

# ABSTRACT

Ignition system of a spark ignition (SI) engine is responsible to initiate the combustion of air-fuel mixture inside the combustion chamber. The ignition system must generate adequately high-voltage to create spark between the spark plug electrodes. Development of electronic controls to trigger ignition and use of distributor-less ignition system has made electronic ignition systems more effective and reliable. However, these ignition systems pose limitations for the future development of the spark ignition engines. Stringent exhaust emissions norms and demand for high thermal efficiency can be met by ignition of lean air-fuel mixtures. However lean combustion is associated with slower flame propagation speeds, and reduced power output. Engine power output can be improved by increasing initial cylinder pressure using turbo-charging. An increase in the cylinder pressure keeping the same spark plug electrode distance would require increased secondary coil voltage, which leads to severe erosion of electrodes over time. Flame propagation speed in lean air-fuel mixtures can be increased either by optimizing the position of ignition spot inside the combustion chamber or by multi-point ignition. Ignition spot always remains close to the top of the combustion chamber in a conventional spark ignition engine and cannot be varied too much from its location. These limitations of conventional ignition system can be overcome by a durable high-energy, electrode-less ignition system, which also has flexibility in terms of spark location, such as laser ignition system.

Laser is fast emerging contender as an alternative ignition source for internal combustion engines. Short laser pulses of few nanoseconds pulse duration can be focused by a converging lens system to achieve ignition inside the cylinder containing combustible air-fuel mixture. If the energy density at the focal point exceeds threshold level, breakdown of combustible charge occurs, leading to plasma formation. If the energy of the spark generated by plasma is high enough, the mixture ignites and combustion is initiated.

Laser ignition of compressed natural gas (CNG) was experimentally investigated in a custom-build constant volume combustion chamber (CVCC) as well as in a customized single cylinder engine. Experiments were first conducted in the CVCC to evaluate the fundamental properties of laser ignition. Minimum ignition pulse energy was determined for different relative air-fuel ratios ( $\lambda$ ) and initial chamber filling pressures. Flame kernel development of the air-fuel mixture was investigated under different values of  $\lambda$  and the flame kernel images were analyzed for determining temporal propagation of the flame front. Pressure-time history inside the combustion chamber was recorded and analyzed. Laser ignition was performed in a customized naturally aspirated, water cooled, four stroke single cylinder engine. Engine experiments were carried out for different values of  $\lambda$  and ignition timings at wide open throttle (WOT) conditions. In laser ignition, a converging lens of 30 mm focal length was used to focus the laser beam inside the engine combustion chamber. Engine combustion, performance and exhaust emissions were measured for each ignition timing and  $\lambda$  and results were compared for both ignition systems under identical operating conditions. After direct comparison of conventional spark ignition and laser ignition system, detailed engine experiments were carried out only for laser ignition. Effects of laser parameters, optics and cylinder pressure were investigated on engine performance, emissions and combustion.

Results of this work demonstrated that laser is an important tool to ignite leaner air-fuel mixtures. Laser parameters, optics and initial pressure influence minimum pulse energy required for successful ignition. A laser having beam profile close to Gaussian profile and lowest possible beam quality factor require relatively lower pulse energy for ignition of combustible mixture. Minimum pulse energy required for ignition decreases with increasing initial chamber filling pressure. Thus, laser ignition emerges as a suitable option for lean-burn combustion engine using higher compression ratios, where conventional spark plugs experience electrode erosion due to higher breakdown voltage required for combustion under these operating conditions. Focal spot size and energy density at the focal spot, both govern the performance of the engine using laser ignition. Larger focal spot size and maximum possible energy density at the focal spot increases the flame propagation speed. It is therefore necessary to provide as high as possible laser pulse energy to achieve superior combustion stability and engine performance. However, excessive laser pulse energy may also possibly damage the piston because excess transmitted laser pulse energy may hit the piston surface and damages it. Laser ignition has potential to increase the flame speed and enhance the engine performance by optimizing the ignition location inside the combustion chamber. Therefore, required flame speed in lean-burn combustion can be achieved with laser ignition by optimizing ignition location, energy density and focal spot.