Laser Ignition System for IC Engines

Swapnil S. Harel[1], Mohnish Khairnar[2], Vipul Sonawane[3]

[1, 2]Dr. Babasaheb Ambedkar Technical University, Lonere, Raigad, Maharashtra, India

[3]Saraswati College of Engineering, Kharghar, New Mumbai, Maharashtra, India

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.

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, the latter being caused by photolytic generation of radicals.

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

Licensed Under Creative Commons Attribution CC BY

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.
- 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.

5. LASER

Lasers provide intense and unidirectional beam of light. Laser light is monoc hromatic (one specific wavelength).

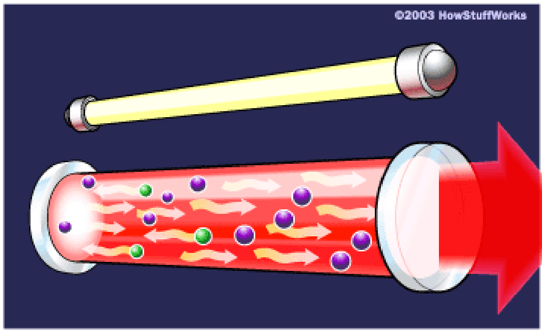


Figure 1

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.

5.1 Types of lasers

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

6. LASER Ignition

Laser ignition, or laser-induced ignition, is the process of starting combustion by the stimulus of a laser light source.

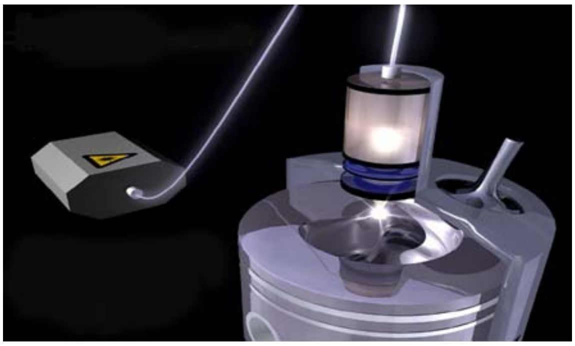


Figure 2

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, see fig.7

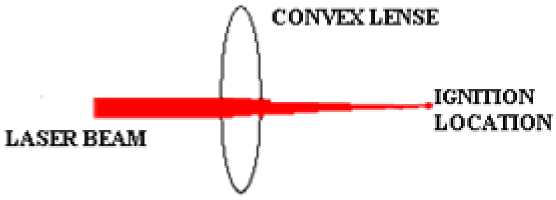


Figure 3: Ignition in combustion chamber

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.

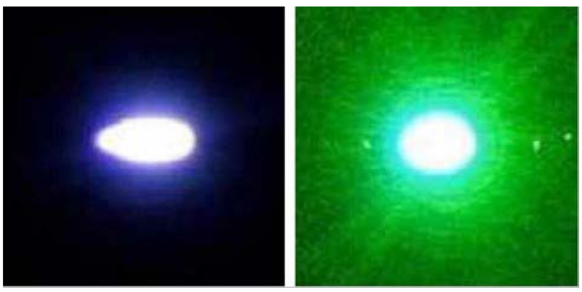


Figure 4

Licensed Under Creative Commons Attribution CC BY

Optical breakdown in air generated by a Nd:YAG laser.

Flame propagation in combustion chamber

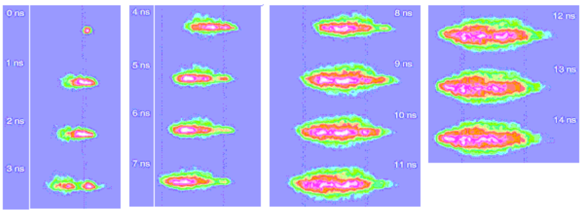


Figure 5

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 *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.

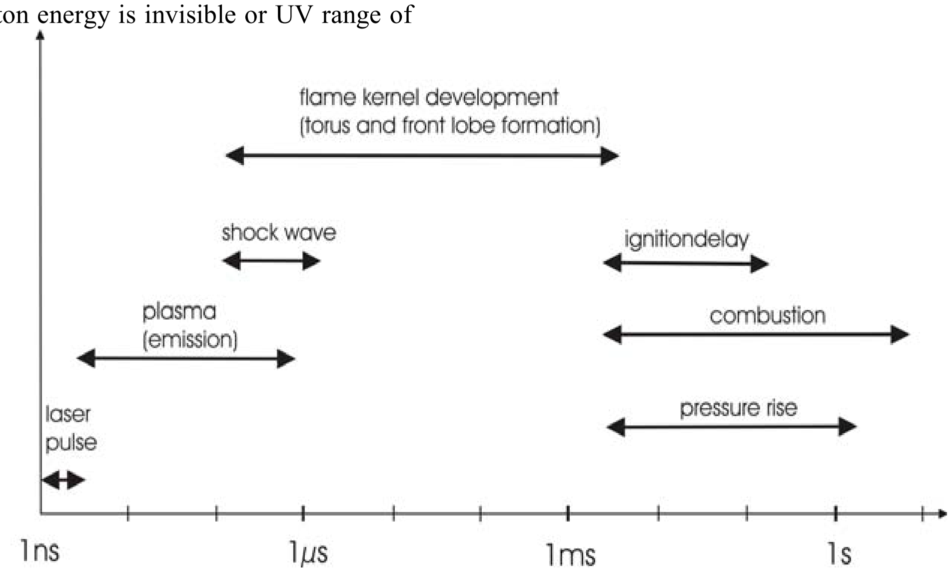


Figure 6

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.

Licensed Under Creative Commons Attribution CC BY

8. 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 10^{10} to 10^{11} *W/cm*^{2}. 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 3×10^4 *V/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 2×10^6 *W/cm*^{2}, 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 $10^{10}$to 10^{11}*W/cm*^{2}) 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

$$D = 2 \times wf = 2 \times M2 \times \left(\frac{2\lambda f}{\pi d}\right) \quad ..(1)$$

where M^2 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

$$V = \frac{4\pi w_f^3}{3}$$

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

$$N = \frac{pv}{kt} \quad ..(2)$$

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

$$W = \left(\frac{\pi p d^3}{6kt}\right) \times (Wd + 2Wi) \quad ..(3)$$

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.

$$I \propto \frac{1}{p^n} \quad (4)$$

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.

9. Experiment and Results

9.1 Combustion chamber experiments

Following the calculations above, even moderate pulse energies should be sufficient for laser induced ignition of combustibles. As a feasibility test, an excimer laser has been used for ignition of inflammable gases inside a "combustion bomb". The laser used for the first experiments was a Lambda Physik LPX205, equipped with an unstable resonator system and operated with KrF, delivering pulses with a wavelength of 248 nm and a duration of approximately 34 ns with maximum pulse energy of 400 mj.10 The combustion chamber has had a diameter of 65 mm and a height od 86 mm, with a resulting volume of 290*cm*3 and was made of steel. The laser beam was guided into the chamber through a window. Pressure sensors, filling and exhaust lines were also connected to the combustion chamber. The laser beam was focused into the chamber by means of a lens with a focal length of 50 mm.

Variations of pulse energies as well as gas mixtures have been performed to judge the feasibility of the process. Results indicate that ignition-delay times are smaller and pressure gradients are much steeper compared to conventional spark plug ignition.

9.2 Engine experiments

Since the first feasibility experiments could be concluded successfully, an engine was modified for laser ignition. The engine has been modified by a replacement of the conventional spark plug by a window installed into a cylindrical mount. The position of the focusing lens inside the mount can be changed to allow variations of the location of the initial optical breakdown.

Licensed Under Creative Commons Attribution CC BY

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

Research engine		Q-switched Nd: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 cm^3	Power Consumption	6 mm
Compression ratio	1.6	Type	Quantel Brilliant

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.

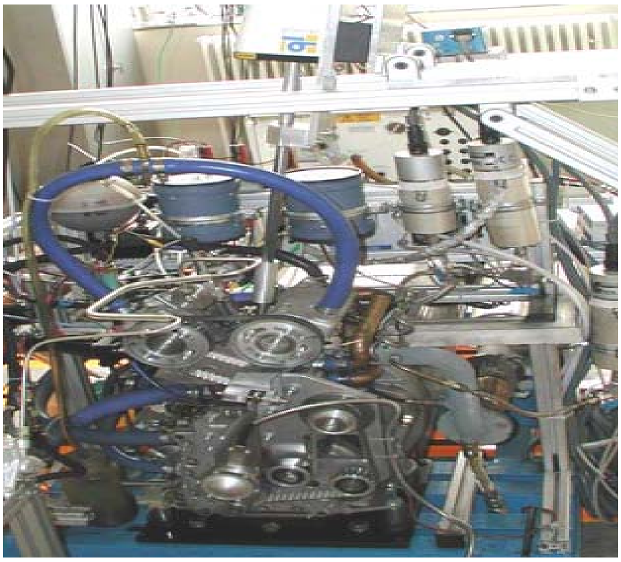


Figure 7

Research engine with the q-switched Nd:YAG laser system

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 fluctuations.

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.

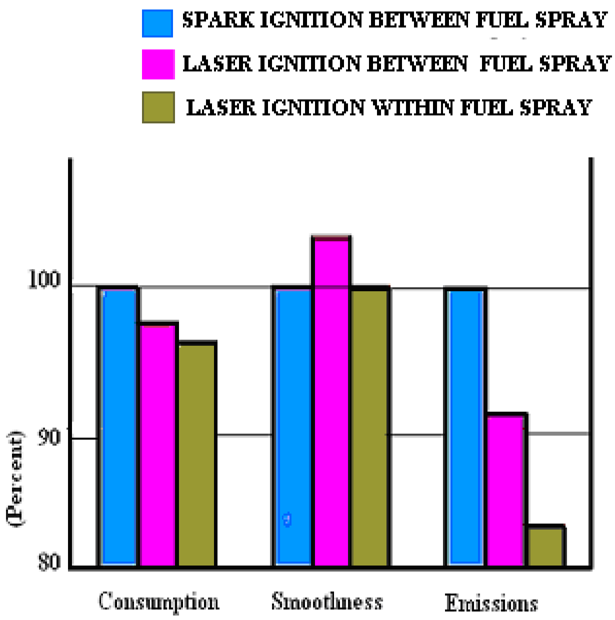


Figure 8

10. 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.

Licensed Under Creative Commons Attribution CC BY

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.

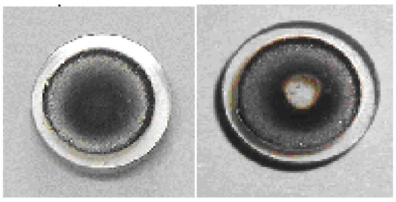


Figure 9

Beam entrance window: left side after 20 h operation with spark plug ignition, right side: immediately after 100 laser pulses. Beam area is cleaned by the laser beam.

10.1 Additional possibilities for the application of laser Ignition

To fully utilize the potentialities of laser ignition, the developer must understand and master the interrelationships in the engine perfectly. There is no sense in utilizing only the NOX advantages with a costly system and not paying attention to the specific fuel consumption. Consequently, additional measures must be taken to maintain the fuel consumption level under conditions of extremely lean operation and even to improve it. In this regard, researchers place great emphasis on its experience with high turbulence to accelerate combustion (HEC concept). However, there are also other innovative approaches possible with laser ignition. One tested approach is so-called multi-point ignition, which has been investigated not only in terms of the theoretical approach, but also through studies dealing with combustion vessels. As an example, Figure 8 presents the result of the calculated flame front of a 4-point Laser ignition after 29° CA in operation at Lambda 2.05. In this manner, the spark duration (90 %) can be reduced approximately to less than half (NOX level 30 ppm) – see figure 9.

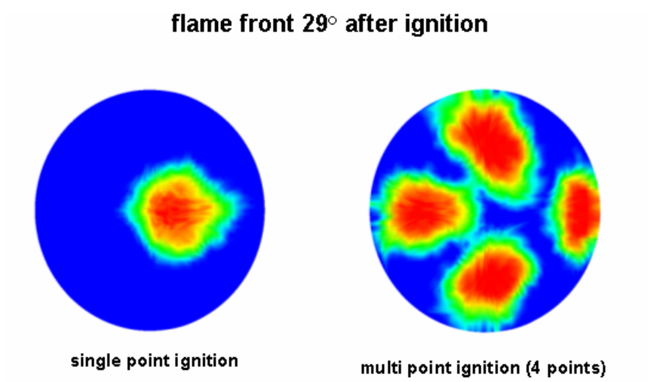


Figure 10: Multi-point ignition

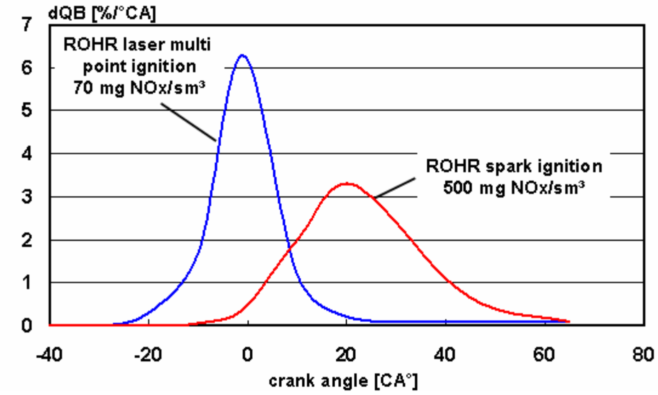


Figure 11: ROHR of multi-point ignition.

The use of optical components offers additional possibilities to generate several plasma sparks at different points in the combustion chamber. One investigated approach is the use of diffractive lenses -- see foci splitting in figure 10.

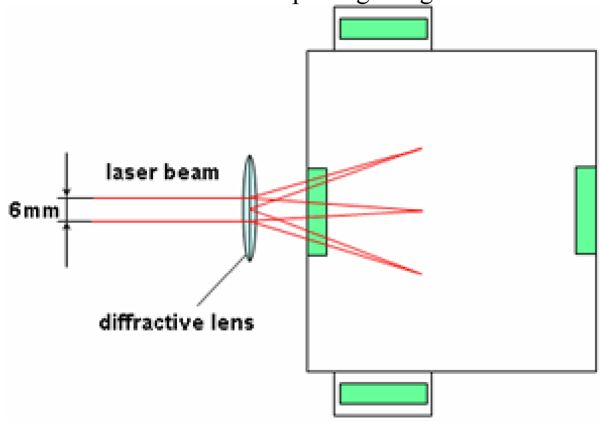


Figure 12: Optical triplication of foci

Another approach is to improve ignition conditions and flame propagation by increasing combustion chamber temperatures. As well, this allows the required ignition energies to be reduced considerably. An example regarding this approach is shown in Figure 21. With a very lean mixture it is possible to reduce the required ignition energy by about 30 % by increasing the temperature by 50°C (from 150 to 200°C). At full load the temperatures at the firing point are a good deal higher. To be able to better understand the interrelationships, the tests with the combustion vessel were extended to a temperature level of 400°C. The results in the case of methane are presented in Figure 11. Using this approach, the required ignition energy can be kept at less than 2 mj up to Lambda 2.2. Knowledge of the global interrelationships is therefore very important for the design of the laser.

Licensed Under Creative Commons Attribution CC BY

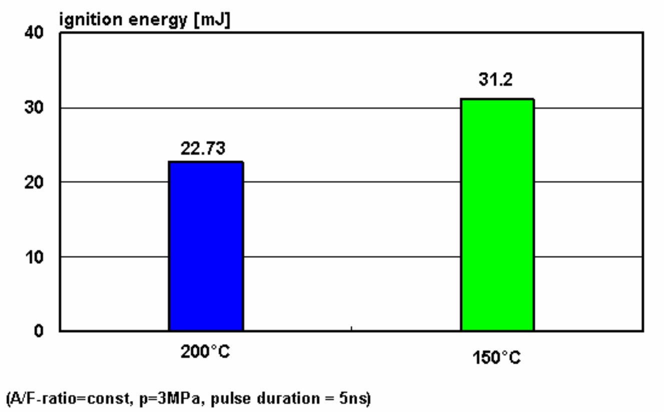


Figure 13

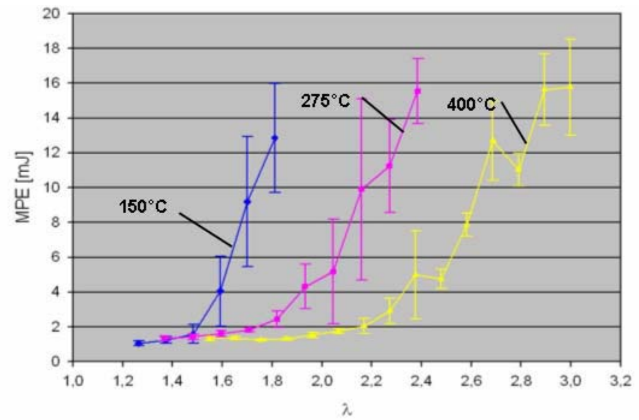
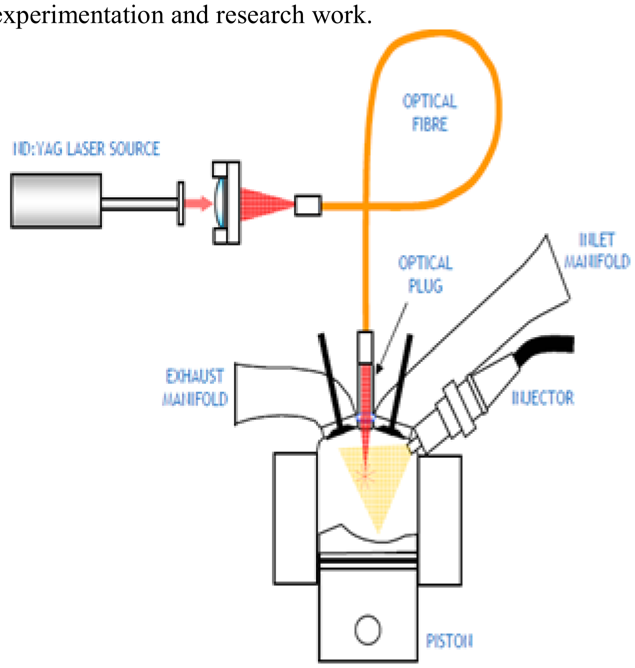


Figure 14: Dependence of minimal ignition energy on temperature and Lambda

10.2 Equipment and Tooling

Laser ignition technology is in research and developments phase in many of the reputed universities and organizations. These different organizations used equipment and tooling that are slightly differing from each other in certain cases for experimentation and research work.



One of the most common equipment and tooling that had been used by NETL lab (U.S.A) is discussed here as shown in schematic fig.14.

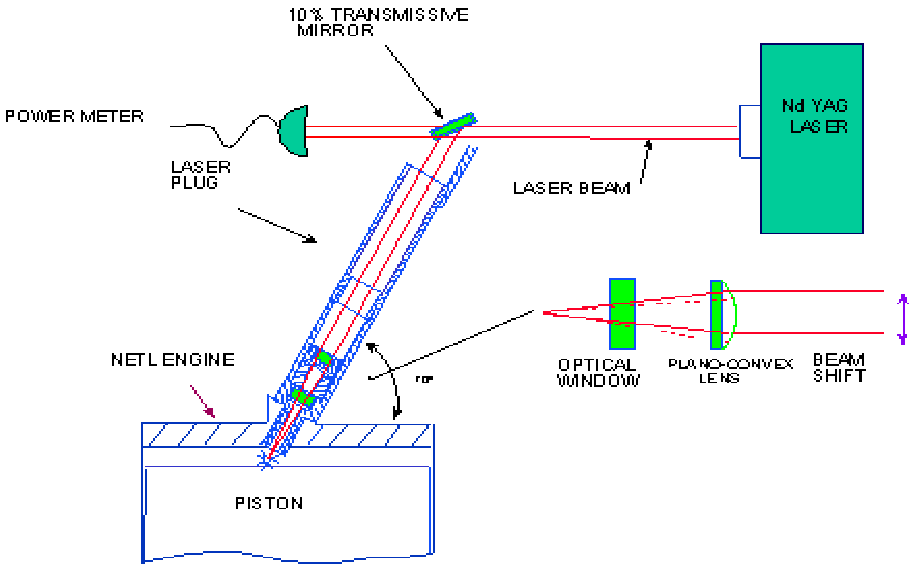


Figure 15

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

Licensed Under Creative Commons Attribution CC BY

laser plug axis and tangent to an arc centered on the crankshaft.

10.3 Equipment used by University of Liverpool

There are a number of different ways to deliver the laser beam to each of the four cylinders in the test engine. 1. One could have an individual laser for each cylinder,

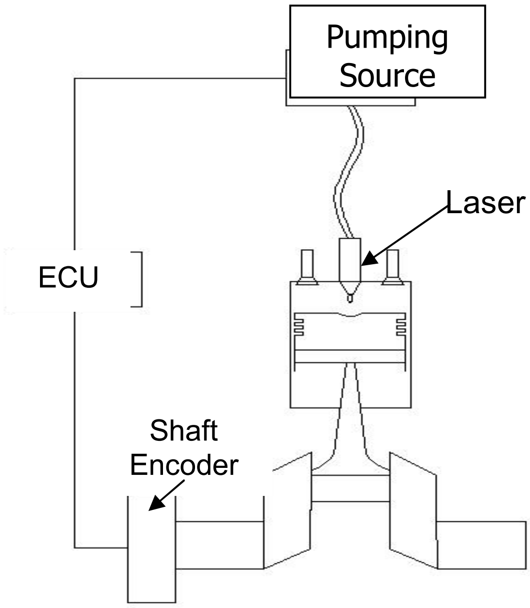


Figure 16: laser per cylinder system

2. One could use a single laser, or a pair of laser heads, and split the beam or 3.deliver the beam via an optical fiber. An optical bench is created beside the test engine, with the laser fixed to it horizontally – although they also ran some experiments with the laser positioned above the test engine. They used two beam splitters and four engine mirrors mounted at a 45° angle to direct the beams towards the cylinders.

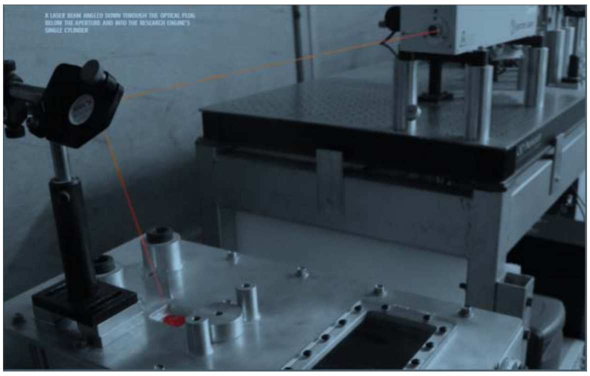


Figure 17

Initially they channeled the beam into the combustion chamber through an access hole formed by removing a sensor from a conventional spark plug. Later, they created an optical plug by fitting an optical lens at one end of a hollow spark plug and an optical window at the other. They also constructed a series of plugs with different focal points in order to establish whether their laser ignition system could cope with a stratified charge

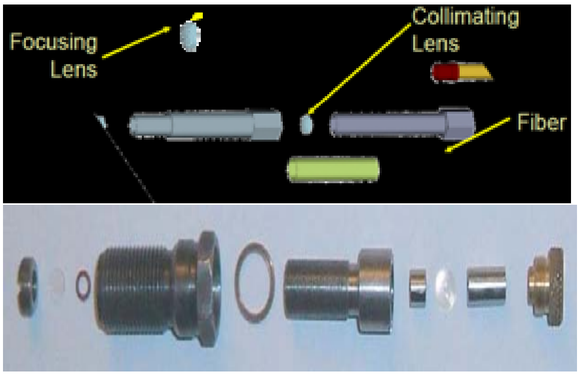


Figure 18: laser spark plug

10.4 Challenges

Delivering the beam through free space and channeling it into the combustion chamber through the optical plug achieved the best results – reducing the Coefficient of Variation, making combustion smoother and more fuel-efficient. The team was particularly keen to deliver the beam via optical fiber, since this was likely to be less susceptible to engine vibration and could facilitate improved engine layout. They tried out a range of optical fibers, including silica and sapphire, and experimented with different internal fiber structures, core sizes and beam coupling optics.

Delivering the beam via optical fiber proved to be more difficult than the research team had hoped. The fiber didn't respond well to engine vibration, which increased the divergence of the output beam and reduced the beam mode quality. Bending the fiber was also problematical and up to 20 per cent of the beam energy was lost with small bend diameters, while tight bends caused the fiber to fail altogether after a period. What's more, the high density of laser energy can cause immediate or long term degradation, leading to loss of beam transmission – and therefore loss of ignition. Careful design of laser parameters, fiber coupling and choice of optical media is crucial to avoid this. These problems can be solved with further research.

10.5 Next steps

The project generated a series of invention disclosures, some of which have already been submitted for patent protection.

10.6 Current Status

Some of leading institutes and organizations researching and came with adaptive results are

1. University of Liverpool in collaboration with Ford Motor Company
2. National Energy Technological laboratory, United States of America
3. Colorado State University,
4. National Institutes of Natural Sciences-Japan, etc.

The leading automobile companies that are developing laser ignition system for their vehicles are:

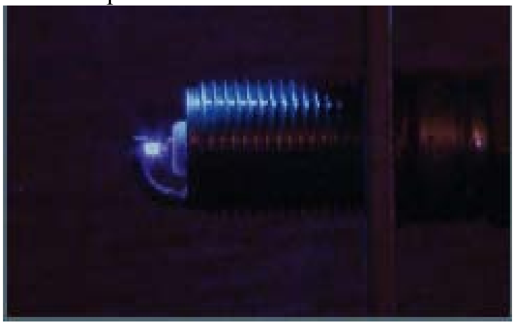
1. Ford Motor Company
2. Mazda.

Licensed Under Creative Commons Attribution CC BY

11. Comparative Advantages of LI

11.1 Spark ignition system

- Less intense spark



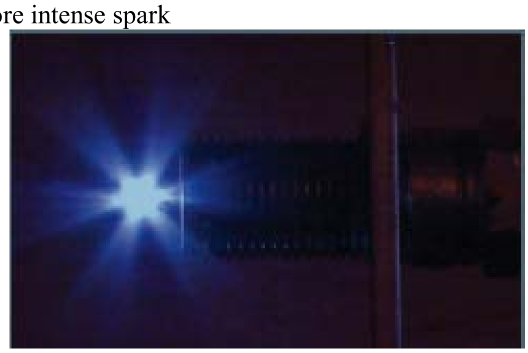
- Restrictions while choosing the ignition location
- Leaner mixtures cannot be burned
- Spark plug ignite the charge in a fixed position, so they can't cope with a stratified charge.
- Flame propagation is slow
- Multi point fuel ignition is not feasible.
- NO_X emission

Ratio between fuel and air has to be within the correct range. It causes more NO_x emission

No_x emission [mg/Nm^3]

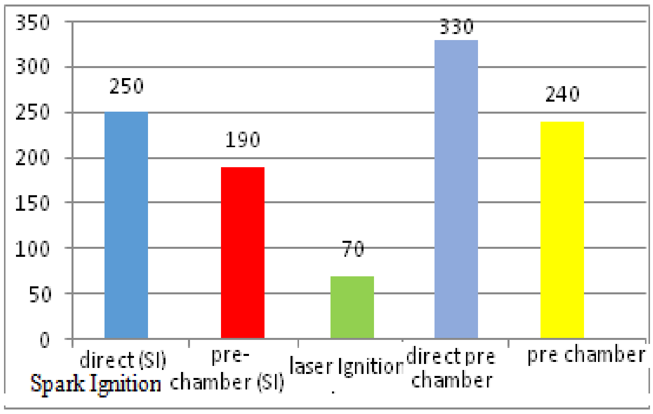
11.2 Laser ignition system

- 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
- 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 NO_x emission



11.3 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

12. 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. 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

Licensed Under Creative Commons Attribution CC BY

9. At present, a laser ignition plug is very expensive compared to a standard electrical spark plug ignition system and it is nowhere near ready for deployment. But the potential and advantages certainly make the laser ignition more attractive in many practical applications.

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] Lambda Physik, Manual for the LPX205 Excimer Laser, 1991
[5] M. Gower, "Krf laser-induced breakdown of gases," Opt. Commune, pp.43–45, 1981.
[6] R. Hill, "Ignition-delay times in laser initiated combustion," Applied Optics, pp. 2239–2242, 1981.
[7] T. Huges, Plasma and laser light, Adam Hilger, Bristol, 1975.
[8] J.D. Dale, P.R. Smy, R.M. Clements, Laser Ignited Internal Combustion Engine An Experimental Study, S.A.E. Conference in Detroit, 29March 1978

Author Profile

Swapnil Harel received the B.Tech degree in Mechanical Engineering from Dr. Babasaheb Ambedkar Technological University, Lonere in 2013.

Licensed Under Creative Commons Attribution CC BY