

# Laser Ignition System for IC Engine – A Review

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**Abstract**— Performance of future ignition system for internal combustion engines should be reliable and efficient to enhance and sustain combustion stability, since ignition not only initiates combustion but also influences subsequent combustion. Lean burn systems have been regarded as an advanced combustion approach that could improve thermal efficiency while reducing exhaust gas emissions. However, current engines cannot be operated sufficiently lean due to ignition related problems such as the sluggish flame initiation and propagation along with potential misfiring. A high exhaust gas recirculation engines also has similar potential for emissions improvement. Laser ignition (LI) has been shown to offer many potential benefits compared to spark ignition (SI) for improving the performance of internal combustion (IC) engines. In general, a well-defined ignition location and ignition time is of great importance for an IC engine. Spark plugs are well suited for such tasks but suffer from disadvantages, like erosion of electrodes & inflexible or un-optimal location of spark plug. Over the conventional ignition systems, ignition of combustible materials by means of high power laser pulses could be beneficial. Because the thermodynamic requirements of a high compression ratio and a high power density are fulfilled well by laser ignition. This paper outlines the current state of the relevant knowledge on fuel ignition and discuss selected applications, advantages, in the context of combustion engines

**Key words:** Laser-ignition, emissions, Combustion parameters

## I. INTRODUCTION

### A. Need and Invention:

With the development of industry and economy, energy short- age and environmental problems have been becoming more and more serious. The internal combustion engine and automotive industry are confronted with severe and realistic challenges. Lean burn is one of the effective methods to solve the above mentioned problems. However, current engines cannot be operated sufficiently lean due to ignition related problems such as the sluggish flame initiation and propagation along with potential misfiring. It is anticipated that the spark ignition engine of the future will operate with much higher compression ratios, faster compression rates, and much leaner fuel-to-air ratios.

Overcoming these challenges. Loss of engine power output can be compensated by boosting the charge density in the combustion chamber Increased charge density however requires higher secondary coil voltage to initiate combustion in a spark ignition engine which is using conventional spark ignition system. The voltage required to produce the spark depends on factors such as pressure inside the combustion chamber at the time of ignition, distance between the electrodes, and cylinder gas temperature. Providing the

required voltage under these conditions would lead to spark electrode erosion. Since lean mixtures have relatively slower flame speed than stoichiometric mixtures, any technique which may provide increase in the air–fuel mixture burning rate, would be beneficial. Flame speed in the lean burn SI engine can be increased either by generating turbulence in the cylinder or by shortening the flame travel distance for the same mixture strength. Reduction in flame travel path can be realized by employing multiple spark plugs in each cylinder or by placing the ignition point at an optimum location inside the combustion chamber.

### B. Laser Ignition System:

**Laser spark plug:** In recent years, laser ignition has become an active research topic because of its many potential benefits over the conventional electric spark ignition. The major benefits are greater control over the timing and locations of ignition. Moreover, it is accomplished without electrodes, which allows the lifetime of a laser-ignition system to be significantly longer. What is more, laser induced spark ignition would also allow ignition in multiple locations inside the chamber to shorten the combustion time of lean mixtures.

LI provides 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, NOx 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.

## II. LITERATURE REVIEW

### A. Thermal Initiation & Ignition:

Bruce Chehroudi [1], In order to ignite a mixture of gaseous fuel and air and initiate a flame, a localized input energy in a form of heat or active chemical species (radicals) must be added. The magnitude of this energy should be higher than a critical value called minimum ignition energy ( $E_{min}$ ). The physics of combustion initiation guides us to a requirement of a minimum flame embryo (flame kernel) size or radius of, say  $L_k$ , see Ronny (1994). The  $L_k$  can be approximated by the thickness of a flame front ( $L_f$ ) consuming the charge in a homogeneous fuel-air mixture. Hence, the simplest physical picture of the ignition process can be formed as an injection of a certain minimum amount of energy ( $E_{min}$ ) to raise the temperature of a spherical zone of fuel-air mixture with size of  $L_f$  to a distinct temperature referred to as “adiabatic flame temperature”. The term “adiabatic flame temperature” defines a terminal temperature of a fuel-air mixture when its combustion occurs under adiabatic condition (i.e., no heat losses from the combustion chamber). For example, experimentally speaking, the  $E_{min}$  of about 0.02 mJ energy is needed to ignite a stoichiometric mixture of hydrogen in

air, whereas 0.4 mJ is required for methane and air mixture. Fundamentally, there are four different methods in which laser light can interact with a combustible gaseous mixture for ignition. They are referred to as thermal initiation, nonresonant breakdown, resonant breakdown, and photochemical ignition. 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 either translational, rotational, or vibrational forms. Consequently, molecular bonds are broken and chemical reaction occurs.

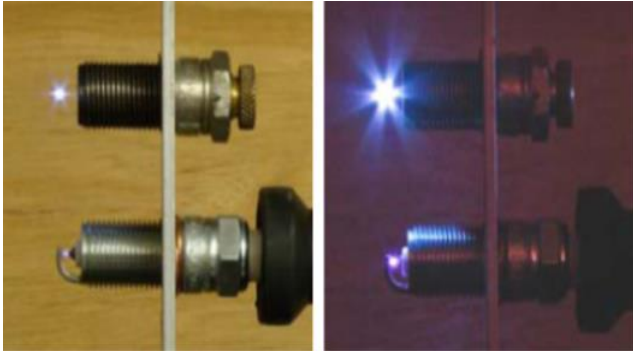


Fig. 1: Two photographs comparing a sparking optical laser plug (top) and a conventional spark plug (bottom).

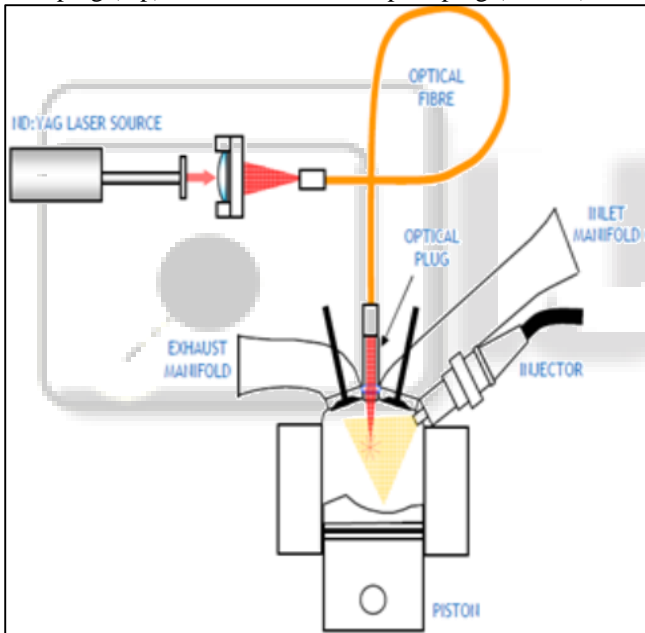


Fig. 2: Ignition System of laser spark in engine

There are four principle mechanisms by which laser radiation can ignite combustible gas mixtures: i/ Thermal initiation (TI); ii/ Non-resonant breakdown (NRB); iii/ Resonant breakdown (RB); iv/ Photo-chemical ignition (PCI). TI involves the gas mixture consuming laser energy to heat it to beyond the threshold ignition temperature. TI is also possible by heating of a target surface in the combustion chamber. In NRB, which is similar to electric SI, the focused laser beam creates an electric field of sufficient intensity to cause dielectric breakdown of the air-fuel mixture. The process steps are: multi-photon (MP) ionization of a few molecules to release electrons; ‘inverse bremsstrahlung’ to increase the electron kinetic energies, collision with and ionization of other molecules; electron avalanche and breakdown of the gas mixture. At atmospheric pressure, the electric field strength necessary for laser induced breakdown (LIB) in gases is higher than for SI and, for ms duration

pulses, the threshold optical intensity for NRB is of the order 1011 W/cm<sup>2</sup>. Increasing the pressure to levels representative of real engine conditions reduces the MIE. RB involves resonant absorption (by the atoms) of laser radiation at one or more specific wavelengths. iii/ differs from ii/ in that the free electrons needed for breakdown are created by two preceding steps: non-resonant MP photo-dissociation of a molecule, and then resonant photo-ionization of the atom created by the first step. MP absorption and ionization are thus key initiating steps for both ii/ and iii/. PCI involves single photon absorption and dissociation, usually requiring UV light. At high intensities, two-photon or MP absorption in matter can result in release of the accumulated energy as a single high-energy photon. In this way, resonant absorption at short wavelengths by the action of longer wavelength laser light is possible.

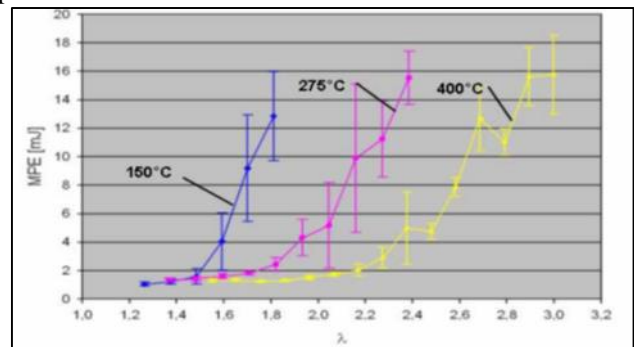


Fig. 3: Dependence of minimal ignition energy on temperature and Lambda

### III. EQUIPMENT AND TOOLING

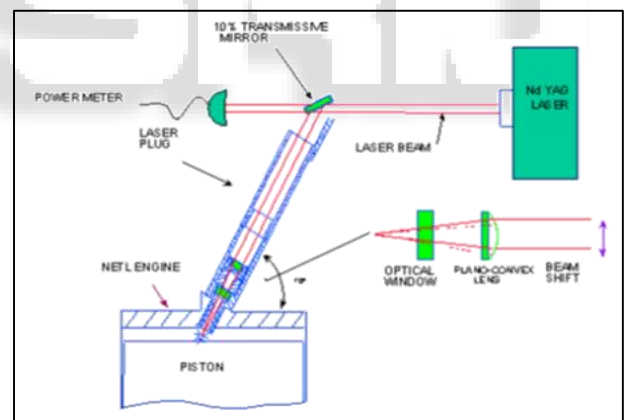


Fig. 4: Firing of Laser Spark

NETL Researchers designed a laser ignition system and coupled it with a fully-instrumented internal combustion engine. Focusing a laser pulse into the cylinder through the spark plug port generates a laser ignition spark. The laser pulse comes from a Quanta Ray DCR-2 Nd:YAG laser directed to the cylinder with high energy laser mirrors. A lens is placed at a certain distance from the final focusing lens to reduce the diameter of the laser beam before entering the lens tube. The laser is focused into the cylinder with lens through sapphire window. The lens is positioned on a lens tube aligned radially to the crankshaft axis of the engine. The final mirror directing the laser beam to the lens is positioned directly above the tube and 45 degrees to the tube axis such that the beam incident on to the mirror is perpendicular to the laser plug axis and tangent to an arc centered on the crankshaft.

#### IV. LASER SPARK PLUG COST AND PERFORMANCE REQUIREMENTS

Mechanical: Laser and mounting must be hardened against shock and vibration.

Environmental: Laser should perform over a large temperature range.

Peak power: Laser should provide megawatts raw beam output.

Average power: 1-laser per cylinder requires 10Hz for 1200rpm engine operation.

Lifetime: 100million shots–good, 500million shots–better.

Cost (stationary): Laser cost less than \$3000 each (100M pulse life \_ break even).

Cost (automotives): Laser cost less than \$600 each.

#### V. DRAWBACKS OF CONVENTIONAL IGNITION SYSTEM

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

#### VI. BENEFITS OF LI

The potential benefits of LI have been cited as:

- 1) variation of ignition location in the cylinder;
- 2) no electrodes to disturb cylinder geometry or to quench a propagating flame kernel;
- 3) potential for engine control by varying ignition energy;
- 4) multiple ignition points in a cylinder;
- 5) lower energy needed for combustion ;
- 6) more stable combustion and increased engine performance;
- 7) reduced tailpipe emissions ;
- 8) combustion of leaner air-fuel mixtures;
- 9) shorter ignition delays and faster combustion ; and
- 10) potential for optical combustion sensing.

#### VII. CONCLUSION

- 1) Laser ignition system allows almost free choice of the ignition location within the combustion chamber, even inside the fuel spray.
- 2) Significant reductions in fuel consumption as well as reductions of exhaust gases show the potential of the laser ignition process.
- 3) 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.
- 4) No differences of the laser ignition process could be found at different laser wavelengths

- 5) 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.
- 6) More importantly, it shows better minimum ignition energy requirement than electric spark systems with lean and rich fuel/air mixtures.
- 7) It possesses potentials for combustion enhancement and better immunity to spurious signals that may accidentally trigger electric igniters.
- 8) With proper control, improvements can enable engines to be run under leaner conditions, with higher EGR concentrations, or at lower idle speeds without increasing the noise, vibration and harshness characteristics of a vehicle.

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