The evolution of a shock wave pressure induced by a laser pulse in a liquid filled thin tube using the background-oriented schlieren technique

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In this study we investigate an angular variation of pressure at a laser-induced shock front in a liquid filled thin tube. We adopt the background-oriented schlieren (BOS) technique (Venkatakrishnan & Meier 2004). This technique enables us to measure two- or three-dimensional pressure field in a small region with a simple setup. We obtain the spatiotemporal evolution of the pressure field thanks to an ultra high-speed video camera and a laser stroboscope.

Figure 1 shows a schematic of the experimental setup. A BOS setup consists of a background with random dot pattern, a density gradient, and a camera. The principle of BOS technique exploits the variation of reflective index of the fluid due to its density gradients. It is obtained by comparing the non-disturbed background image with the “disturbed” background image using a PIV-type cross-correlation algorithm. A 532 nm, 6 ns laser pulse is focused through a 10x microscope objective to a point inside a water-filled glass cuvette (10x10x45 mm), where a shock wave emerges. We use an ultra high-speed video camera (Kirana, Specialized Imaging co., UK) with up to 5 M frames per second and 924 × 768 pixel array. The experiment requires exceedingly short exposure time due to the non-stationary flow. Hence we utilize a laser stroboscope with a pulse width of 20 ns as an illumination source (CAVILUX Smart, CAVITAR co., Finland). A digital delay generator synchronizes the camera, the laser, and the stroboscope.

The pressure distribution of the laser-induced shock wave is shown in Fig. 2. Remarkably, we found an angular variation of the pressure at the shock front in spite of spherical-like shape of the shock wave. The maximum pressure is at the region in the direction of the laser shot. It is about four times higher than that in the perpendicular direction. Note that the bubble grows not as spherical shape but as spheroidal shape. The growth of the direction toward laser shot is faster than that of the perpendicular direction. Thus the non-spherical growth of the laser-induced bubble might cause non-uniformity of pressure distribution at the shock front.

We also adopted another method which uses the position of the shock front (e.g. Vogel et al. 1996). Figure 3 shows the shock pressure as a function of the propagation distance. A black line shows a pressure estimated from the shock front. The markers show those from the BOS technique (plotted pressure values are at top, bottom, left, and right part of the shock front). With increasing the propagation distance, the pressure obtained from both methods show a similar trend (i.e. decreasing). The pressure from the shock front position exists between the maximum and minimum values from the BOS technique. The reason is that the method using the shock front position regards a shock wave as a perfect sphere, resulting in averaging out the value of the non-uniform pressure distribution.

In conclusion, using our BOS technique we measured the spatiotemporal evolution of the pressure field. We found the angular variation of the pressure at the laser-induced shock front. Our results might be used for efficient generation systems of the microjet which is applicable for needle free drug injection devices (Tagawa et al. 2012).

Fig. 1 Schematic of the experimental setup

Fig. 2 The time evolution of shock pressure distribution.

Fig. 3 Shock pressure obtained from two quantification methods as a function of the propagation distance.


