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To improve performance of Internal combustion engine with an aid of neodymium-doped yttrium aluminium garnet Laser Ignition System

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Abstract : Nowadays, combustion engines and other combustion processes play an overwhelming and important role in everyday life. As a result, study of ignition of combustion processes is of great importance. In most cases, a well-defined ignition location and ignition time is crucial for an IC engine. Spark plugs are well suited for such tasks but suffer from disadvantages, like erosion of electrodes or restricted positioning possibilities. Over the conventional ignition systems, ignition of combustible materials by means of high power laser pulses could be beneficial. Due to market demands aimed at increasing the efficiency and the power density of IC engines, existing ignition systems are rapidly approaching their limits. To avoid this, IC engine manufacturers are seeking new technologies. The thermodynamic requirements of a high compression ratio and a high power density are fulfilled well by laser 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. Ignition is the process of starting radical reactions until a self-sustaining flame has developed. In technical appliances such as internal combustion engines, reliable ignition is necessary for adequate system performance. Ignition strongly affects the formation of pollutants and the extent of fuel conversion. Laser ignition system can be a reliable way to achieve this. Fundamentally, there are four different ways in which laser light can interact with a combustible mixture to initiate an ignition event. They are referred to as 1. Thermal initiation, 2.Non resonant breakdown, 3. Resonant breakdown, and 4. Photochemical ignition. By far the most commonly used technique is the non-resonant initiation of combustion primarily because of its freedom in selecting the laser wavelength and ease of implementation. Optical breakdown of a gas within the focal spot of a high power laser allows a very distinct localization of the ignition spot in a combustible material. The hot plasma which forms during this breakdown initiates the following self-propagating combustion process. At the end we have discussed some experimental results regarding measurements of fuel consumption and emissions which prove that laser ignition has important advantages compared to conventional spark ignition systems.
Keywords : Nd: YAG Laser, Thermal initiation, Non resonant breakdown, Resonant breakdown, Photochemical mechanism, Self-cleaning,Multi point Ignition.

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1. 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.

2.Background Study of Ignition in IC Engine

2.1 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,

2.2 Ignition Types

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.

3. Conventional Sparking Plug Ignition

Conventional spark plug ignition has been used for many years. For ignition of a fuel-air mixture the fuel-air mixture is compressed and at the right moment a high voltage is applied to the electrodes of the spark plug.

3.1 Alternative ignition systems

In technical appliances like automatic burners and internal combustion engines, the electric spark plug has been in use for more than a century. For the ignition of especially fuel lean mixtures, alternatives to conventional electric spark ignition systems have been devised: high-energy spark plugs, plasma jet igniters, rail plug igniters, torch jet igniters, and pulsed-jet igniters, exhaust gas recirculation (EGR) ignition systems, laser-induced spark ignition and flame jet igniters.

4. 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.
- Flame propagation is slow.
- Multi point fuel ignition is not feasible.

- Higher turbulence levels are required.

5. 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; 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.

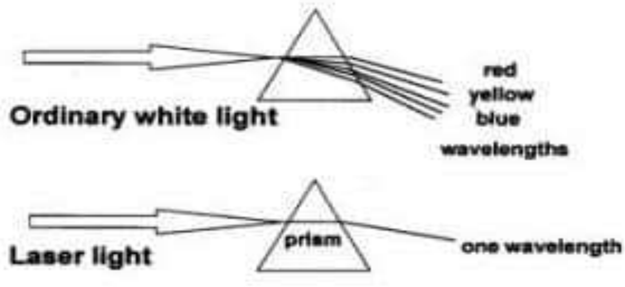

Figure 1: Laser light is monochromatic (one specific wavelength).

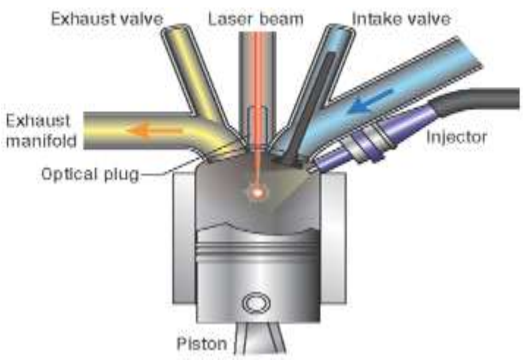

Figure 2: Arrangements of Laser Ignition system

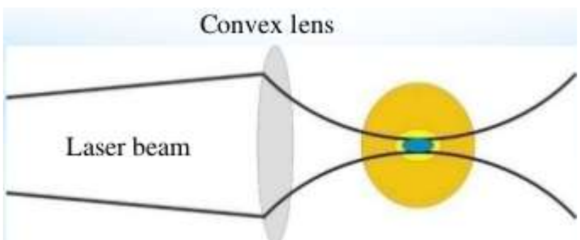

Figure 3:Ignition in combustion chamber by a Nd: YAG laser

6. 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. 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.

7. Types of Laser Ignition

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

• 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 non-resonant 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 non-resonant 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 non-resonant 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.

First experiments with laser ignition of the engine have been performed with an excimer laser, later a q-switched Nd: YAG has been used, see table 1.The replacement of the excimer laser was mainly caused by the fact that especially at very low pulse energies the excimer laser shows strong energy fluctuation. Pressure within the combustion chamber has been recorded as well as fuel consumption and exhaust gases. The laser was triggered at well-defined positions of the crankshaft, just as with conventional ignition systems. Pulse energies, ignition location and fuel/air ratios have been varied during the experiments. The engine has been operated at each setting for several hours, repeatedly. All laser ignition experiments have been accompanied by conventional spark plug ignition as reference measurements. Comparison between conventional spark plug ignition and laser ignition is as shown in figure 7 below. Laser ignition within the fuel spray of an injector shows the best results in reducing fuel consumption and exhaust emission at the same engine smoothness.

Table 1: Technical data of the research engine and the Nd: YAG laser used for the experiments.

Research engine		**Q-switchedNd:YAG laser**	
Number of cylinders	1	Pump source	Flash lamp
Number of valves	1	Wavelength	1064 or 532 nm
Injector	Multi-hole	Maximum pulse energy	160 mJ
Stroke	85 mm	Pulse duration	6 ns
Bore	1.6	Power Consumption	1 kw
Displacement volume	517 cm3	Power Consumption	6 mm
Compression ratio	1.6	Type	QuantelBrilliant
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8. Results

Results of the experiments are summarized in fig. 6. Fig. 6 shows that laser ignition has advantages compared to conventional spark plug ignition. Compared to conventional spark plug ignition, laser ignition reduces the fuel consumption by several per cents. Exhaust emissions are reduced by nearly 20%. It is important that the benefits from laser ignition can be achieved at almost the same engine smoothness level, as can be seen from fig. 6. Additionally, a frequency-doubled Nd: YAG laser has been used to examine possible influences of the wavelength on the laser ignition process. No influences could be found.

Best results in terms of fuel consumption as well as exhaust gases have been achieved by laser ignition within the fuel spray. As already mentioned, it is not possible to use conventional spark plugs within the fuel spray since they will be destroyed very rapidly. Laser ignition doesn't suffer from that restriction.

Another important question with a laser ignition system is its reliability. It is clear that the operation of an engine causes very strong pollution within the combustion chamber. Deposits caused by the combustion process can contaminate the beam entrance window and the laser ignition system will probably fail. To quantify the influence of deposits on the laser ignition system, the engine has been operated with a spark plug at different load points for more than 20 hours with an installed beam entrance window. As can be seen in fig. 4, the window was soiled with a dark layer of combustion deposits. Afterwards, a cold start of the engine was simulated. Already the first laser pulse ignited the fuel/air mixture. Following laser pulses ignited the engine without misfiring, too. After 100 cycles the engine was stopped and the window was disassembled. As can be seen from fig. 7, all deposits have been removed by the laser beam.

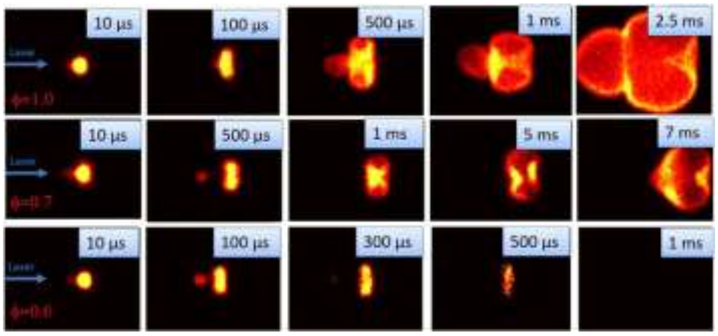

Figure 4:Flame propagation in combustion chamber

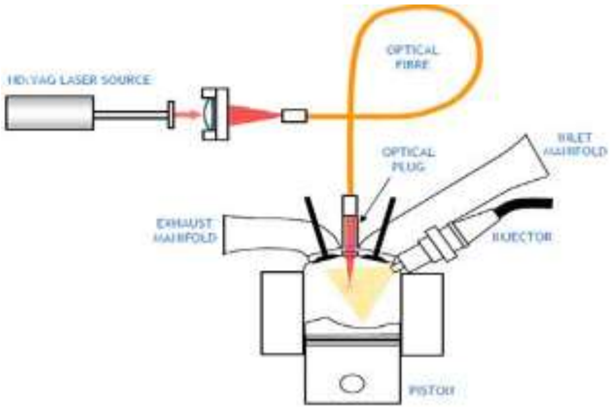

Figure 5: Arrangement set up of Laser ignition system

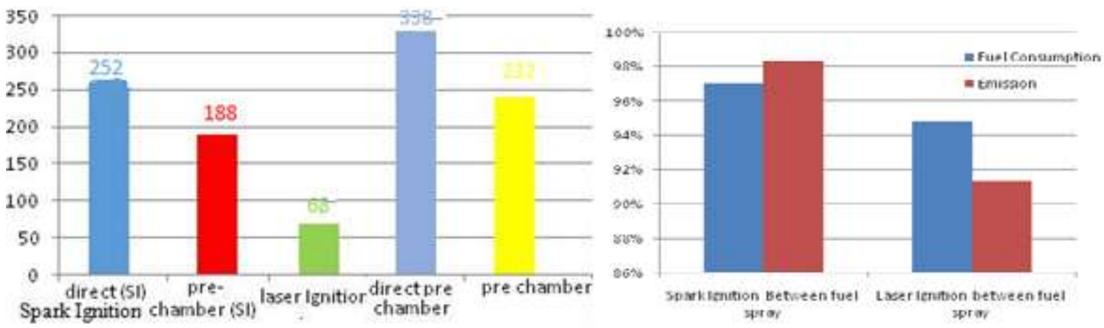

Figure 6: Performance chart for Spark ignition vs Laser Ignition system

Additional experiments showed that for smooth operation of the engine the minimum pulse energy of the laser is determined by the necessary intensity for cleaning of the beam entrance window. Estimated minimum pulse energies from eq. 3 are too low since such “self -cleaning” mechanisms are not taken into account. Engine operation without misfiring was always possible above certain threshold intensity at the beam entrance window. For safe operation of an engine even at cold start conditions increased pulse energy of the first few laser pulses would be beneficial for cleaning of the beam entrance window.

9. Comparative Advantages of LI

9.1 Spark ignition system

- Less intense spark
- Restrictions while choosing the ignition location
- Flame propagation is slow
- Multi point fuel ignition is not feasible.
- NOxemission, Ratio between fuel and air has to be within the correct range. It causes more

9.2 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
- 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

9.3 Additional advantages of LI:

- Absence of quenching effects by the spark plug electrodes
- System expected to be significantly longer than that of a spark plug
- 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

10. 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.
- More importantly, it shows better minimum ignition energy requirement than electric spark systems with lean and rich fuel/air mixtures.
- 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

11. References

1. Bergmann and Schaefer, Lehrbuch der Experimental physik: Elektrizit¨at und Magnetismus, vol. 2, Walter de Gruyter Berlin, 1981.
2. J. Ma, D. Alexander, and D. Poulain, “Laser spark ignition and combustion characteristics of methane-air mixtures,” Combustion and Flame, pp. 492–506, 1998
3. J. Syage, E. Fournier, R. Rianda, and R. Cohn, “Dynamics of flame propagation using laser-induced spark initiation: Ignition energy measurements,” Journal of Applied Physics, pp. 1499–1507, 1988.
4. M. Gower, “Krf laser-induced breakdown of gases,” Opt. Commune, pp.43–45, 1981.
5. R. Hill, “Ignition-delay times in laser initiated combustion,” Applied Optics, pp. 2239–2242, 1981.
6. T. Huges, Plasma and laser light, Adam Hilger, Bristol, 1975.

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