization of the vehicle by the means of a reduction of the running resistance as well as a low-consumption arrangement of the entire powertrain system. The most important contribution for lower fuel consumption lies in the spark ignition (SI) engine systems, due to the outstanding thermodynamic potential which the direct fuel injection provides. Wall and air guided combustion processes already found their way into standard production application and serial development, whereas quite some fundamental engineering work is still needed for combustion processes of the second generation. Problems occur primarily due to the fact that with conventional spark ignition the place of ignition cannot be specifically chosen, due to several reasons. By the means of laser induced ignition these difficulties can be reduced significantly. The combination of technologies (spray-guided combustion process and laser induced ignition) seems to become of particular interest, since the ignition in the fuel spray is direct and thus the combustion initiation is secure and non-wearing [4].

III. LASER

Lasers provide intense and unidirectional beam of light. Laser light is monochromatic (one specific wavelength). Wavelength of light is determined by amount of energy released when electron drops to lower orbit. Light is coherent and thus all the photons have same wave fronts that launch to unison. Laser light has tight beam and is strong and concentrated. To make these three properties occur something called "Stimulated Emission", in which photon emission is organized is needed. The process begins with multi-photon ionization of few gas molecules which releases electrons that readily absorb more photons via the inverse bremsstrahlung process to increase their kinetic energy. Electrons liberated by this means collide with other molecules and ionize them, leading to an electron avalanche, and breakdown of the gas. Multiphoton absorption processes are usually essential for the initial stage of breakdown because the available photon energy at visible and near IR wavelengths is much smaller than the ionization energy. For very short pulse duration (few picoseconds) the multiphoton processes alone must provide breakdown, since there is insufficient time for electron-molecule collision to occur. Thus this avalanche of electrons and resultant ions collide with each other producing immense heat hence creating plasma which is sufficiently strong to ignite the fuel. The wavelength of laser depends upon the absorption properties of the laser and the minimum energy required depends upon the number of photons required for producing the electron avalanche [3, 4].

3.1. LASER as Ignition System for I.C. engines:

For igniting the compressed air-fuel mixture in the I.C. engine, an alternative method is laser ignition system. Laser has the ability to produce short sparks which are very powerful irrespective to the pressure built up in the combustion chamber. Laser ignition system uses high voltage spark plugs which are good enough for the automotive use. The compression ratio goes around 10:1 and in some rare cases 14:1. Hence we need a special spark plug as here high pressure and high voltage is created. These spark plugs are expensive but would prove to be economical as they last long. The life and durability are far better than the normal spark plugs.

3.2. Types of Laser Ignition [5]:

Basically, energetic interactions of a laser with a gas may be classified into one of the following four schemes:

a. Thermal initiation: In thermal initiation molecular bonds are broken down to chemical reaction and this leads to ignition with typically long ignition delay time. This method is suitable for fuel or oxidizer mixture with strong absorption at the laser wavelength. Thermal initiation is used for solid fuels due to their absorption ability at infrared wavelengths.
b. Non-resonant breakdown: Mostly, laser ignition system works on the principle of non-resonances break down. The process begins with multi photons ionization. Electrons liberated are collide with the gas molecules, ionize them leading to an electron avalanche and breakdown of the gas. The resultant collision of ions produces immense heat energy hence creating plasma which is sufficiently strong to ignite the fuel.
c. Resonant breakdown: Resonance breakdown process involves multi photon dislocation of molecules resulting to freed atoms. This process generates sufficient electrons needed for gas breakdown. Theoretically, less input energy is required due to the resonance nature to this method.
d. Photochemical mechanisms: In photochemical ignition approach, with less direct heating takes place the laser beam brings about molecular dissociation leading to formation of radicals (i.e., highly reactive chemical species), if the production rate of the radicals produced by this approach is higher than the recombination rate (i.e., neutralizing the radicals), then the number of these highly active species will reach a threshold value, leading to an ignition event. This (radical) number augmentation scenario is named as chain-branching in chemical terms.

3.3. Advantages of Laser Ignition Systems [4, 6, 7]:

a. Location of spark plug can be placed anywhere in the combustion chamber as focal point can be placed to its independent point where as for spark plug it cannot change it place it need to place according to the adjusted place, its fixed.
b. In SI engines the spark plugs cannot combust the whole lean mixture but in LIS we can completely burn or combust the lean mixture.
c. In LIS it doesn't require to maintenance to remove carbon deposit because of its complete combustion property but we need to maintain the SI engine as the carbon material gets deposited on them.
d. Laser ignition leads to less pollution but SI partially can reduce the pollution to less extension.
e. It is easier to have a multipoint ignition system, where as in SI its highly difficult to have a multipoint ignition system.
f. Ignition of leaner mixtures than with the spark plug and lower combustion temperature result in less NOx emissions thereby reducing the pollution in environment.
g. Easier possibility of multipoint ignition.
h. Precise ignition timing possible.
i. Shorter ignition delay time and shorter combustion time.

3.4. Limitations of Laser Ignition Systems [6]

a. High system costs.
b. Concept proven, but no commercial system available yet.

IV.CONCLUSION

LI engines improve stability of combustion with proper control, can run under leaner conditions and at lower speeds without increasing noise, vibration, and harshness. LI systems can also control misfiring under a high level of dilution. As Laser igniters will be able to combust the fuel with lean air-fuel mixture when compared to conventional spark plug, they lower down the NOx emission and give better fuel efficiency and cleaner environment. The only limitation of LI systems is that it is highly expensive to setup. According to latest international reports, Mazda's rotary sport car could feature laser ignition system which would replace the spark plug ignition system, it is yet to come into the market. With the potential advantages over the conventional ignition systems, there is every possibility that LI systems would replace conventional spark plug based ignition systems in the near future.

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