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Full Length Review Article

BURNING FUEL WHITH THE HELP OF LASER IN AUTOMOBILE

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ABSTRACT

In today's world there is massive reduction in the fuel supply due to excessive use of vehicles. The moment when there is a direct inject of fuel engine shows the highest reducing in the fuel consumption and exhaust emission. Spark plugs offer only limited possibilities for optimising 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 is non-invasive and has greater flexibility in terms of the ignition position, allowing the possibility of multipoint ignition. Through this paper, the objective is to present the current state of the relevant knowledge on fuel ignition and discuss selected applications, advantages, in the context of combustion engines. Sustainability with regard to internal combustion engines is strongly linked to the fuels burnt and the overall efficiency. Laser ignition can enhance the combustion process and minimize pollutant formation. This paper is on laser ignition of sustainable fuels for future internal combustion engines.

INTRODUCTION

In technical appliances such as internal combustion engines, reliable ignition is necessary for adequate system performance. Economic as well as environmental constraints demand a further reduction in the fuel consumption and the exhaust emissions of motor vehicles. At the moment, direct injected fuel engines show the highest potential in reducing fuel consumption and exhaust emissions. Unfortunately, conventional spark plug ignition shows a major disadvantage with modern spray-guided combustion processes since the ignition location cannot be chosen optimally. From the viewpoint of gas engine R&D engineers, ignition of the fuel/air mixture by means of a laser has great potential. Especially the thermodynamic requirements of a high compression ratio and a high power density are fulfilled well by laser ignition. Additionally, the spark plug electrodes can influence the gas flow inside the combustion chamber. Ignition strongly affects the formation of pollutants and the extent of fuel conversion. Laser ignition system can be a reliable way to achieve this.

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Study of Ignition in IC Engine

What is ignition?

Ignition is the process of starting radical reactions until a self-sustaining flame has developed. One can distinguish between auto ignition, induced ignition and photo-ignition, the latter being caused by photolytic generation of radicals

Ignition Types

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.

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.

Drawbacks of Conventional Ignition System

- Location of spark plug is not flexible as it requires shielding of plug from immense heat and fuel spray
- Ignition location cannot be chosen optimally.
- Spark plug electrodes can disturb the gas flow within the combustion chamber.
- It is not possible to ignite inside the fuel spray.
- It requires frequent maintenance to remove carbon deposits.
- Leaner mixtures cannot be burned, ratio between fuel and air has to be within the correct range.
- Degradation of electrodes at high pressure and temperature.
- Flame propagation is slow.
- Multi point fuel ignition is not feasible.
- Higher turbulence levels are required.
- Erosion of spark plug electrodes.

Alternative ignition systems

The protection of the resources and the reduction of the CO2 emissions with the aim to limit the greenhouse effect require 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 sector, 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. The engine tests in this paper are on laser ignited, spray-guided combustion. Another approach is laser ignition of a homogeneous mixture. Within the scope of this paper, laser ignition in homogeneous fuel/air mixtures was investigated in a combustion bomb without turbulence. In , other alternative ignition systems than laser ignition are reviewed. Laser ignition, microwave ignition, high frequency ignition are among the concepts widely investigated. In this article the basics of applied laser ignition, will be illustrated and it potential compared to a conventional ignition system.

Laser

Lasers provide intense and unidirectional beam of light. Laser light is mono chromatic (one specific wavelength). Wavelength of light is determined by amount of energy released when electron drops to lower orbit. Light is coherent; 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 takes something called "Stimulated Emission", in which photon emission is organized. Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source. Basically, energetic interactions of a laser with a gas may be classified into one of the following four schemes as de Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source.

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- thermal breakdown
- non-resonant breakdown
- resonant breakdown
- photochemical mechanisms

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Types of lasers

- Ruby laser
- Chemical lasers
- Excimer lasers
- Solid-state lasers
- Semiconductor lasers
- Dye lasers

LASER Ignition

Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source. Laser ignition uses an optical breakdown of gas molecules caused by an intense laser pulse to ignite gas mixtures. The beam of a powerful short pulse laser is focused by a lens into a combustion chamber and near the focal spot and hot and bright plasma is generated. Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source. Laser ignition uses an optical breakdown of gas molecules caused by an intense laser pulse to ignite gas mixtures. The beam of a powerful short pulse laser is focused by a lens into a combustion chamber and near the focal spot and hot and bright plasma is generated.

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 depend upon the absorption properties of the laser and the minimum energy required depends upon the number of photons required for producing the electron avalanche. Optical breakdown in air generated by a Nd:YAG laser.

Types of Laser Ignition

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Thermal initiation

In *thermal initiation* of ignition, there is no electrical breakdown of the gas and a laser beam is used to raise the kinetic energy of target molecules in translational, rotational,or vibrational forms. Consequently, molecular bonds are broken and chemical reaction occur leading to ignition with typically long ignition delay times. This method is suitable for fuel/oxidizer mixtures with strong absorption at the laser wavelength. However, if in a gaseous or liquid mixtures is an objective, thermal ignition is unlikely a preferred choice due to energy absorption along the laser propagation direction. Conversely, this is an ideal method for homogeneous or distributed ignition of combustible gases or liquids. Thermal ignition method has been used successfully for solid fuels due to their absorption ability at infrared wavelengths.

Non-resonant breakdown

In nonresonant breakdown ignition method, because typically the light photon energy is invisible or UV range of spectrum, multiphoton processes are required for molecular ionization. This is due to the lower photon energy in this range of wavelengths in comparison to the molecular ionization energy. The electrons thus freed will absorb more energy to boost their kinetic energy (KE), facilitating further molecular ionization through collision with other molecules. This process shortly leads to an electron avalanche and ends with gas breakdown and ignition. By far, the most commonly used technique is the nonresonant initiation of ignition primarily because of the freedom in selection of the laser wavelength and ease of implementation.

Resonant breakdown

The resonant breakdown laser ignition process involves,first, a nonresonant multiphoton dissociation of molecules resulting to freed atoms, followed by a resonant photo ionization of these atoms. This process generates sufficient electrons needed for gas breakdown. Theoretically, less input energy is required due to the resonant nature of this method.

Photochemical mechanisms

In photochemical ignition approach, very little direct heating takes place and 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.

Laser Ignition process along time Laser ignition encompasses the nanosecond domain of the laser pulse itself to the duration of the entire combustion lasting several hundreds of milliseconds. The laser energy is deposited in a few nanoseconds which lead to a shock wave generation. In the first milliseconds an ignition delay can be observed which has duration between 5– 100 ms depending on the mixture. Combustion can last between 100 ms up to several seconds again depending on the gas mixture, initial pressure, pulse energy, plasma size, position of the plasma in the combustion bomb and initial temperature.

Mechanism of Laser Ignition

It is well know that short and intensive laser pulses are able to produce an "optical breakdown" in air. Necessary intensities are in the range between 1010 to 1011W/cm2. At such intensities, gas molecules are dissociated and ionized within the vicinity of the focal spot of a laser beam and hot plasma is generated. This plasma is heated by the incoming laser beam and a strong shock wave occurs. The expanding hot plasma can be used for the ignition of fuel-gas mixtures. By comparing the field strength of the field between the electrodes of a spark plug and the field of a laser pulse it should be possible to estimate the required laser intensity for generation of an optical breakdown. The field strength reaches values in the range of approximately 3×104V/cm between the electrodes of a conventional spark plug. Since the intensity of an electromagnetic wave is proportional to the square of the electric field strength $I \propto E^2$, one can estimate that the intensity should be in the order of 2 × 106W/cm2, which is several orders of magnitude lower as indicated by experiments on laser ignition. The reason is that usually no free electrons are available within the irradiated volume. At the electrodes of a spark plug electrons can be liberated by field emission processes. In contrary, ionization due to irradiation requires a "multiphoton" process where several photons hit the atom at nearly the same time. Such multiphoton ionization processes can only happen at very high irradiation levels (in the order of 1010to 1011W/cm2) where the number of photons is extremely high.For example, nitrogen has an ionization energy of approximately14.5 eV, whereas one photon emitted by a Nd:YAG laser has an energy of 1.1 eV, thus more than 13 photons are required for ionization of nitrogen. The pulse energy of a laser system for ignition can be estimated by the following calculation. The diameter d of a focused laser beam is

$$D= 2*wf = 2*m2 *(2f\lambda/\pi d) \quad ....(1)$$

where M2 is the beam quality, F is the focal length of the optical element and D is the diameter of the laser beam with the wavelength λ.Now it is assumed that the laser beam irradiates a spherical volume

$$v =(4\pi w^3{}_f / 3)$$

From the thermodynamical gas equation the number of particles N in a volume V is

$$N=PV/KT \quad .....(2)$$

With the pressure p, temperature T and Boltzmann's constant k = 1.38 × 10 -23J/K. Inside the irradiated volume, N molecules have to be dissociated where first the dissociation energy Wd is required and finally 2N atoms are ionized (ionization energy Wi). Using known values for Wd= 9.79 eV and Wi= 14.53 eV for nitrogen, the energy for dissociating and ionizing all particles inside the volume can be calculated as

$$W=(\pi pd^3/6kt) * (Wd+2Wi) \quad ....(3)$$

For a spot radius of about 100 μm the equation gives a maximum energy of approximately 1 mJ. Since not all particles inside the irradiated volume have to be ionized, even smaller energies should be sufficient for generation of an optical breakdown. It is assumed that the intensity which is necessary for the generation of an optical breakdown processes is related to the pressure of the gas.

$$I \alpha (1/P^N) \quad ......(4)$$

With n =1…5 depending on the mechanism of multiphoton process. Higher pressures, like in a combustion chamber should ease the ignition process what favors the laser induced ignition.

Comparative Advantages of LI

Spark ignition system

- Less intense spark
- Restrictions while choosing the ignition location
- Leaner mixtures cannot be burned
- Spark plug ignite the charge in a fixed position, so they can't cope with a stratified charge.
- Flame propagation is slow
- Multi point fuel ignition is not feasible.
- NO_X emission Ratio between fuel and air has to be within the correct range.

It causes more NO_X emission

Laser ignition system

- More intense spark
- Free choice of the ignition location within the combustion chamber
- Leaner fuel can burn effectively
- Laser ignition system could cope with a stratified charge.
- Flame propagation is relatively fast resulting in shorter combustion time
- Easier possibility of multipoint ignition
- NO_X emission

Engines would produce less NOx if they burnt more air and less fuel, but they would require the plugs to produce higher-energy sparks in order to do so. Less NOx emission

Additional advantages of LI

- Absence of quenching effects by the spark plug electrodes
- No erosion effects as in the case of the spark plugs = lifetime of a laser ignition
- System expected to be significantly longer than that of a spark plug
- High load/ignition pressures possible => increase in efficiency
- Precise ignition timing possible
- Exact regulation of the ignition energy deposited in the ignition plasma
- Easier possibility of multipoint ignition
- Shorter ignition delay time and shorter combustion time

Conclusion

- Laser ignition system allows almost free choice of the ignition location within the combustion chamber, even inside the fuel spray.
- Significant reductions in fuel consumption as well as reductions of exhaust gases show the potential of the laser ignition process.
- Minimum ignition energy is mainly determined by the necessary "self-cleaning" mechanism at the beam entrance window from combustion deposits and not by engine- related parameters.
- No differences of the laser ignition process could be found at different laser wavelengths.
- Laser ignition is nonintrusive in nature; high energy can be rapidly deposited, has limited heat losses, and is capable of multipoint ignition of combustible charges.
- More importantly, it shows better minimum ignition energy requirement than electric spark systems with lean and rich fuel/air mixtures.
- It possesses potentials for combustion enhancement and better immunity to spurious signals that may accidentally trigger electric igniters.
- Although the laser will need to fire more than 50 times per second to produce 3000 RPM, it will require less power than current spark plugs. The lasers can also reflect back from inside the cylinders to relay information based on fuel type used and the level of ignition, enabling cars to readjust the quantities of air and fuel for optimum performance.

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