

A Study of Differential Pressure Measurement in Vortex Flowmeter

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Abstract Vortex flowmeter based on piezoelectric transducer is subjected to noise disturbances caused by pipe vibrations and fluid turbulence during measurement. According to the characteristics of the fluid field near the bluff body, the method using differential pressure between two sides of the bluff body to measure vortex frequency is presented in the paper. Numerical simulations have been carried out to help the optimally sensor structure design. The experimental results show that this method is effective to measure vortex frequency and has robustness to disturbances.

Keywords: vortex flowmeter; differential pressure; numerical simulation

1. Introduction

Vortex flowmeter has been widely used in industrial liquid, gas and steam flow measurement because of its low price, simple installation, high reliability (no moving parts) and high accuracy.

The operation of a vortex flowmeter depends on the complex von Kàrmàn vortex shedding. Figure 1 shows the principle of vortex flowmeter. When the bluff body is appropriately shaped, the frequency f of the vortex is proportional to the mean flow velocity v within a broad range of velocities. The relationship between them is given by:

$$f = \frac{S_t}{d} v \quad (1)$$

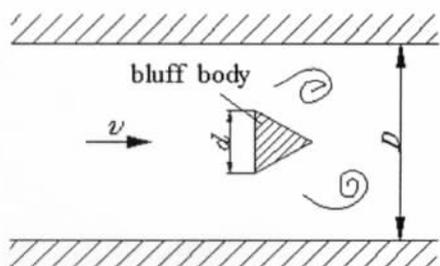


Fig.1 Principle of vortex flowmeter

Where S_t is the Strouhal number and d is width of the vortex shedder. Therefore volumetric flowrate can be obtained.

There are various methods to measure the frequency of vortex shedding using different principles, for example, by using thermo-resistance, capacitor sensor, piezoelectric sensor or ultrasonic sensor as well. Piezoelectric transducer is now widely used. It has such advantages as quick response, strong signals and non-touch with the fluid medium. The flowmeter, however, has poor anti-noise-disturbance ability to the pipe vibrations and fluid turbulence during the measurement in the industrial field, which influence the measurement accuracy dramatically. Much efforts have been made to improve the sensor structure and signal processing in recent years^[1-5].

The method using the differential pressure to measure the frequency of vortex shedding is presented in this paper. It can reduce the noise disturbance and ensure the measurement accuracy. In order to achieve good flow measurement characteristics, numerical simulations and

experiments have been carried out to optimally design the sensor structure.

2. Measurement principle

The research to the characteristics of the fluid field near the bluff body indicated that the fluid separated at both sides of the bluff body, thus producing alternant vortex and the pressure fluctuations, which entirely reflected the characteristics of the vortex^[6]. The vortex frequency, therefore, could be obtained from the measurement of the pressure fluctuations.

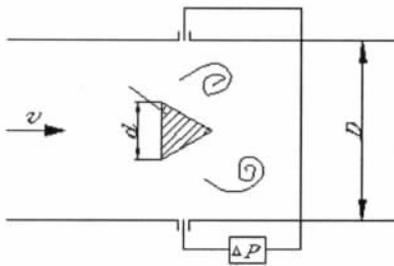


Fig.2 Differential pressure measurement

As shown in figure 2, two pressure taps are used to form differential structure to detect the pressure fluctuations. With this arrangement, the time mean pressures sensed at each pressure tap are counterbalanced. But the pressure fluctuations associated with the vortex shedding frequency component are expected to behave in an antiphase manner, which was proved by experiments. Therefore the differential pressure signal amplitude is about twice as large as that sensed at one of the pressure taps, and the disturbance signal can be counteracted. Therefore this structure can effectively reduce the disturbance and improve the signal amplitude.

At different locations, the frequencies of pressure signals are all the same as that of vortex shedding. But the amplitude and stability of signals are different. So the locations to place two pressure taps are important for the pressure signals. Therefore numerical simulations and experiments

were carried out to help the locations determination to obtain stable and reliable signals with sufficient amplitude.

3. Numerical simulation

When fluid flows past the bluff body more complicated phenomena like separation, reattachment and unsteady vortex shedding occur^[7]. These phenomena have been a subject of interest to engineers as well as scientists for a great many years^[8]. There is a great need in practice to predict such flow phenomena and provide useful information for the flowmeter design. Approaches to this problem have been principally experimental for a long time. Until recently, the development of CFD technology and high performance of computers provide the possibility to deal with such complex flow by highly-accurate numerical simulation along with experiments^[9].

In this paper, numerical simulations have been performed by a commercial CFD codes (FLUENT 6.0). FLUENT system can handle unsteady viscous flow over a wide range of applications. FLUENT solvers are based on the finite volume method^[10]. Before using FLUENT to calculate, pre-processor GAMBIT(2.0) should be used to complete geometry creation, mesh generation, mesh quality examination, boundary zone assignment

Consider viscous incompressible fluid past a triangular cylinder in the pipe with a constant velocity v . According to the Reynolds number of the pipe, the flow is turbulent. Turbulence plays an important role in the flow phenomena considered. The exact Navier-Stokes equations should be solved time-dependent completely. The unsteady RANS turbulence models are used in the numerical simulation to compute periodic shedding. It has been proved that unsteady RANS can indeed predict periodic vortex shedding^[11].

Segregated solver is chosen to solve each equation separately. The spatial derivatives are discretized using first order upwind scheme while the time integration employs implicit second-order stencil. The SIMPLE algorithm is used for pressure-velocity coupling. The RANS simulation is carried out with RNG $k-\epsilon$ model derived using a rigorous statistical technique (called renormalization group theory). The unsteady RANS model was directly used from the beginning. The time step is about 10 time steps per shedding period (based on experimental results and empirical formulation). The other parameter is set up as the experiment facility.

4. Experimental setup

The vortex flowmeter used in the experiments is a circular pipe, with 50mm in diameter. The bluff body is triangle shaped. The width of the bluff body frontal surface is 14mm. Two pressure taps are located on both sides of the bluff body to achieve differential pressure. A piezoelectric sensor embedded in the bluff body was also used to compare with the pressure sensors. Two signals are sampled and saved by Tektronix TDS 430A oscilloscopes for further calculation and analysis.

Experiments were carried out for gas and water material respectively. A bell prover flowmeter calibration device was used for gas fluid. The device is shown in figure 3. Bell prover covers flow rate ranging from 20 to 160 m³/h.

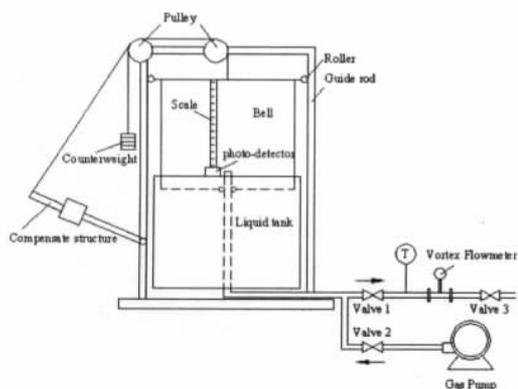


Fig 3. Bell prover gas flow calibration facility

Experiments were performed in a closed-loop flow pipe with water. The schematic diagram of experimental system is shown in figure 4. The water flow rate was from 4 to 20m³/h.

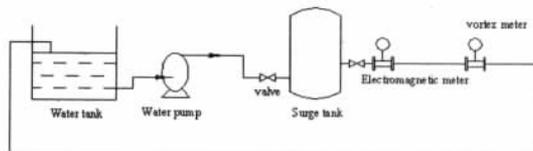


Fig 4. A closed-loop water flow rig

5. Results and discussions

5.1 Numerical Results

The flow meter inlet is defined as velocity inlet. When the inlet velocity varies, the generation of vortex shedding, the field of velocity and static pressure are similar whereas the amplitude and frequency are different. In order to determine the best locations to place the pressure taps, points were picked up along x and y directions, illustrated in figure 5, to calculate the time dependent static pressure. The exact locations are the intersections of x and y lines.

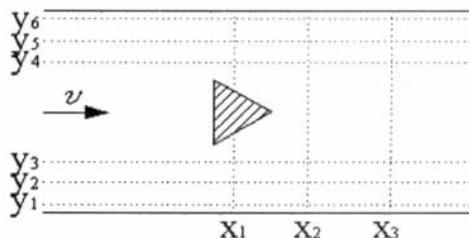


Fig 5. Locations of the calculated points

At first, the static pressure in points y_1 and y_6 along x_1 line were calculated. The distance between x_1 and the frontal area of bluff body is 0.2D. The result is shown in figure 6. The inlet velocity is 30m/s. The computed frequency of pressure fluctuation was 555.56Hz while the experimental frequency was 548.4Hz, giving a relative error of 1.3%. The phase of the pressure fluctuation is just 180 degree antiphase. When points move downstream the bluff body along y_1 , a secondary vortex will be sensed along with the

primary vortex (figure 7). So the position in x direction should near bluff body to avoiding further downstream disturbance and instability affect. Static pressure in different y positions also calculated. When the points move to the center of the pipe and near the bluff body along x_1 line, the amplitude of the pressure fluctuation are increased (figure 8). Considering simply structure and maintain convenience the pressure detect location is better at the pipe boundary. So the designed structure is shown in figure 9. The positions to detect pressure fluctuations are near the bluff body and 45 degree away from the horizontal plane. The intensity of the pressure signal in these positions is strong enough to detect.

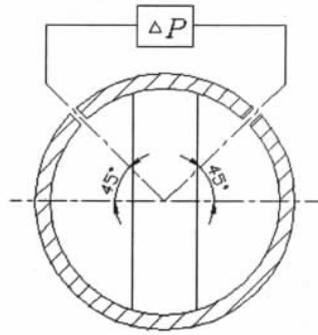


Fig 9. The arrangement of pressure taps

5.2 Experimental results

At first, the frequencies of differential pressure signals are compared with piezoelectric signals. The piezoelectric sensor has been calibrated so that it can be used as a reference. Its uncertainty is within 1%. Experiments were carried out in the bell prover system. Two signals were sampled simultaneously. Figure 10 shows two signals in time domain and frequency domain which is the result of Fourier transformation, with flow velocity being 15.6m/s. It can be seen that both frequencies are 283.2 Hz, indicating that the vortex signal frequencies from pressure sensors were accordant to the output of the piezoelectric sensor. It is illustrated that the differential pressure signals can really reflect the fluid fluctuation caused by vortex shedding.

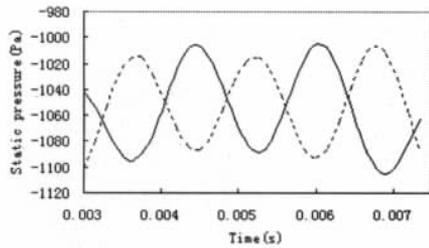


Fig 6. Static pressure in y_1 and y_6 along x_1

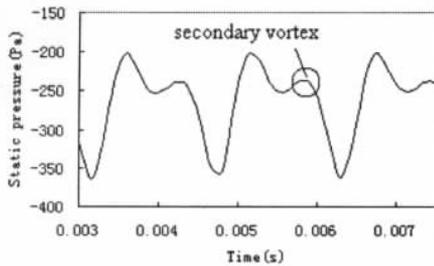


Fig 7. Static pressure in the intersection of y_1 and x_3

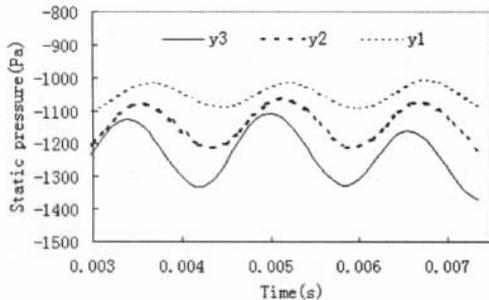


Fig 8 Static pressure in x_1 line

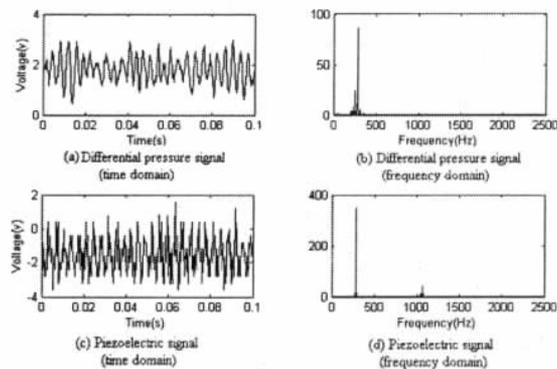


Fig 10. Pressure signal and Piezoelectric signal

($v=15.6\text{m/s}$)

Figure 11 shows the relationship between vortex shedding frequency derived from differential pressure and inlet velocity. The results are

integrated the gas and water measurements. Good linearity is achieved and the linearity is accordance between different material.

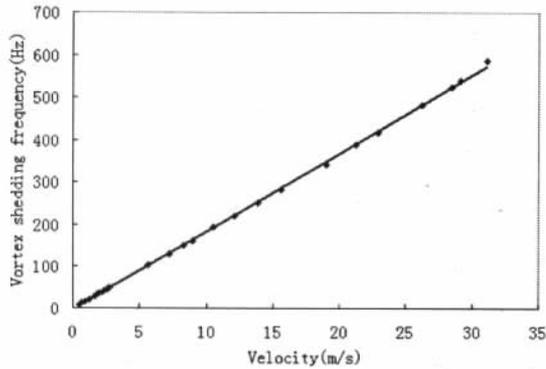


Fig 11. Vortex shedding frequencies of experiment results

6. Summary

The method using differential pressure to measure the vortex frequency is discussed in this paper. With help of numerical simulation and experiments, the ideal point locations to detect pressure fluctuation are less than $1/5 \sim 1/2 D$ after bluff body and 45 degree away from center axis at the pipe boundary in the cross section. This method is an ideal method to measure vortex frequency. It has stronger anti-noise ability. It can be used under high temperature. It has better stability in long term use and stronger adaptability.

Acknowledgment

This work is being supported by foundation of Ph.D research by Ministry Education, P.R. China (20030335058).

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