Laser Ignition For Combustion Engines – Part II

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In Part I of this tutorial, the nature of interaction between lasers and matter was discussed. This part described four ways a laser beam can bring about ignition of a combustible mixture, of which only the nonresonant interaction was identified as practical due to its wavelength independence, facilitating application for different fuel oxidizer systems. In part II of this tutorial, some applications of laser ignition in the context of reciprocating combustion engines are discussed.

An observed advantage of the laser ignition over the electric spark ignition method is the reduction of the so-called minimum ignition energy, Emin, as the charge pressure is increased. For example, a nine-fold decrease in Emin was observed as pressure was raised from 1 to 10 bars for methane/air mixture. As engine compression ratios are increased to gain higher efficiencies, this could become an important selection criterion. It was also showed that the use of optimized optics and laser systems can reduce the required minimum laser pulse energy for the ignition to where the application of the laser becomes reasonable. A minimum useful focal spot size of 20 μm was found to be independent of the laser wavelength.

One of the earliest application of the laser ignition in a gasoline engine was demonstrated by Dale et al. (1978). They reported that the laser ignition was able to ignite a leaner mixture and that the pressure rise time was shorter compared to an electric ignition unit. However, the smaller pressure rise time led to a higher emission of the nitric oxide (NO). In particular, the use of laser increased the peak cylinder pressure by 5% and 15%, without the exhaust gas recirculation (EGR) and with 16% EGR, respectively. Additionally, they found that the CO and HC emissions were comparable for the two ignition systems. Figure 1 indicates the so-called tradeoff between the specific fuel consumption and NO emissions for the two ignition systems. It is clear that for a given level of NO emission, the laser ignition system offers a superior fuel economy than the spark plug system. Regarding the window fouling, the authors reported that carbon deposit build-up made it necessary to remove the window for cleaning every 30 to 75 minutes of operation.

One of the most promising near-term applications of the laser ignition is for large lean-burn natural gas engines. Regulations on NO_x emissions have continued to force operation of natural gas engines to leaner air/fuel ratios. Engine operation under the lean fuel/air mixtures using a spark plug ignition is limited because of the misfire and unstable operation. Additionally, ignition of the lean mixture is difficult and conventional systems require high ignition energies. High energies are usually achieved through an increased ignition coil energy. However, this measure tends to rapidly burn out even the precious metal spark plugs utilized in stationary engines for power generation. Also, natural gas is more difficult to ignite than gasoline due to the strong C-H bond energy. Considering the foregoing, and the recent availability of small-sized high-power solid-state rugged lasers, the near-future use of the laser ignition in this application is promising.

Figure 2 shows the coefficient of variation (COV) of the indicated mean effective pressure (IMEP) from a single-cylinder lean-burn natural gas engine using two ignition, systems (electric and laser) for power generation, see McMillan et al. (2003). Generally, the lower the COV value, the smoother, cleaner, and more efficient engine operation, see Chehroudi (1999) for details. A much lower COV values are seen with the laser especially when the ignition timing is retarded to 15 degrees before top dead center (BTDC). Similarly, 0-to-10% mass burn duration was also reduced with laser ignition indicating accelerated combustion in the early development phase. In this study, a Q-switched Nd;YAG laser with 10 ns pulse is used at 1064 nm with 60 to 180 mJ/pulse of energy. No issues were reported with vibration or with combustion products fouling the sapphire window installed on the engine for the laser beam.

References:

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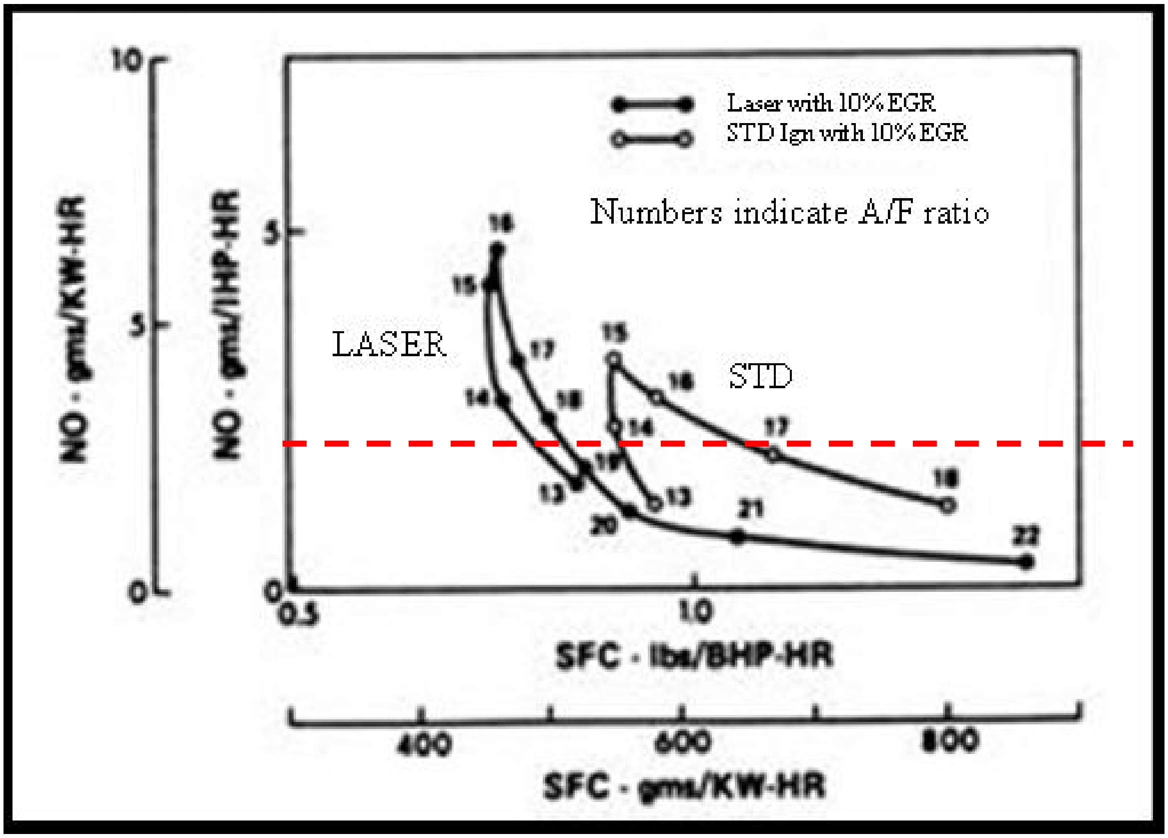

Figure 1. Plots of NO emissions versus specific fuel consumption (SFC), the trade-off curves, for laser and standard (STD) electric ignition systems. Dale et al. (1978).

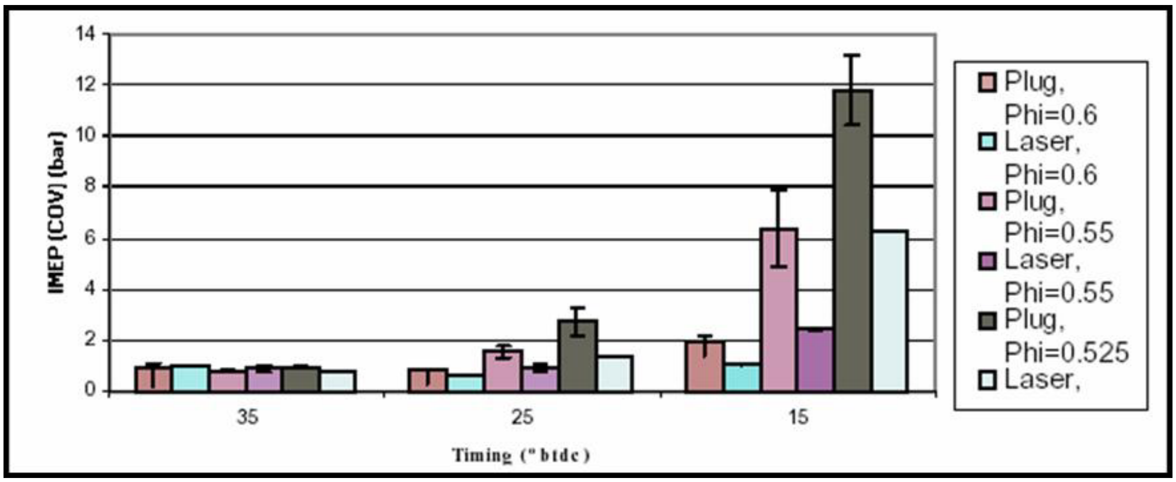

Figure 2. Coefficient of variation of the IMEP at three different ignition timing. Results are shown for three different equivalence ratios (phi). McMillan et al. (2003).