Spatio-temporal analysis of a liquid jet using a sub-picosecond optical gate

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Abstract

A BBO crystal is used as an optical gate to select ballistic light, or delayed light that interacts with an object. The temporal resolution is about 270 fs and is compatible with the dimensions of a Diesel injector spray. Spatio-temporal diagrams demonstrate the potential of the method.

Introduction

In order to reduce carbon dioxide emission, it is necessary to increase energy efficiency in combustion process, especially in automotive engines. A critical point for thermal engines using liquid fuel is the injection and the break-up of the jet. The atomization process leads to a droplets size distribution, which governs evaporation and the whole combustion. In Diesel engine, high injection pressures (1000 to 2000 bars) result in very dense sprays with large velocities (100 to 700 m/s). For these reasons, classic optical techniques are difficult to use, especially near the injector nozzle. Recently, ballistic imaging has been successfully applied to spray issued from aeronautical injectors [1], using an optical time gate based on a Kerr effect in liquid CS_2 [2-4]. Unfortunately, the typical duration of this gate is not compatible with the dimensions of a Diesel injector (~200 μm diameter jet).

In this work an optical gate based on a BBO crystal is used to reduce the duration of the gate to less than 1 ps.

Experimental set-up

The experiment [5] consists in a classical pump-probe set-up (fig. 1): the beam of an amplified Ti:Sapphire laser (pulse duration = 100 fs, repetition rate = 1 kHz, energy per pulse =1mJ, wavelength = 800 nm) is divided into two parts by a beam splitter. The first beam (probe) is directed through the spray to form an image on a BBO crystal. The second beam (pump) passes through a delay line and is also directed towards the BBO crystal. The angle between the beams is θ. When the probe and pump pulses coincide in space and time, a second harmonic generation (SHG) at λ = 400 nm occurs at angle $\theta/2$. The image of the BBO is formed on a CCD camera. The BBO orientation is fine-tuned to ensure the best compromise between images resolution and SHG efficiency.

Results

The resolution of the images is about12 μm (measured by an USAF 1951 resolution chart) and the duration of the gate is 270 fs. By changing the delay $\Delta\tau$ between pump and probe pulse, some part of the light interacting with the spray may be isolated. However, due to angle θ between pump and probe pulses, the instant frozen by the gate is not exactly the same along the horizontal axis of the camera. In other words, there is a time drift of the gate along the x horizontal axis. Without any spray, the background image corresponding to the ballistic photons have an elongated shape along vertical axis (fig. 2). In presence of an object on the path of the probe pulse and without changing the time delay $\Delta\tau$, time-delayed light would be excluded from the central part of the imageand would appear at the left side of the image, due to the time drift of the gate.

Background images are recorded for different values of the time delay $\Delta\tau$. For each image, the pixels intensity are averaged over vertical columns to obtain an intensity map $I(\Delta\tau, x)$. When no object interacts with the probe beam, the enlightened area in $(\Delta\tau, x)$ space corresponds to the ballistic light localisation (fig. 3). The orientation of this area can be characterized by a slope coefficient α. This coefficient represents the time drift of the time gate and may be used to correct the (x, t) dependence on images. The method has been first validated on spatio-temporal diagram build from a single fibre images. The same experimental set-up has been applied on a Diesel jet (hole diameter = 200 μm, injection pressure = 400 bars). Due to the instability of the liquid jet, only averaged images have been used. The spatio-temporal diagram corrected from the time drift is shown in figure 4. It shows that ballistic light is detected at each side of the spray due to the intermittency of the jet. Delayed light,

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due to refraction through large liquid structures or scattering, is also observed. Further interpretation of this phenomenon is in progress.

Conclusion

A time gate based on a BBO crystal provides a very good time accuracy and an acceptable spatial resolution that can be probably improved. The present study opens the way to a new optical metrology based on spatio-temporal diagrams.

References

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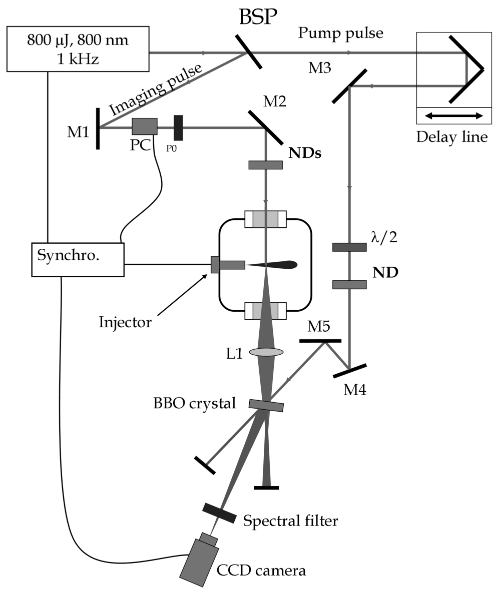

Figure 1. Experimental set-up. All beams lay in the horizontal plane

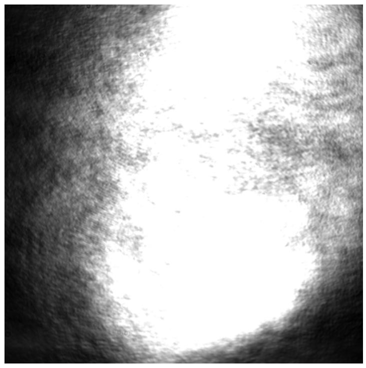

Figure 2. Ballistic light on the camera

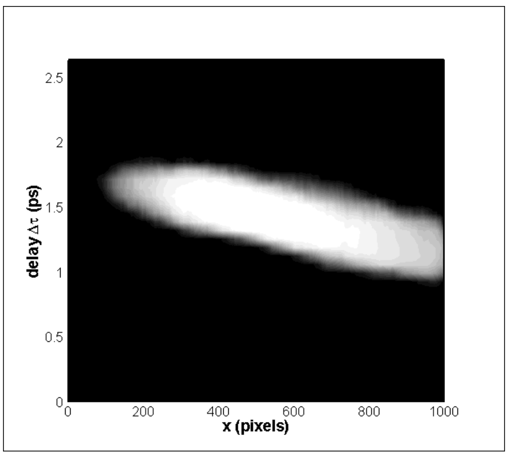

Figure 3. Spatio-temporal diagram of the ballistic light

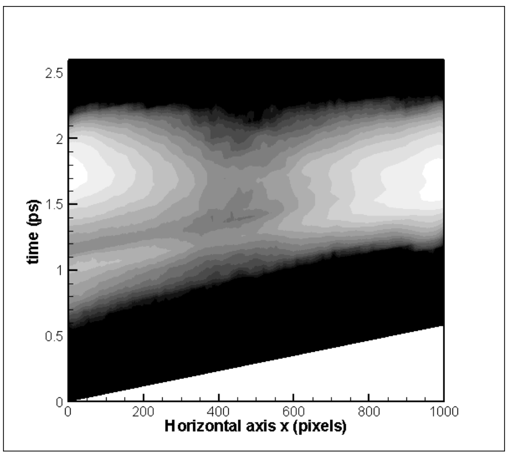

Figure 4. Corrected spatio-temporal diagram of transmitted light through a spray