Numerical analysis of optical fiber probing by ray tracing method

Akihiro Sakamoto¹, Takayuki Saito²

¹: Sumitomo Metal Industries, Ltd., Ibaraki, Japan, sakamoto-ak2@sumitomometals.co.jp
²: Graduate School of Science and technology, Shizuoka University, Shizuoka, Japan, ttsaito@ipc.shizuoka.ac.jp

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1. Introduction

Optical fiber probing is one of reliable measurement techniques especially in high-condensed multiphase flow. It can detect not only the gas-liquid phase fraction but also the bubbles’/droplets’ diameters and velocities.

Figure 1 shows the basic structure of the optical fiber probe. The material of the fiber is plastic or glass, the sharpened-cut edge forms a sensing point for detecting gas or liquid phase and the other edge is optically connected to a laser diode (LD) and a photo detector (PD). The PD detects whether the sensing edge is in air or water based on the amount of the returned beams reflected at the sensing edge by Snell’s law.

The signal pattern in figure 1 is easy to clarify air phase or water phase; however, many signals have noisy peaks (see figure 3). Conventional analysis neglects the peaks because the mechanism is unclear. We have developed a numerical model in order to get more information from the promising signals.

2. Ray tracing method

The ray tracing method is well known algorithm in making 3D computer graphics. It simplifies continuous light waves as discrete ray segments. This method is applicable if the waveguide media is enough larger than the light wavelength. Figure 2 shows the algorithm overview.

Three following phenomena were investigated by using the numerical model and visualization experiments:

1. The light emission trajectories from the sensing edge of the optical fiber probe. From the result, the numerical analysis seemed a good accordance with the experiments. In addition, it was found that the optical fiber probe emits almost straight light by around 10°.

2. The signal pattern of the fiber piercing a bubble. From the result, the numerical analysis could simulate well the experimental pre-signal as Figure 3.

3. Signal pattern of the fiber piercing an air-water free surface. From the result, the surface deformation was found to affect strongly to the signal pattern. To improve the accuracy of the numerical analysis, a simple static meniscus model was applied to simulate the surface deformation. The numerical signal seems a good accordance with the experiment in case of the meniscus radius to be assumed to 0.2 mm as Figure 4.

Fig. 1 Measurement principle of the optical fiber probing

Fig. 2 Algorithm of the ray tracing method

Fig. 3 Numerical analysis of the fiber piercing a bubble

Fig. 4 Numerical analysis of piercing an air-water surface