Bispectral Analysis of Nonlinear Void-Signals in Inclined Two-Phase Flow

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1. Introduction

Nonlinear void-signal is a measurement signal, which has the information of void fraction fluctuation in two-phase flow, such as impedance signal, conductivity signal and pressure fluctuation signal [1-4]. And it used to analyze two-phase flow transients system like nuclear reactors under various accident conditions. These void-signals have much nonlinearity, so it has possibility of getting more information about two-phase flow transients system by analyzing nonlinearity of void-signal [5].

For detecting and analyzing nonlinearities, bispectral analysis, which is based on the concepts of higher order spectra (HOS), is generally used [6-8]. Bispectral analysis determines the degree of second-order phase coupling that exists between constituent frequencies of nonlinear signals. It can be viewed as a decomposition of the third moment (skewness) of a signal over frequency and proves useful for analyzing and characterizing the state of systems.

In this paper, the nonlinear characteristics of void-signal were investigated by using bispectral analysis.

2. Methods and Results

2.1 Bispectrum Analysis

The bispectrum can be viewed as a decomposition of the third moment (skewness) of a signal over frequency and proves useful for analyzing systems with asymmetric nonlinearities. It investigates the degree of second-order phase coupling between the *n* constituent harmonics, $X_n(w_n)=c_n \sin(w_n t+\phi_n)$, of a void-signal, where w_n is angular frequency, c_n is amplitude, ϕ_n is phase and *t* is time.

The bispectrum, $B(w_p, w_q)$, is a measure of the degree of second-order phase coupling between $X_p(w_p)$, $X_q(w_q)$ and $X_{p+q}(w_p+w_q)$, while also taking into account the amplitudes of these harmonics. $B(w_p, w_q)$ is calculated by breaking the void-signal into L successive epochs and applying the following equation :

$$B(w_p,w_q)=\left|\sum_{m=1}^{L}(X_p(w_p)\cdot X_q(w_q)\cdot X^*_{p+q}(w_p+w_q))_m\right|, \quad (1)$$
$$=\left|(c_p c_q c_{p+q} e^{i(\phi_p+\phi_q-\phi_{p+q})})_m\right|$$

Where the index, m, is the current epoch and $X^*_{p+q}(w_p+w_q)$ is the complex conjugate of $X^*_{p+q}(w_p+w_q)$.

2.2 Adjusting to Void-Signal of Two-Phase Flow

The impedance in the cross sectional area of the test section was used as void signal. The data were sampled at 1000 Hz for 60 s and measured by void-impedance meter.

Figure 1 illustrates the magnitude of bispectrum of each flow pattern and Figure 3 is the contour plot of them in the bispectrum plane. In figure 2, large magnitudes of spectrum are observed in both cap bubbly flow and slug flow regime. However, relatively low magnitudes were observed in the other flow regimes. Therefore, it is more valuable to depict the contour map of the bispectrum as shown in Fig.2.

The contour plots of the bispectrum information are depicted in Figure 2 to quantify the nonlinear characteristics of void fraction signals, as for the bubbly flow bispectrum exists in the region low frequency region below 50 Hz. This means that it is fairly possible that the signals with higher frequency than 50Hz may be caused from noise. The real void signals form the bubbles can be represented by the harmonic combinations of signals below 50Hz.

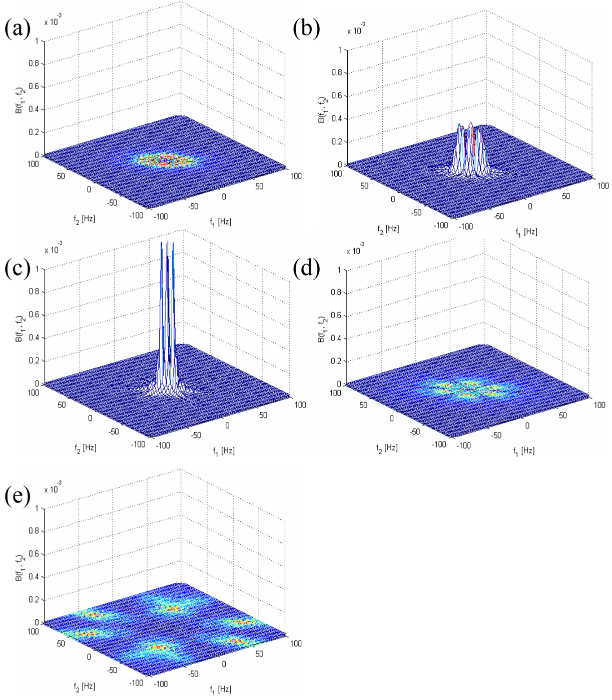

Figure 2. The magnitude of bispectrum; (a) bubbly flow (b) cap-bubbly flow (c) slug flow (d) churn flow (e) annular flow

As for the cap bubbly flow, the signals are concentrated below 25Hz as shown Fig.2.(b). Also, the slug flow has the concentration below 10Hz. Theses low frequency concentrations of bispectrim mean that these cap-bubbly and slug flow regime have the periodic occurrences of a certain distinguished void signals.

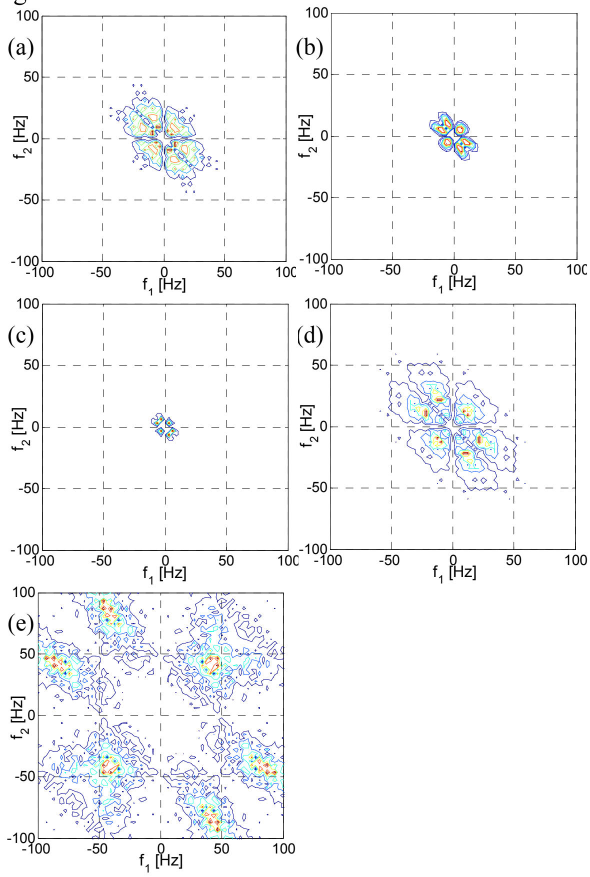

Figure 3. Contour plot of bispectrum (a) bubbly flow (b) cap-bubbly flow (c) slug flow (d) churn flow (e) annular flow

Also, the periodicity of the periodic void wave in the slug flow regime is less frequent than the cap-bubbly flow regime. It is physically sound due to the size of slug bubbles. The present results may be useful when we try to separate the periodic signals and nonlinear signals in such a cap bubbly flow or slug flow regime. As for the churn turbulent region, the wide spread in the frequency plane means that no more periodic signals can be observable in the region, rather chaotic signals are presented (Fig. 2(d)). The complicated nonlinear signals in the annular flow regime are very interest. The major reason of this highly nonlinearity came from the fact that there are many nonlinear waves in the annular flow as reported in the analysis of film flow. All known nonlinear waves including solitary waves are participating in the contribution of nonlinearity. Therefore, in the time average point of view, the annular flow may be very ordered nature but it has high frequency fluctuations.

3. Conclusion

In the present study, the nonlinearity of the void fractional signals in the two-phase flow was investigated using the bispectrum analysis. The second phase couplings in the void signals results in several important observation of two-phase flow:

- The bubbly flow regime has the chaotic character but below 50Hz signals.
- The cap bubbly flow regime and slug bubbly flow regime shoed a sort of periodic character in the void signals due tot the periodic occurrence of cap bubble or slug bubble.
- The churn turbulent flow and annular flow showed chaotic character in the high frequency region.

It was found that the present bispectrum analysis is useful to identify the nonlinearity in the two-phase flow signals and one who wants to control the two-phase flow may use the present results as the guidance of controller design.

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