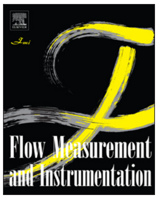
Flow Measurement and Instrumentation 35 (2014) 16–27

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst



Response of a dual triangulate bluff body vortex flowmeter to oscillatory flow

Jiegang Peng*, Min Fang

School of Automation Engineering, University of Electronic Science and Technology of China, Chengdu 610054, People's Republic of China

ARTICLE INFO

Article history:
Received 28 August 2012
Received in revised form
28 June 2013
Accepted 6 November 2013
Available online 14 November 2013

Keywords:
Hilbert–Huang transform (HHT)
EMD-scales filter
Oscillatory flow
Dual triangulate bluff body
Vortex flowmeter

ABSTRACT

In this paper, on an experimental facility, the measurement characteristics of a diameter 50 mm dual triangulate bluff body vortex flowmeter in steady flow and oscillatory flow were investigated. Then, the Hilbert Huang Transformation (HHT) method was used to assess the anti-interference performances and the vortex street stability in oscillatory flow for the dual triangulate bluff body vortex flowmeter and a single bluff body vortex flowmeter. Offline simulation was carried out on the anti-interference performances of the dual triangulate bluff body vortex flowmeter signal noise in oscillatory flow by the method of the EMD-scales filter. The major findings are: (a) in most case, the EMD-scales filter may be as good at de-noising effect for the dual bluff body vortex flowmeter in oscillatory flow than that for the single bluff body vortex flowmeter in oscillatory flow. The vortex street stability in oscillatory flow for the dual bluff body is similar to that for the single bluff body. (b) In some special case, the EMD-scales filter is unable to play a better de-nosing role for the dual bluff body vortex flowmeter in oscillatory flow. The invalid condition of the EMD-scales filter for the dual bluff body vortex flowmeter in oscillatory flow is different to that of the single bluff body vortex flowmeter and it was advanced in this paper. (C) The vortex street stability for the dual bluff body vortex flowmeter is better than that for the single bluff body vortex flowmeter.

1. Introduction and background

The phenomenon of vortex shedding from bluff bodies has been studied over one hundred years. When a bluff body is placed in a flow stream, vortices shed alternately from each side surfaces of the body. The non-dimensional shedding frequency, the Strouhal number, is defined as:

$$S = \frac{fD}{U_m}$$

where f is the vortex shedding frequency. D is the bluff body diameter, and U_m is the mean free-stream velocity. Over a wide range of Reynolds numbers, the Strouhal number is a constant, implying a linear relationship between shedding frequency and mean velocity, thus providing the basis of a flowmeter [1,2].

The vortex flowmeter has a number of attractive advantages, i.e. high reliability, low maintenance, and insensitivity to fluid properties and temperature. So it is widely used in the measurement of flow rate in a pipe flow. However, it has its own disadvantage i.e. poor noise immunity and low flowrate sensitivity [3,4]. In order to improve the noise immunity and low-flowrate sensitivity of the vortex flowmeter, great efforts have been made by a number of researchers. One method of improving low-flowrate sensitivity and repeatability of the vortex flowmeter is to use two bluff bodies in series or tandem separated by a narrow gap. Many researchers [5–12] have investigated the characteristics of vortex shedding for two bluff bodies in series or tandem separated by a narrow gap. Those works showed that dual bluff body combinations gave more regular and stable vortex shedding than a number of single bluff bodies of different shapes. Based on above works, Jiegang Peng proposed a new type vortex flowmeter of dual triangulate bluff body [13,14]. From their work, the low flowrate sensitivity of a dual triangulate bluff body vortex flowmeter is superior to that of a single bluff body vortex flowmeter. However, their previous works, which were aimed at improving low-flowrate sensitivity and repeatability of the vortex flowmeter by using a dual triangulate bluff body, did not mention anything about the response of the dual triangulate bluff body vortex flowmeter to oscillatory flow. But the signal characterization of flowmeter in oscillatory flow is an important influential factor in industrial application because of fluid oscillation in fluid transfer process and it is a key phenomenon for the stability of the vortex shedding from bluff bodies too. Now, the response of the dual triangulate bluff body vortex flowmeter to oscillatory flow is still an unresolved problem. So, it deserves further investigation.

In this study, we investigated the measurement characteristics of a diameter 50 mm dual triangulate bluff body vortex flowmeter in steady flow and oscillatory flow on an experimental facility. The dates of the dual triangulate bluff body vortex flowmeter in

---

* Corresponding author. Tel.: +86 134 0860 4905.
E-mail addresses: pjg2000cn@163.com, pengjiegang@uestc.edu.cn (J. Peng).

0955-5986/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.flowmeasinst.2013.11.001

Nomenclature

e_{11}	the relative error of the main frequency of the noisy test signal for the single bluff body vortex flowmeter
e_{21}	the relative error of the main frequency of the noisy test signal for the dual bluff body vortex flowmeter
e_{12}	the relative error of the main frequency of the reconstructed signal for the single bluff body vortex flowmeter
e_{22}	the relative error of the main frequency of the reconstructed signal for the dual bluff body vortex flowmeter
S_t	the Strouhal number
d	the bluff body diameter
Q	the experiment volume flow rate (m^3/h)
U_m	the flow velocity of the fluid (m/s)
$f(n)$	the original signal without adding noise
SNR_{d1}	the *SNR* of the noisy test signal for the single bluff body vortex flowmeter
SNR_{d2}	the *SNR* of the noisy test signal for the dual bluff body vortex flowmeter
$f_{d1}(n)$	the noisy test signal for the single bluff body vortex flowmeter
$f_{d2}(n)$	the noisy test signal for the dual bluff body vortex flowmeter
SNR_{r1}	the *SNR* of the reconstructed signal for the single bluff body vortex flowmeter
SNR_{r2}	the *SNR* of the reconstructed signal for the dual bluff body vortex flowmeter
$f_{r1}(n)$	the reconstructed signal for the single bluff body vortex flowmeter
$f_{r2}(n)$	the reconstructed signal for the dual bluff body vortex flowmeter
f_{01}	the main frequency of the original signal without adding noise for the single bluff body vortex flowmeter
f_{02}	the main frequency of the original signal without adding noise for the dual bluff body vortex flowmeter
f_{d1}	the main frequency of the noisy test signal for the single bluff body vortex flowmeter
f_{d2}	the main frequency of the noisy test signal for the dual triangulate bluff body vortex flowmeter
f_{r1}	the main frequency of the original signal without adding noise for the single bluff body vortex flowmeter
f_{r2}	the main frequency of the original signal without adding noise for the dual bluff body vortex flowmeter
f	the imposed disturbing frequency of oscillatory flow
f_d	the main frequency of the noisy test signal for a pipe
$IMFi_1$	IMFi for the single bluff body vortex flowmeter
$IMFi_2$	IMFi for the dual bluff body vortex flowmeter
K_1	decomposition layers for the single bluff body vortex flowmeter
K_2	decomposition layers for the dual bluff body vortex flowmeter

oscillatory flow are inherently nonstationary and nonlinear because they are the result of propagation of various type waves with different amplitude, frequency, and wave speed in fluid that are likely nonlinear.

In order to analyze those nonstationary and nonlinear dates, an analysis method for nonlinear and non-stationary data, the Hilbert Huang Transformation (HHT) method, was used [15–17].In the flow measurement, the HHT method was used in many areas. Sun et al. proposed a novel vortex flowmeter signal de-noising method based on Hilbert–Huang transform (HHT) [18]. Zheng et al. proposed a HHT-based signal processing method to overcome the problem of weak vortex signal detection at low flow rate [19]. Jiegang et al. using HHT method, the signal characteristics of swirlmeter and a single bluff body vortex flowmeter in oscillatory flow were analyzed [20,21].

In this paper, the HHT method was used to analyze the signal characterization for a dual triangulate bluff body vortex flowmeter in oscillatory flow. For the dual bluff body vortex flowmeter, the anti-interference performances and the vortex street stability were discussed. Offline simulation was carried out on the anti-interference performances and the vortex street stability of the dual triangulate bluff body vortex flowmeter in oscillatory flow by HHT method. In the end, we compared the data of the dual triangulate bluff body vortex flowmeter and that of the single bluff body vortex flowmeter in literature [20].

2. Hilbert–Huang transform (HHT)

First, We give a brief description of HHT algorithm. A detailed presentation can be found in the articles of Huang et al. [15,16]. The HHT consists of two parts: empirical mode decomposition (EMD) and Hilbert spectral analysis (HSA). The key part of the transform is EMD, with which any complicated data set can be decomposed into a finite and often small number of intrinsic mode functions (IMFs) that admit well behaved Hilbert transforms. However, each IMF is defined as any function satisfying the following conditions [17]: ① In the whole data set, the number of extrema and the number of zero crossings must either equal or differ by at most one. ② At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is Zero. Then, to extract the IMF from a given dataset, the sifting process can be implemented as follows [23]: ① Take the signal $x(t)$ for example and identify all the local extrema of $x(t)$; ② Connect all of the local maxima by a cubic spline line as the upper envelope $e_{max}(t)$), Repeat the procedure for the local minima to produce the lower envelope $e_{min}(t)$. ③ Calculate the mean value$m_1(t)$ of upper and lower envelopes, that is $m_1(t)=(e_{\max}(t)+e_{\min}(t))/2$. ④ Subtract $m_1(t)$ from original signal, named as $h_1(t)$:$h_1(t)=x(t)-m_1(t)$. Judge whether $h_1(t)$ satisfies IMF conditions or not, if so, then as the first IMF it is denoted $c_1(t)=h_1(t)$; if not, replace $x(t)$ with $h_1(t)$, and then calculate $h_{11}(t)=h_1(t)-m_{11}(t)$, where $m_{11}(t)$ is the mean of the upper and lower envelopes of $h_1(t)$. This process can be repeated up to k times, until $h_{1k}(t)$ satisfies IMF conditions, then the first IMF component from the data is designated as $c_1(t)=h_{1k}(t)$. ⑤ Once $c_1(t)$ is obtained, it can be separated from the rest of the data by using $x(t)-c_1(t)=r_1(t)$. ⑥ Repeat above five steps using $r_1(t)$ as $x(t)$ to obtain $c_2(t)$ until $r_n(t)$ is a monotone function or a direct current component. That is: $r_1(t)-c_2(t)=r_2(t)\cdots r_{n-1}(t)-c_n(t)=r_n(t)$. ⑦ By summing up above Eqs., we finally obtain

$$x(t)=\sum_{i=1}^{n} c_i(t)+r_n(t)$$

To guarantee that each IMF component retain enough physical sense of both amplitude and frequency modulations, the sifting process can be accomplished by limiting the size of the standard deviation, *SD*, computed from the two consecutive