Experimental study of single-tip optical fiber probing in dispersed gas-liquid two-phase flow and micro-processing of the optical fiber probe using the femtosecond pulse laser

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学 位 論 文 要 旨

Abstract of Doctoral Thesis

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論文題目：単一光ファイバープローブを用いた気液分散流計測,
ならびにフェムト秒レーザーによる光ファイバー微細加工に関する実験的研究
Title of Thesis : Experimental study of single-tip optical fiber probing in dispersed gas-liquid two-phase flow and micro-processing of the optical fiber probe using the femtosecond pulse laser

論文要旨：
Abstract :

In this thesis, I studied how the potentials of the optic signals of the single-tip optical fiber probe (S-TOP) could be brought out. From the signal-centric viewpoint, in the chapter 2, the output signal was deeply investigated theoretically, experimentally, and numerically. The phase detection principle of the optical fiber was confirmed by a classic description, then it was applied to the S-TOP measurement. The qualitative discussion corresponded to the experimental results, however, more quantitative investigations were needed to analyze the S-TOP signal. According to the 3D raytracing simulator and various experiments, I found that a spike signal buried in the S-TOP signal was very informative “noise” to overcome the inevitable problems of the S-TOP measurement. Its important advantages were; i) its peak-time indicated a precise time of piercing the bubble/droplet and ii) its peak-intensity indicated piercing position on the bubble/droplet. These properties contributed to correct measurement for the size of the bubble/droplet, and were confirmed empirically in the chapter 3. Based on the results, therefore, the pre-signal threshold method was established for the S-TOP measurement in a bubbly flow. I extracted the signals which included the clear pre-signal above a threshold value, then the velocity and pierced length were calculated. Thus the signals when the S-TOP has touched the bubbles near their pole were extracted. To examine the effects of the pre-signal threshold method, I conducted the S-TOP measurement in a quasi-practical bubbly flow. The bubbles’ sizes were kept as constant value thanks to the 2-precise pressure controllers. By the application of the pre-signal threshold method, the S-TOP measurement was remarkably enhanced.

The residual uncertainty was categorized into the following types: type 1, deceleration of the bubble due to contact with the S-TOP; type 2, uncertainty owing to the bubble interface geometry; type 3, uncertainty owing to random touch positions restricted within an allowance of the pre-signal threshold method; type 4, uncertainty due to the randomness of the bubble motion. Type 3, in particular, was quantified with Monte Carlo simulations. As for the droplet measurement, in the chapter 4, the post-signal threshold method was introduced. This method was also extracting the signals which included the clear post-signal above a threshold value, then the velocity and pierced length of the droplet were calculated. Its effectiveness was confirmed, however, the spatial limit of the S-TOP becomes non-negligible in the measurements for tiny droplets (the droplets of few dozen micrometer in diameter).

Hence from the probe-centric viewpoint, the Fs-TOP (femtosecond-laser-processed S-TOP) was hopefully introduced, and fs-laser processing for optical fiber is studied in the chapter 5 for optimizing its processing. Bubble nucleation and growth following plasma channeling and white-light continuum in liquid irradiated by a single-shot fs-pulse were experimentally investigated with close observation of the time scale. Making full use of a new confocal system and time-resolved visualization techniques, I obtained evidence suggestive of a major/minor role of the non-linear/thermal effects during the fs-pulse-induced bubble's fountainhead (10^{-13} s) and growth (10^{-7} s), which was never observed with the use of the ns-pulse (i.e., optic cavitation). In this context, the fs-pulse-induced bubble is not ordinary optic cavitation but rather is nonlinear-optic cavitation. I presented the intrinsic differences in the dominant-time domain of the fs-pulse and ns-pulse excitation.

I used these results in a practical way, a different atmosphere for the Fs-TOP processing was examined in the chapter 6 because the nonlinear effect depends on the types of liquid. The filament length formed along the optic axis of the fs-laser was a depth for processing. According to the result of the chapter 5, the filament could be easily formed in water; hence I made the Fs-TOP in water. This practice served my purpose; the groove-sensor processed in water detected gas-liquid interface sensitively better than that in air. This was an advantage of small droplet detection over conventional S-TOP. There were many parameters including the processing atmosphere for making the Fs-TOP. More validations were still my due; however, my study provided enough evidence of effectiveness of the physical-mechanism-based optimization for the S-TOP.