Development of a Vortex Flowmeter with good Performance at Low-Flowrate

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Abstract: Due to the mechanism of vortex flowmeter, it is susceptible to the random disturbance from the ambient. With the goal of improving the poor sensitivity and noise immunity of conventional vortex flowmeter at low-flowrate, many researchers have done lots of work, focusing on innovation about the bluff, including the geometry or combinations, and the signal processing. This paper presents an adaptive algorithm for a vortex flowmeter with dual bluff body to improve its sensitivity for low flowrate applications. In our study, we get the distance where intension of vortex getting strongest by experiment. Comparative experimental results of vortex with single bluff body, dual bluff body and dual bluff body combing self-adaption FFT verify the improvements of the flow performance at small flowrate.

Keywords: Vortex flowmeter, Dual bluff, Self-adaption FFT

1. Introduction

Since early 1970s, vortex flowmeters (based on the well-known Karman vortex street phenomenon) have been widely used in flow measurements in industry and daily life because of several attractive advantages which include no moving part, high reliability, low maintenance, and insensitivity to fluid properties and temperature [1, 2]. However, vortex meters exhibit poor sensitivity when the flowrate is low (or small Renolds number R_e [3]), which significantly limits the measurement applications. Their signals are also susceptible to ambient noise (such as flow turbulence and pipe vibrations) as well as noise from different acoustic sources. For this reason, this paper presents an adaptive algorithm for a vortex flowmeter to improve its sensitivity for low flowrate applications.

Von Karman [4] (1912) studied the vortex shedding from bluff bodies, and his findings have provided the basis for the subsequent design of vortex flowmeters. Honda and Yamasaki [5] investigated the stability of the vortex shedding from bluff bodies. Igarashi [6] demonstrated the regularity of vortex shedding and strength of vortices from circular cylinder bodies in a uniform flow. In order to improve the poor sensitivity and noise immunity above, a number of researchers did lots of work. Some devoted to improvements on the bluff. One method is enlarging the size of bluff, but larger bluff occupies more space (almost 24 to 28 percent of the pipe's diameter), which causes high pressure loss [7]. Other researchers found that certain optimum combinations of two bluff bodies in series can improve sensitivity greatly, for the purpose of generating stronger vortex intension. Bentley and Benson [8] investigated experimentally that higher repeatability of vortex shedding may be obtained with optimal dual bluff body combinations by a number of rectangular bluff body combinations, and their work instituted the foundation of dual bluff body vortex flowmeters. Other researchers focused on the improvement of signal process, i.e. the digital signal process, fourier analysis and cross-correlation techniques, adaptive frequency measurement method (AFM) and the power spectrum method based on fast Fourier transform-FFT.[9-11] In practice, there are mainly three methods: 1) spectra analysis: main frequency can be refined from the signal mixed noise through this, however this method can't simultaneously adapt to high and low frequency, bringing little contribution to reduction of lower limit; 2) raising the bottom limitation of cut-off frequency for trigger action, but this method narrows the measurement range; 3) comparison with threshold in signal transformation: but this may lead to mission frequency and increasing the errors in measurement

In this paper, we combine dual bluff and adaptive FFT signal process for the purpose of getting better lowest flowrate performance, and the experimental results achieve favorable effect.

2. Principle of dual bluff and self-adaption FFT

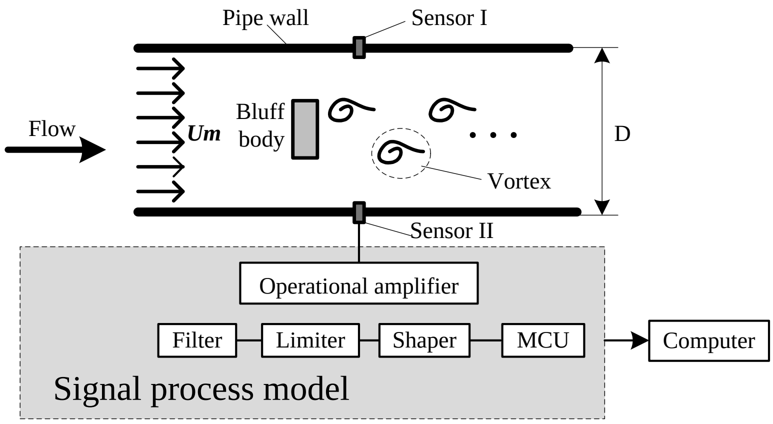
Figure 1 illustrates a typical vortex flowmeter which consists of a bluff body (placed in a flow stream), a pair of sensors (positioned on the pipe but behind the bluff body) to measure the frequency of the vortices which shed alternately on both sides of the bluff body, and the signal processing board through which signals are transmitted to and analyzed in a computer. As shown in Fig. 1(b), the formation of vortex is determined by the magnitudes of flows A, B and C. Ideally C should be maximum, A minimum, and B just sufficient to ensure effective detachment of the growing vortex [12].

The principle of vortex flowmeter is based on Eq. (1):

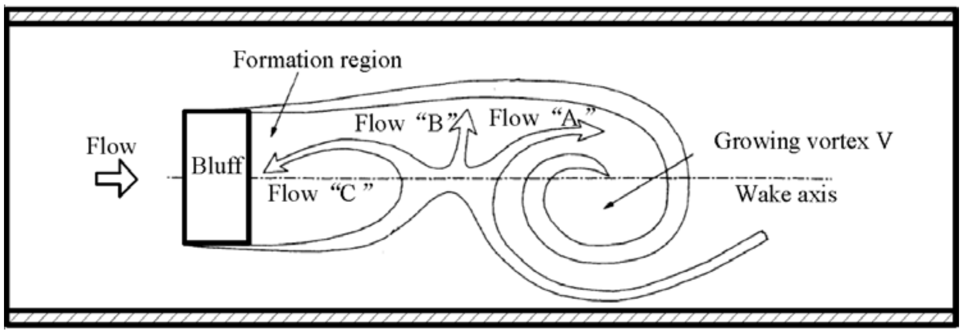
$$U_m = \frac{fW}{S} \tag{1}$$

Where U_m is the mean free-stream velocity (m/s); f is the vortex shedding frequency (Hz); the Strouhal number S depends on the geometry of the bluff and the Reynold number R_e of the flow, R_e is the criterion judging properties of fluid dynamics; W is the width (facing upstream) of the bluff body (For a cylinder bluff, W is its diameter).

As shown Eq. (1), the mean flow velocity U_m is a linear function of the vortex shedding frequency f. In a range of $300 < R_e < 10^4$, the Strouhal number S is a constant (= 0.2) [3].



a. Schematics of a vortex flowmeter



b. Schematics illustrating vortex formation process in single bluff body [13]

Fig. 1 Principle of vortex flowmeter

2.1 Vortex shedding mechanism in dual bluff bodies

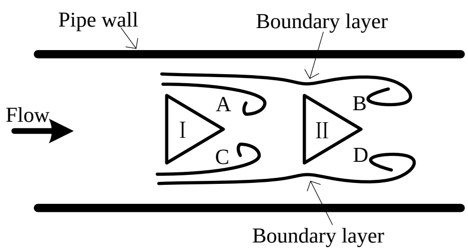


Fig. 2 Mechanism of vortex development

Based on many researchers' work, investigations have shown that the intension of vortex can be much stronger by using certain optimum combinations of two bluff bodies in series [14]. In this section, we will introduce the mechanism of vortex shedding. The study of researchers on the mechanism of dual bluff bodies can be summarized below. As shown in figure 2, there are 3 stages for the formation of vortex. Firstly, a vortex has just been shed from bluff Ⅰ, which causing the pressures at A and B to be minimum, and inner boundary layers along bluff Ⅱ are then pulled up into the gap at C, which leads to increasing in vorticity close to the bluff Ⅱ due to the increased velocity gradient produced in the lower boundary layers. Then with the pressure at points A and B increasing and at points C and D decreasing, boundary layers are pulled down into the gap at A, thus increasing the vorticity of the upper vortex and boundary layers are released from the gap at C, thus encouraging detachment of the lower vortex. At last vortex shed from bluff Ⅰ causes the pressures at D and C to be minimum, and inner boundary layers along the top of the combination are pulled down into the gap at A, resulting an increase in vorticity close to the bluff body.[13, 14] And in this paper the optimum length between two bluffs is tested by experiments.

2.2 Principle of self-adaption FFT

Based on FFT, self-adaption FFT split the sample rate of some sections, rather than simplex sample rate. And to realize FFT transformation, we chose radix 2 FFT algorithm. The butterfly flow figure of arithmetic is shown in figure 3[15].

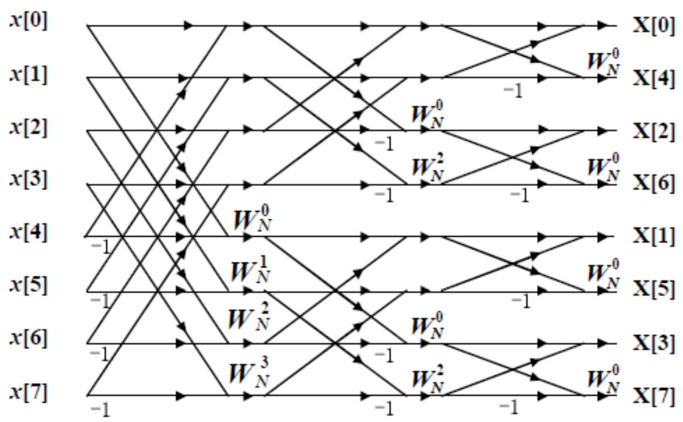


Fig. 3 Step computation flow of 8 points DIF

Where

X (k) = DFT[x(n)] (0≤n, k≤n-1, N is even number)

$X_0(r)$ = X (2r), $X_1(r)$ = X (2r+1) (0≤r≤n/2-1)

If $x_0(n)$ = IDFT[$X_0(r)$], $x_1(n)$ = IDFT[$X_1(r)$] then

$$\begin{cases} x_0(n) = x(n) + x\left(n + N/2\right) \\ x_1(n) = \left[x(n) - x\left(n + N/2\right)\right] W_N{}^n \end{cases} \qquad \left(0 \le n \le N/2 - 1\right) \tag{2}$$

Where

$W_N{}^n$ is twiddle factor.

Normally more sample points bring the spectrum of FFT more close to the ideal one, and stronger ability to restrain noisy. However, more sample points will occupy more time in calculation. Therefore considering the time and accuracy of calculation comprehensively, based on the premeasured range of output signal number of sample point is determined to 1024.

And determination of sample frequency is based on Shannon sampling theorem and resolution. Here we get sample frequency in different frequency section, as shown in table 1.

Table. 1 Sample frequency in different section

Frequency(Hz)	<64	64~128	128~256	256~512	>512
Sample frequency(Hz)	256	512	1024	2048	4096

3. Experiment and results

Experiments were performed on sonic nozzle air flow standard device. The schematic diagram of the experimental apparatus is shown in figure 4.

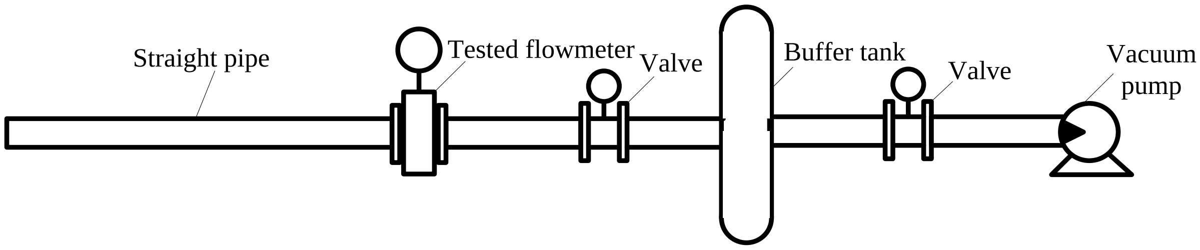


Fig. 4 Schematics of sonic nozzle air flow standard device

The vortex flowmeter tested in the experiment is a dual prism vortex flowmeter with flat side facing to the inflow.

3.1 chosen of optimum length between dual bluffs

In experiment of different pipes, the distance between two sensors (axisymmetric positioned beside the bluff) E keeps 31mm and sensor to the flat side of bluff F keeps 2.5mm, as is shown in figure 4. The experiment result of pipe diameter of 80mm is shown in table 2.

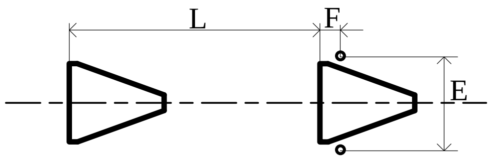


Table. 2 Calibration results of different distance between two bluffs

L (mm)	Calibration flowrate (m/s)					
	1.96		4.40		11.73	
	Linearity (%)	Repeatab-ility (%)	Linearity (%)	Repeatab-ility (%)	Linearity (%)	Repeatab-ility (%)
72.2	0.89	0.05	0.50	0.10	2.07	0.01
82.2	1.26	0.32	0.24	0.23	0.42	0.00
87.2	0.32	0.01	-0.59	0.05	-0.62	0.10
92.2	0.78	0.05	-0.69	0.07	-0.78	0.14

For pip of different diameters, the tested optimum lengths of dual bluffs are shown in table 3, including the magnitude and arrangement of bluffs.

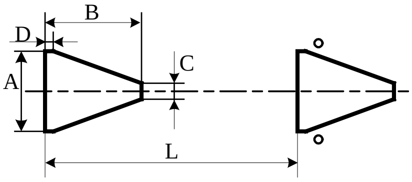


Table. 3 Optimum lengths, magnitude and arrangement of dual bluffs

Diameter(mm)	A	B	C	D	L
50	14.0	18.2	2.4	1.4	58.0
80	20.8	29.2	3.8	2.2	87.2
100	26.0	33.0	5.6	3.3	112.5
200	55.0	67.5	11.0	6.8	207.0

Flow velocity in experiment is controlled in a range of 1.96 to 28.4m/s. We compared the lowest flowrate of single bluff body, dual bluff body and dual bluff body coupled with self-adaption FFT, on the condition that measuring error ≤1%.

Table.4 Comparison of the lowest flowrate subject to the criterion: measuring error≤1%

Diameter (mm)	Lowest flowrate (m^3/h)		
	Single bluff	Dual bluff	Dual bluff & FFT
50	25	15	12
100	120	70	60
200	570	300	250

The results in table 4 show that the lowest flowrate of vortex flowmeters with dual bluff combining self-adaption FFT reduced to nearly half of that with single bluff. This verifies well the improvements of the flow performance at small flowrate.

4. Discussion and Conclusion

The goal of this work is to get better sensitivity and noise immunity of vortex flowmeter at low-flowrate. The optimum distance of dual bluff and self-adaption FFT are tested in our study. And from the experimental results, we achieve smaller lowest flowtate with higher accuracy.

In our study, the locations of bluff bodies and the distance of dual bluff are not studied systematically. Besides, from the results in experiment of self-adaption FFT we can see that the change of hard ware circuit brings improvement in increase of lowest flowrate. In further study, with these in consideration the performance of vortex flowmeters in small flowrate will be improved greatly.

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