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# LASER IGNITION SYSTEM FOR INTERNAL COMBUSTION ENGINE

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## ABSTRACT
Laser ignition is considered to be one of the most promising future ignition concepts for internal combustion engines. It not only combines requirement of reduction of pollutant emissions but also improves engine efficiencies. 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. Also the conventional ignition system cannot burn leaner air fuel mixture properly. In order to overcome the disadvantages of conventional ignition system, laser ignition system is researched upon. Laser ignition system gives the advantages like-it will reduce the NOx emission by 20%,it will be able to give improved efficiencies .Also the Thermodynamic requirements of a high compression ratio and a high power density are fulfilled well by laser ignition system. . This paper outlines progress made in recent research on laser ignited IC engines, discusses the potential advantages and control opportunities and considers the challenges faced, construction and working of laser ignitor and the system requirements for laser ignitor. The igniting plasma is generated by a focussed pulsed laser beam. In order to generate the laser Nd:YAG is chosen as laser active medium emitting at λem = 1064 nm, and Cr:YAG as passive saturable absorber. There are four different ways in which laser light can interact with a combustible mixture to initiate an ignition event namely- 1. Thermal initiation, 2. Non resonant breakdown, 3. Resonant breakdown, and 4. Photochemical ignition .Out of the above stated different ways non resonant breakdown is more frequently used because of its freedom in selecting the laser wavelength and ease of implementation. At present the laser ignition plug is very expensive and commercially not yet available**.**

**Keywords**: Laser-ignition, Alternative Fuels, Nd: YAG Laser, Multi point Ignition. emissions

## INTRODUCTION
Combustion processes of various kinds are widely used in industrial as well as in everyday life, like combustion engines. In most cases, a well defined ignition location together with a well defined ignition time of combustion processes is of great importance. Ignition of a combustible material is usually defined as an initiation of a self sustained reaction which propagates through the combustible material even after removing the ignition source. Conventional ignition systems, like spark plugs are well suited but suffer from disadvantages like NOx emission, Electrode erosion, influences on the gas flow as well as restricted positioning possibilities are the main motives in search of alternatives to conventional ignition systems. Additionally, violent combustion processes can even destroy the ignition system and thus inhibit repeated ignitions. On the other hand, it is well known that short and intensive laser pulses are able to produce an"optical breakdown" in air. Necessary intensities are in the range between 1010 . . . 1011W/cm2. At such intensities, gas molecules are dissociated and ionized within the vicinity of the focal spot of a laser beam and a 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 a combustible material. Other laser ignition methods, like thermal ignition of a combustible due to heating of a target or resonant absorption which generates radicals are not able to fulfill the requirements on a well defined ignition location or time and will not be discussed further. This paper is on laser ignition of sustainable fuels for future internal combustion engines. In most cases,

only slow combustion processes have been investigated. Basics of fast combustion processes will be discussed briefly.

**Background Study of Ignition in IC Engine 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.

**Types of Ignition**

**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 and 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.

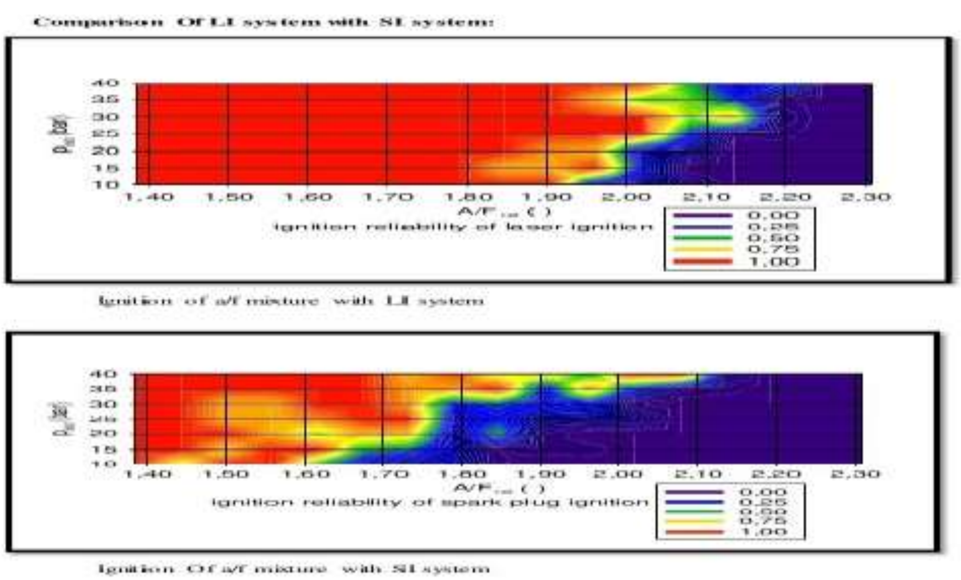
**Conventional Sparking Plug Ignition**

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.

**Alternative ignition systems**

**Laser ignition** As mentioned earlier, only laser ignition by optical breakdown fulfils the requirements on a well defined ignition location and time. A powerful short pulse laser beam is focused by a lens into a combustion chamber and near the focal spot a hot and bright plasma is generated.

**Comparision Between Laser Ignition System And Spark Ignition System:**




**TYPES OF LASER IGNITION SYSTEM:-**

**1. 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.

**2. 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.

**3. 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.

**4. 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.

**TYPES OF LASER:**

There are different types of laser which can be used:-

1. Ruby laser
2. Chemical lasers
3. Excimer lasers
4. Solid-state lasers
5. Semiconductor lasers
6. Dye lasers

## Mechanism of laser ignition system:

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 to1011W/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 ∝E2, one can estimate that the intensity should be in the order of 2 × 106 W/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 approximately 14.5 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

$$D=2x\ wf=2xM2x(2\ \lambda f/\pi d)..(i)$$

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

$$V=4\pi wf3/3$$

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

$$N=pv/kt \quad ..(ii)$$

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

$$W= (\pi pd3/6kt) \times (wd+2wt) \quad ..(iii)$$

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.

$$I\alpha \ 1/pn \quad \text{-----(iv)}$$

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

## WORKING OF LASER IGNITION SYSTEM

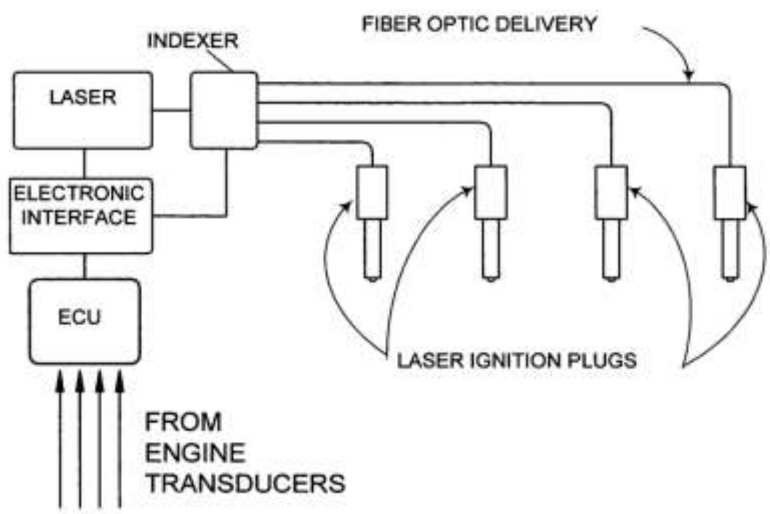



***Fig.Block Diagram of Laser Ignition System***

To provide appropriate ignition timing for combustion, igniter is in communication with an electronic control module (ECM) via a power supply and fibre optics. Based on various input received by ECM like engine speed, engine load, emissions production or output ,engine temperature, engine fueling, and boost pressure, ECM may selectively direct a high-energy light beam from a laser energy generator to each igniter via fibre optics cable.ECM include components like memory, a secondary storage device, and a CPU.A battery of 12v to 24v gives power to either ECM or Laser generator or both. The ECM controls the laser energy generator to direct one or multiple laser beams into the combustion chamber. In the laser ignitor multi-photon ionization of few gas molecules takes place 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 numberof photons required for producing the electron avalanche.

## PERFORMANCE REQUIRMENTS FOR LASER IGNITERS

There are certain performance requirements which a practical laser spark plug should posses, are listed below:
**(i) Mechanical** - Laser and mounting must be hardened against shock and vibration
**(ii) Enviromental** - Laser should perform over a large temperature range
**(iii) Peak Power** - Laser should provide megawatts raw beam output
**(iv) Average Power** - 1-laser per cylinder requires 10Hz for 1200rpm engine operation
**(v) Life Time** - 150 million shots – good, 600 million shots - better

**Disadvantages of conventional ignition system:**

- Location of spark plug is not flexible as it requires shielding of plug from immense heat and fuel.
- Spray and spark plug 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 electrodesrequires frequent maintenance to remove carbon deposits.

**Advantages of using laser ignition system:**

- The lifetime of laser ignitor is much more as compared to the conventional ignition system.
- Laser ignition system can burn leaner mixture more efficiently.
- Precise timing is possible in laser ignition system.
- Reduced fuel consumption rate.
- Free choice of the ignition location within the combustion chamber.
- As laser ignition system can ignite leaner mixture more effectively it will reduce the NOx emissions to a great level.
- Lasers can be focused and split into multiple beams to give multiple ignition points, which means it can give a far better chance of ignition.
- Optical wire and laser setup is much smaller than the current spark plug model, allowing for different design opportunities.
- Easier possibility of multipoint ignition
- Quenching effects of spark plug electrodes are avoided.
- Erosion effects are avoided in laser ignition system.
- The laser also produces more stable combustion so you need to put less fuel into the cylinder, therefore increasing efficiency.
- The power required by laser ignition system is less as compared to conventional ignition system.
- Flame propagation is relatively fast combustion time is shorter.

## CONCLUSION

Laser ignition system allows almost free choice of the ignition location within the combustion chamber, even inside the fuel spray. Laser ignition system helps in significant reduction in consumption of fuel and also in NOx emission. Laser ignition system requires less energy requirement as compared to conventional ignition system with lean and rich air fuel mixture. 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. 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.

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