Measurement of pressure fluctuation in gas-liquid two-phase vortex street

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Abstract. The pressure fluctuation in the wake is an important parameter to characterize the shedding process of gas-liquid two-phase Karman vortex street. This paper investigated such pressure fluctuations in a horizontal pipe using air and water as the tested fluid media. The dynamic signal representing the pressure fluctuation was acquired by the duct-wall differential pressure method. Results show that in the wake of the gas-liquid two-phase Karman vortex street, the frequency of the pressure fluctuation is linear with the Reynolds number when the volume void fraction is within the range of 18%. Moreover, the mean amplitude of the pressure fluctuation decreases with the volume void fraction, and the mean amplitude is larger at higher water flowrates under the same volume void fraction. These findings contribute to an in-depth understanding of the gas-liquid two-phase Karman vortex street.

1. INTRODUCTION
The Karman vortex street may exist in some gas-liquid two-phase flow under certain fluid conditions (Hulin et al., 1982; Inoue et al., 1986). The gas-liquid two-phase vortex street is as the same as the single-phase vortex street in generating pressure fluctuations in the wake flow (Sun et al., 2006). The positive aspect of this kind of pressure fluctuation is that it can be used for measuring or analyzing partial parameters of the gas-liquid two-phase flow (Li et al., 1998; Shakouchi et al, 2001, 2002), and the negative aspect is that the pressure fluctuation may induce vibrations which is dangerous to the piping system (Yokosawa et al., 1986a, 1986b). Therefore, it is of importance to study the dynamic property of the pressure fluctuation induced by a gas-liquid two-phase vortex street.

In this paper, investigations were carried out on the fluctuating property of the pressure in the wake of the gas-liquid two-phase vortex street developed in a horizontal pipe. Experiments were conducted using air and water as the tested fluid media, and the dynamic signal representing the pressure fluctuation was acquired by the duct-wall differential pressure method (DDPM). Analyses and discussion were focused on the change of frequency and amplitude of the pressure fluctuation with the Reynolds number and the volume void fraction.

2. EXPERIMENT
Experiments were conducted in a horizontal 50mm-diameter pipe using air and water as the tested fluid media. As shown in Fig. 1, the water in the pool and the air from the compressor were first pressed into surge tanks before their flowrates were measured respectively by an electromagnetic
flowmeter and a rotameter. After the water and air were mixed by a two-phase mixer, they entered in the test section where a bluff body was placed in the middle of the pipe perpendicular to the flow direction. The Karman vortex street was generated behind the bluff body and was shed in the wake flow. The bluff body was a trapezoidal cylinder with a blockage ratio of \( b = d/D = 0.28 \), where \( d \) was the width of the cylinder and \( D \) was the diameter of the pipe. The upstream and downstream straight pipe before and behind the bluff body were \( 30D \) and \( 20D \), which ensured the Karman vortex street fully developed.

From the two pressure tags on the pipe wall downstream of the front face of the bluff body, dynamic differential pressure signals were detected by a Honeywell 24PC sensor, were conditioned by an analogue electric circuit scope and then processed by a computer (Sun et al., 2004, 2007). The sampling rate used was 1000 Hz throughout the experiments. Each data set contained 10000 points. Signals were acquired only when the vortex street was stable. During the experiments, the air flowrate was 0.2–4.0 m\(^3\)/h with 1.5% accuracy degree, and the water flowrate was 5.0–19.0 m\(^3\)/h with an accuracy of 0.5%. Additionally, pressures and temperatures of air and water at the flowmeters and the test section were also measured.

![Experimental set-up](Fig. 1)

**3. RESULTS AND DISCUSSION**

**3.1 Dynamic Differential Pressure Signal**

Fig.2 shows the raw pressure fluctuation signal in vortex street wake respectively obtained from single water and gas-liquid two-phase flows. The two cases presented are featured with the same Reynolds number \( Re \), which is defined as follows:

\[
Re = \frac{v_{TP} \rho_{TP} D}{\mu_{TP}} \quad (1)
\]

\[
v_{TP} = \frac{(Q_G + Q_L)}{S} \quad (2)
\]

\[
\rho_{TP} = \rho_G \beta + \rho_L (1 - \beta) \quad (3)
\]

\[
\mu_{TP} = \mu_G \beta + \mu_L (1 - \beta) \quad (4)
\]

where \( v_{TP} \) is the mean flow velocity of the two-phase mixture, \( Q_G \) and \( Q_L \) are the flowrates of the gas-phase and liquid-phase components, \( S \) is the cross-sectional area of the pipe, \( \rho_G \), \( \rho_L \) and \( \rho_{TP} \) are the density of the gas-phase component, the liquid-phase component and the two-phase mixture, \( \mu_G \), \( \mu_L \) and \( \mu_{TP} \) are the dynamic viscosity of the gas-phase component, the liquid-phase component and the two-phase mixture.

It is seen that the pressure fluctuation in Fig.2(b) is quite stable as in the single water flow, which reveals that there still exist regular vortex shedding in the gas-liquid wake behind the bluff body. Within a certain range of the volume void fraction \( \beta \) (\( \beta = Q_G/(Q_G + Q_L) \)), the introduction of gas into the
liquid component has little impact on the Karman vortex shedding. The corresponding power spectral densities (PSDs) of the raw signals were also calculated and were shown in Fig. 2.

![Fig. 2 Raw pressure fluctuation signal in vortex street wake and its corresponding power spectral density: (a) Single water; (b) Two phase.](image)

### 3.2 Fluctuating Frequency

As mentioned above, the frequency $f$ of gas-liquid two-phase vortex street could be calculated by analyzing the dynamic differential pressure signal in the frequency domain. Fig. 3 shows the relationship between the vortex frequency and the Reynolds number. It demonstrate that $f$ increased with $Re$ linearly regardless of the volume void fraction, which was just the same as that of single-phase flows. However, the linearity between $f$ and $Re$ maintained until the volume void fraction $\beta$ was up to 18%, that is to say, when $\beta$ was greater than 18%, the fluctuating differential pressure at vortex shedding frequency was not detectable.

![Fig. 3 Frequency of pressure fluctuation versus Reynolds number.](image)

### 3.3 Fluctuating Amplitude

The amplitude of the fluctuating pressure in the vortex street wake has a close connection to the vortex shedding process and it is an important parameter to study the characteristics of the Karman vortex street. The relationship between the mean amplitude $A$ of the fluctuating differential pressure and the volume void fraction are presented in Fig. 4. The calculation of $A$ is as follows: first the number $N$ of complete periods in an experiment data set was computed; then within each complete period the maximal and minimal values were selected respectively, and here we denote $A_{\text{max}}$ and $A_{\text{min}}$ for the maximal and minimal values in the $i$th period; finally the mean amplitude $A$ was calculated by Eq. (5).
\[
A = \frac{1}{2N} \left( \sum_{i=1}^{N} A_{\text{max}}^i - \sum_{i=1}^{N} A_{\text{min}}^i \right)
\]  

(5)

The signal amplitude is usually used to characterize the intensity or energy of the vortices generated from the view of fluid dynamics. Fig. 4 shows a decreasing trend of \(A\) with \(\beta\) at various water flowrates \(Q_L\). The curve at lower \(Q_L\) is flat, which is nearly linear. When \(Q_L\) increases, the reduction in \(A\) turns to be a little faster and eventually it has the trend to be in a power function form at the higher \(Q_L\). These results reveal that the energy of gas-liquid two-phase vortex decreases with the water flowrate.

Fig. 4 Amplitude of pressure fluctuation versus volume void fraction.

4. CONCLUSIONS
This paper studied the pressure fluctuation in the wake of gas-liquid two-phase Karman vortex street in a horizontal pipe. Major findings are summarized as follows.

1) The frequency of the pressure fluctuation in the wake of gas-liquid two-phase Karman vortex street is linear with the Reynolds number when the volume void fraction is within the range of 18%.

2) The mean amplitude of the pressure fluctuation in the wake of gas-liquid two-phase Karman vortex street decreases with the volume void fraction, and under the same volume void fraction the mean amplitude is larger at higher water flowrates.

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NOMENCLATURE
\(A\) signal amplitude \([\text{kPa}]\)
\(b\) blockage ratio
\(D\) inner diameter of pipe \([\text{m}]\)
\(d\) width of bluff body \([\text{m}]\)
\(f\) vortex frequency \([\text{Hz}]\)
\(N\) period number
\(Q\) volume flowrate \([\text{m}^3/\text{h}]\)
\(Re\) Reynolds number
\(v\) mean flow velocity in pipe \([\text{m/s}]\)
Greek Letters

\(\beta\)  volume void fraction
\(\mu\)  dynamic viscosity \([\text{N} \cdot \text{s/m}^2]\)
\(\rho\)  density \([\text{kg/m}^3]\)

Subscripts

G  gas-phase component
L  liquid-phase component
max  maximal value
min  minimal value
TP  two-phase flow

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