Laser-based optical fiber probing improved via 3D ray tracing numerical simulation

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Keywords: Optical fiber probe, Ray tracing simulation, S-TOP, Measurement accuracy, Signal analysis,

The objective of the present study is to numerically analyze optical signals of a laser-based optical fiber probing (LOFP), and to improve its accuracy in a bubble measurement (diameter, velocity and void fraction). For our aims, we developed a new 3D-ray-tracing simulator. The complicated probing signals were evaluated through the simulator computing the polarization and energy of every incident ray. The signals include several peaks corresponding to the physical relationships between a bubble and the LOFP. However, the generation mechanisms and characteristics are completely unknown yet. We examined a single-tip optical fiber probe (S-TOP) (Saito et al., 2009).

First, the probing signals were numerically computed as shown in Fig. 1. Two characteristic peaks (a first peak and pre-signal) were observed just before the S-TOP touched a bubble frontal surface. Analyzing rays contributing to these peaks by using the simulator, we clarified the mechanisms of the peak generation as follows; (1) The first peak is caused by the rays focused from the bubble rear interface like a concave lens (green chain line), (2) The pre-signal is caused by direct reflection from the bubble frontal surface (blue solid line). It takes the maximum value just when the S-TOP touches the frontal surface.

Second, we focused on the pre-signal. A relationship between the intensity of the pre-signal and the position touched by the S-TOP on the bubble is plotted in Fig. 2(a). The vertical axis is the computational intensity of the pre-signal. The horizontal axis is the touched positions defined in Fig. 2(b). The characteristics of the pre-signal were clarified; the pre-signal intensity increased/decreased depending on the touched position. The pre-signal clearly and intensively appeared when the S-TOP touched the center region of the bubble. Based on this result, we newly established a pre-signal threshold method which detects where the S-TOP touched on the bubble.

Finally, we applied the pre-signal threshold method to a practical measurement of a bubbly flow. The difference between measured chord length via the S-TOP and the bubble minor axis obtained from the bubble visualization was significantly improved from 42 % (before processed by the pre-signal threshold method) to 21 % (processed by the method). Moreover, the standard deviation became from 0.36 mm (before processed by the method) to 0.01 mm (processed by the method).

We successfully extracted the hidden potential of the LOFP from the complicated optical signals, and established the signal analysis through the 3D-ray-tracing simulation.

References


Fig. 1 A computational optical signal.

Fig. 2 An intensity distribution of the pre-signal.