Passively q-Switched Laser Ignition: Influence of Focusing Properties on the Combustion of Lean Methane/Air-Mixtures

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Abstract: The influence of focusing properties on the flame kernel development and combustion characteristics is investigated by the application of a passively Q-switched laser ignition system. Focal point properties are varied by changing the distance of the lenses in the focusing line.

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1. Introduction

Miniaturized passively Q-switched laser ignition systems possess the potential to meet the requirements of a future commercial ignition source [1, 2]. On the one hand the laser ignition process can be influenced by parameters of the laser system and on the other hand by changing the focusing properties. By using a concave lens to expand the laser beam and a convex lens to focus the laser beam, the effective focal length of the lens system can be modified by changing the distance between the lenses. It is worthwhile to mention that we have recently investigated the influence of focal point properties on the energy transfer from laser to plasma and also the plasma evolution after laser ignition with a passively Q-switched Nd:YAG/Cr^{4+}:YAG laser [3].

The aim of the presented study is to investigate the influence of different effective focal lengths on the flame kernel development and on combustion characteristics after ignition of lean methane/air-mixtures in a constant volume combustion chamber (CVCC). A miniaturized passively Q-switched Nd:YAG/Cr^{4+}:YAG laser with a focusing unit built up from an expanding lens and a converging lens is used for ignition (see figure 1). The laser pulse energy is set to 6.2 mJ (FWHM pulse width 2.6 ns) and the effective focal length is varied between 6.5 mm and 24.6 mm.

The results show that the combustion characteristics of methane/air-mixtures after laser ignition can be significantly influenced by different focusing properties. An optimum effective focal length was found resulting in the fastest pressure rise. Interestingly, this is not the shortest effective focal length which provides the highest energy density in the focal point. These are important findings for the optimization of a future commercial laser ignition system.

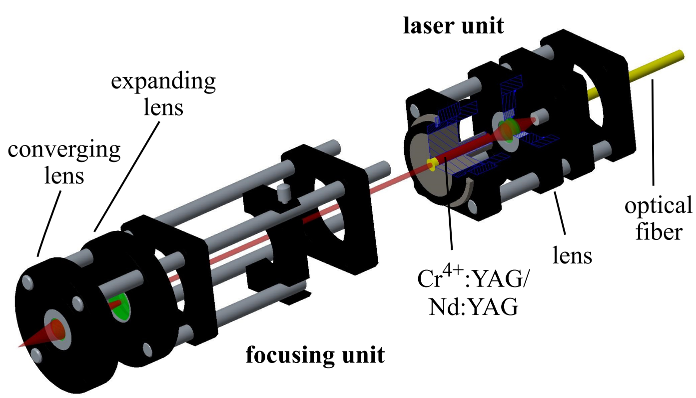

Figure 1. Design of the laser ignition system provided by Robert Bosch GmbH.

2. Flame Kernel Development

The flame kernel development is analyzed by the Schlieren measurement technique in combination with a high-speed-camera (200,000 fps). The detailed Schlieren setup can be found in reference [4]. To investigate the influence of the effective focal length a lean methane/air-flow ($\lambda = 1.6$) is ignited at ambient pressure. The flow velocity is adjusted to 1 m/s to minimize the impact of the flow on the flame kernel development. The effective focal length is varied between 6.5 mm and 14.5 mm. A temporal series of the flame kernel development for the different effective focal lengths is shown in figure 2.

Figure 2 demonstrates that the width of the flame kernel increases by decreasing the effective focal length (first row of figure 2). The influence of the effective focal length on the height of the flame kernel is less apparent. However, the impact on the third lobe formation is clearly evident. The third lobe development is much stronger in case of higher effective focal lengths (third row of figure 2).

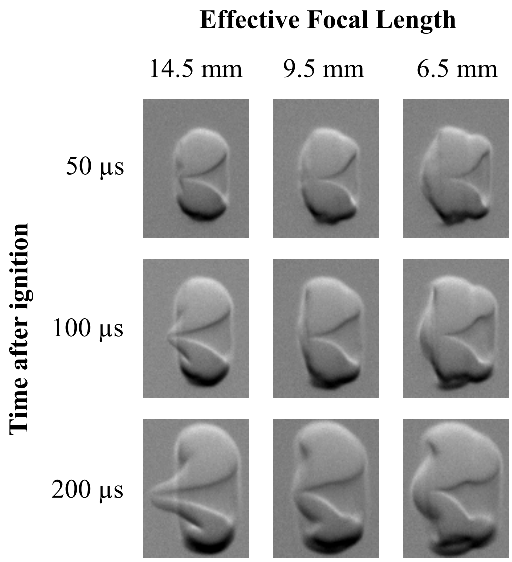

Figure 2. Temporal Series of Flame kernel development for different effective focal lengths (laser pulse energy 6.2 mJ, $\lambda = 1.6$, dimension of images: 6.7 mm x 5.7 mm).

3. Ignition of Lean Methane/Air-Mixtures

Lean methane/air-mixtures are ignited to analyze the combustion characteristics of laser ignition with different effective focal lengths. Therefore, a CVCC is filled up to 10 bar (relative pressure) with a quiescent premixed methane/air-mixture. The CVCC is heated to a temperature of 80 °C. Ignition is performed at air/fuel equivalence ratios between $\lambda = 1.2$ and 1.6. The effective focal length is varied between 9.6 mm and 24.6 mm. Two examples of excess pressure traces of ignitions of a lean methane/air-mixture with different effective focal lengths are shown in figure 3. The air/fuel-ratio is set to $\lambda = 1.2$ and $\lambda = 1.5$, respectively.

If the results of the different air/fuel-ratios are compared, it can be seen that a higher maximum pressure is reached and that the combustion process is more rapid in case of a air/fuel-ratio of $\lambda = 1.2$. This can be explained by the higher amount of methane and by the increased flame propagation speed of the less lean air/fuel-mixture ($\lambda = 1.2$). Considering the different effective focal lengths at a fixed air/fuel-ratio the results demonstrate that the pressure rise is more rapid for decreasing effective focal lengths (24.6 mm to 14.5 mm). A further decrease of the effective focal length (11.5 mm and 9.6 mm) results in a slower pressure rise compared to an ignition with an effective focal length of 14.5 mm. These characteristics are independent of the air/fuel-ratio, although the difference in combustion duration becomes more significant for high air/fuel-ratios. These findings are consistent with investigations of Srivastava et al. [5].

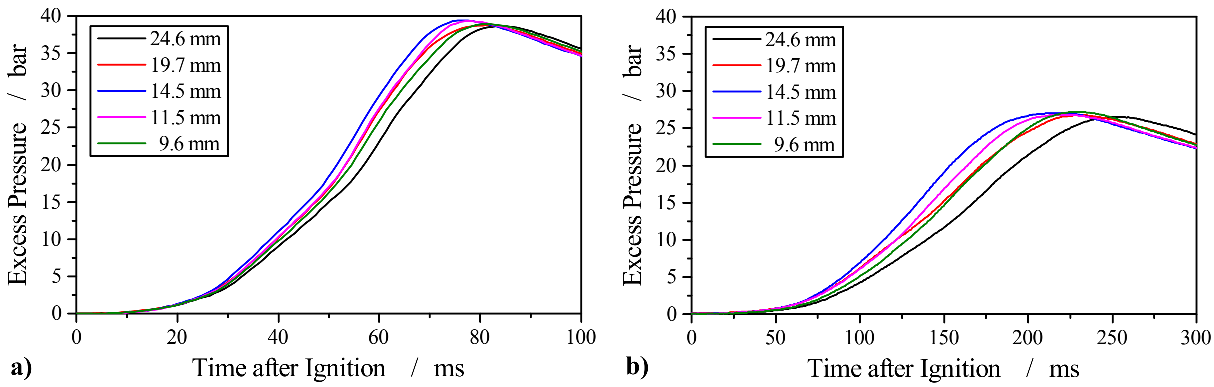

Figure 3. Excess pressure traces of methane/air combustions after laser ignition with different effective focal length, a) $\lambda = 1.2$, b) $\lambda = 1.5$ (laser pulse energy 6.2 mJ).

4. Achnowledgments

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