Study on the Method of the Laser Backward Detection of Underwater Bubble Films Based on the Spatial Analysis

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Abstract

The backward light scattering characteristics of the water body and the bubble films are analyzed by the light transmission theory under water and the Mie light scattering theory, and the result shows that their spatial distributions are different. The backward light scattering of the water body is the monotone decreasing smooth curve, but the backward light scattering of bubble films presents complex change. Based on that, a new underwater bubble films laser backward detection method is proposed in this article. By the multiunit detector, this method could receive the backward scattering light signals, and detect the bubble films by the spatial analysis. The experiment result indicates that this method could realize the effective detection of the underwater bubble films, especial the detection of the distant bubble films.

Keywords: Bubble films, Light scattering, Mie scattering, Laser detection

1. Introduction

In the sailing, ships will produce large numbers of bubbles which will exist for a long time (Pereira, 2000, P.1-11 & LIU, 2003, P.265-267). Because of these bubbles, the optical characteristics of the sea water will change significantly (Zhang, 2002, P.1273-1282 & Zhang, 1998, P.6525-6536 & Alexander, 2004, P.258-263 & Stroud John, 1994, P.161-169 & LIU, 2007, P.24-27), so it is possible to detect and follow ships by measuring the transmission characteristics of laser under water.

In practice, the forward or backward scattering light to the bubble films are received. Comparing with the forward receiving mode, the backward scattering light signal is much weaker, and seriously intervened by the backward scattering light signal of the water body, so the concrete implement is much difficult. By analyzing the spatial distribution characteristics of the backward light scattering signals of the water body and the bubble films, a new judgment method is proposed in this article to better realize the detection of the underwater bubble films.

2. Analysis of theoretical model

As seen in Figure 1, the multiunit detector is put with the laser in parallel, and the optical axes are parallel each other, and the distance is s . The receiving vision angle is ω , and when the diffusion of laser in the water is not computed, the backward scattering light at the distance of L_0 could be received by the detector, so according to the geometric relationship,

$$L_0 = s / tg \frac{\omega}{2} \tag{1}$$

Supposed that the attenuation coefficient of the water body is c and the scattering function of the water body is $\beta(\theta)$, so

$$\beta(\theta) = \beta(90^\circ)(1 + \cos^2\theta) \quad (2)$$

Take the laser export point as the origin of the axes and the optical axis of laser as the X axis to establish the frame of axes, and take the water body in the infinitesimal range of x~x+dx as the research object, and in the backward scattering of the infinitesimal water body, the scattering angle of the backward scattering light received by the photoelectric detector is $\pi - \alpha$, so

$$tg\alpha = s / x \quad (3)$$

The backward scattering light intensity of the infinitesimal water body received by the receiver is (Qian, 2006, P.441-444),

$$dI = I_0 e^{-cx} \cdot [\beta(\pi - \alpha) \cdot S \cdot dx] \cdot e^{-cr} = I_0 S \beta(\alpha) \cdot e^{-c(x+r)} dx \quad (4)$$

And,

$$dI = I_0 S \beta(90^\circ) \cdot \frac{2x^2 + s^2}{x^2 + s^2} \cdot e^{-c\left(x + \sqrt{x^2 + s^2}\right)} dx \quad (5)$$

Therefore, the backward scattering light signal intensity of the infinitesimal water body received by the receiver is

$$I = I_0 S \beta(90^\circ) \cdot \int_{L_0}^{\infty} \frac{2x^2 + s^2}{x^2 + s^2} \cdot e^{-c\left(x + \sqrt{x^2 + s^2}\right)} dx \quad (6)$$

Supposing $g = I_0 S \beta(90^\circ)$, so

$$I = g \int_{L_0}^{\infty} \frac{2x^2 + s^2}{x^2 + s^2} \cdot e^{-c\left(x + \sqrt{x^2 + s^2}\right)} dx \quad (7)$$

It is a function about s. When the optical parameters of the water body and the performance of laser and detector are confirmed, the backward scattering light signal intensity is only related with the distance between the receiver and the laser. When this distance is certain, the backward scattering light signal intensity is only related with the water quality parameters $\beta(90^\circ)$ and c. For appointed water area, the water quality parameters $\beta(90^\circ)$ and c are known, so the backward scattering light signal could be confirmed.

Take $g = 1$, and suppose $c = 0.2$, so the change of the backward scattering light signal intensity with s is seen in Figure 2. From Figure 2, without bubble films, the intensity of the backward scattering light signal of the water body decreases monotonously with the distance s, and when the receiver approaches to the laser, the signal intensity is strong, and when the receiver is far from the laser, the signal is weak, and the curve is very smooth.

Supposing that the bubble film is located at the position of 5m, and when the distance between the receiver and the laser changes in 0m~0.5m, and the light scattering angle of bubbles changes in 180°~174.3°, the change of the backward scattering light signal of the bubble films computed by the Mie scattering theory with the distance between the receiver and the detector (supposing the radius of bubble is 100μm and the wavelength of the laser is 532nm) is seen in Figure 3. It indicates that the change of the backward scattering light of the bubble films is drastic with the distance s, and the minimum value occurs at the position closing with the laser, and the maximum value occurs at the position of 0.5m, which is significantly different with the curve of the backward scattering light signal intensity of the water body.

The backward scattering light signal intensities of the water body and the bubble films are analyzed respectively. But in the practice, when the bubble films exist, not only the backward scattering light signal of the bubble films but also the backward scattering light signal of the water body are received by the receiver. Therefore, the signals received by the receiver at different distances are different with the backward scattering signals of single bubble films seen in Figure 3. But, because the backward light scattering signal intensity curve of single water body is the monotonically decreasing smooth curve, and the backward light scattering signal intensity curve of bubble films is quite complex, when the bubble films exist, the backward light scattering signal intensity curve will not be the monotonically decreasing smooth curve because of the influence of the bubble films light scattering signals, and it must be fluctuated, and based on that, the underwater bubble films could be detected.

3. The laser backward detection method of underwater bubble films based on the spatial analysis

According to above analysis, the backward light scattering signal intensity curve will change to some extent when the bubble films exist, and it is not the monotonously decreasing smooth curve, so the underwater bubble films could be detected. According to this idea, the multiunit detector could receive the backward light scattering signals. As seen in Figure 1, the optical axes of multiple detectors are parallel with the optical axis of the laser, and ranked evenly with certain interval, so the multiple-detector array is composed. Theoretically, the interval among detectors is smaller and better, but in practice, because of the system complexity and spatial limitation, when certain detection unit is ensured, proper interval should be selected.

According to Figure 1, *n* photoelectric detectors are ranked, and because their distances with the laser are different, their received backward light scattering signal intensities will be different too, i.e. I_1, I_2, I_3, …, I_n, and based on these data, the detection of the bubble films could be realized.

4. Result of the experiment

Adopt the experiment equipment seen in Figure 4, and put the laser dynamometer on the lead rail which sliding direction is vertical with the optical axis of the laser, and the back scattering light signal intensity of different distances could be measured by adjusting the position of the laser dynamometer. In the measurement process, the influence of the distance of the bubble films and the density of bubbles on the detection performance could be measured by respectively change the position of the bubble films and the air-feeding pressure of the bubble films.

By adopting the semiconductor continual laser as the illumination source, the wavelength of laser is 532nm, and transmission power is 100mW, and the air-feeding pressure of the bubble films is 15kPa which is kept unchangeably, and the measurement result of the backward scattering light signal intensity is seen in Figure 5 through changing the distance between the bubble films and the laser. From Figure 5, when the bubble films don't exist, the change of the backward light scattering signal intensity with the distance is a monotonously decreasing smooth curve, and when bubble firms exist, the monotonously decreasing characteristic or the smooth characteristic of the curve will change, and when the distance is near, because the backward light scattering signal of bubble films is stronger, whether the monotonously decreasing characteristic or the smooth characteristic will change largely because of the influence of the backward light scattering signal, and the curve is not only monotonously decreasing and smooth. When the distance is far, the curve only changes its monotonously decreasing characteristic or its smooth characteristic in some special regions, which is mainly because the backward light scattering signal of bubble films is weak, and the influence on the backward light scattering signal is limited.

To more clearly show the difference of the backward light scattering signals with bubble films or without bubble films, the result subtracting the backward light scattering signal with bubble films with the backward light scattering signal without bubble films is seen in Figure 6. In the Figure, there is a level line which value is 0, and when the difference is above this line, the signal intensity with bubble films is bigger than the signal intensity without bubble films, and on the contrary, when the difference is blow this line, the signal intensity with bubble films is lower than the signal intensity without bubble films. And the absolute value of the difference is bigger, and the difference of signal intensities is more obvious. From Figure 6, the distance of the bubble films is nearer, the difference will be bigger, and the change of the different will be more drastic with the distance between the detector and the laser, and the distance of the bubble films is farther, the difference will be smaller, and the change of the different will be more even with the distance between the detector and the laser, and it only change drastically in local regions.

The standard deviation of the difference signals is seen in Figure 7. From Figure 7, the standard deviation of the power difference signals could reflect the signal intensity of bubble films and with the increase of the distance of bubble films, the standard deviation of power difference will be smaller and smaller. Therefore, by the standard deviation of the power difference, the existence of the bubble films could be judged by setting the threshold value.

5. Conclusions

Theoretical and experimental research result indicates that the change of the backward light scattering signal intensity of the water body without bubble films with the distance is a monotonously decreasing smooth curve, and when the bubble films exist, the monotonous characteristic and the smooth characteristic of the curve will change, and the distance of the bubble films is nearer, this change is more obvious. Based on that, not only the existence of bubble films could be judged, but the distance of the bubble films could be judged primarily.

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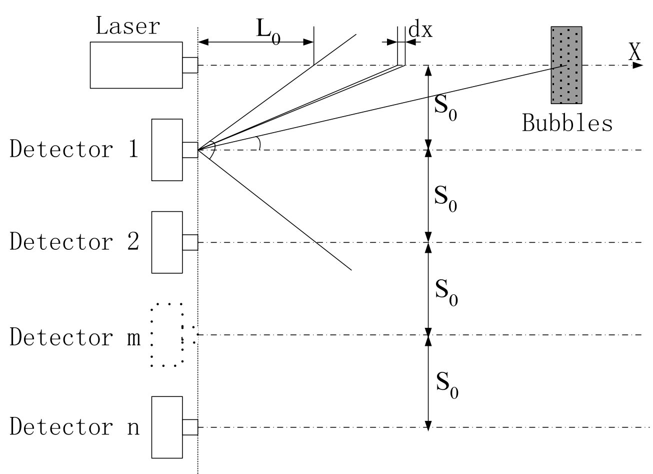

Figure 1. Computation of the Backward Scattering Light Signal Intensity

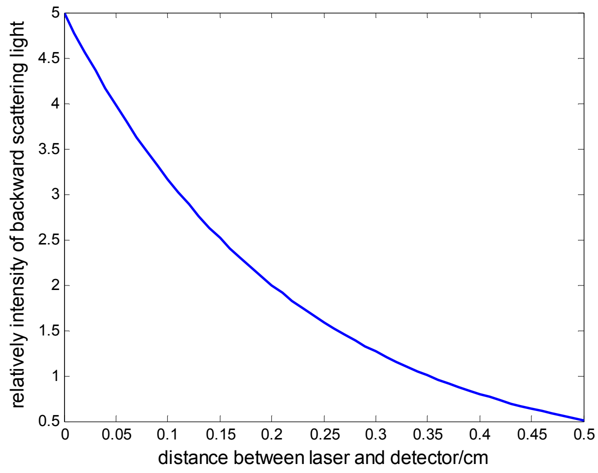

Figure 2. The Change of the Water Backward Scattering Light Signal Intensity with the Distance

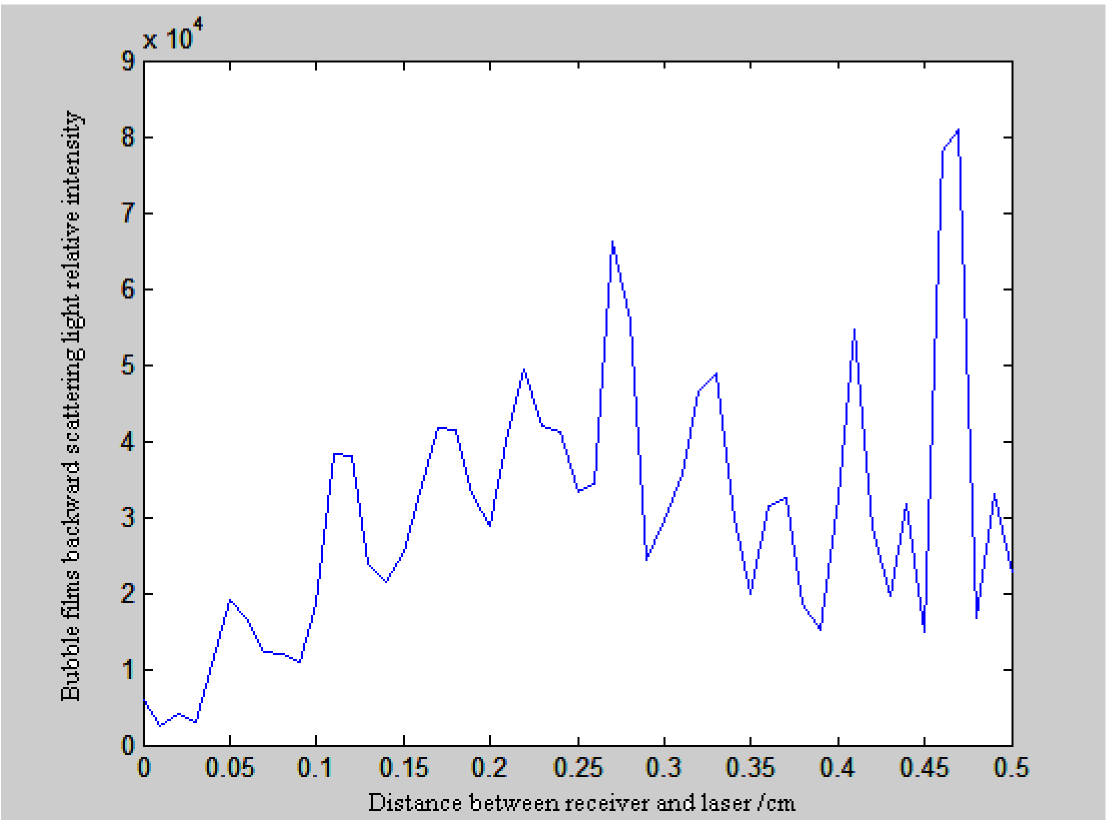

Figure 3. The Change of the Bubble Films Backward Scattering Light Signal Intensity with the Distance

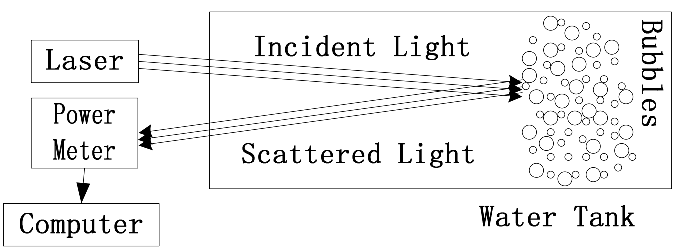

Figure 4. Sketch Map of the Experiment Equipment

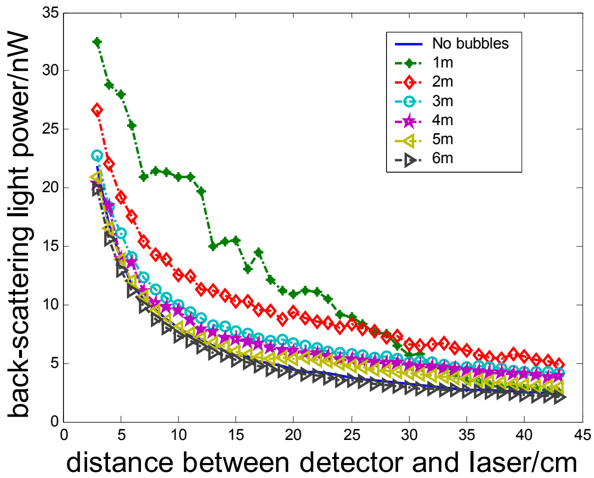

Figure 5. Power of the Backward Light Scattering Signal

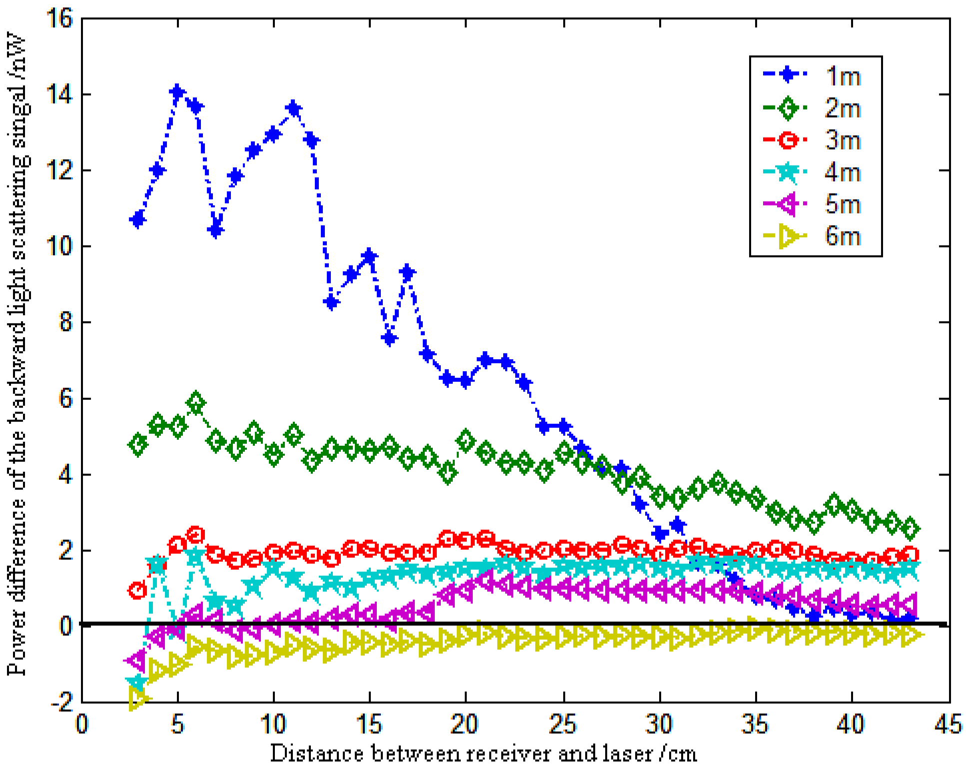

Figure 6. Power Difference of the Backward Light Scattering Signal

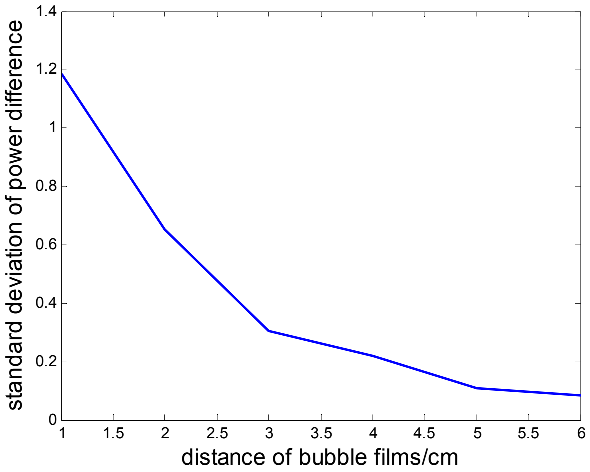

Figure 7. Standard Deviation of Power Difference