Ultrasonics 54 (2014) 285–290

Contents lists available at SciVerse ScienceDirect

Ultrasonics

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

Realization of a multipath ultrasonic gas flowmeter based on transit-time technique

Qiang Chen, Weihua Li, Jiangtao Wu *

MOE Key Laboratory of Thermo-Fluid Science and Engineering, Xi'an Jiaotong University, Shaanxi 710049, People's Republic of China

ARTICLE INFO

Article history:
Received 18 December 2012
Received in revised form 14 March 2013
Accepted 2 June 2013
Available online 12 June 2013

Keywords:
Flowmeter
Ultrasonic
Transit time

ABSTRACT

A microcomputer-based ultrasonic gas flowmeter with transit-time method is presented. Modules of the flowmeter are designed systematically, including the acoustic path arrangement, ultrasound emission and reception module, transit-time measurement module, the software and so on. Four 200 kHz transducers forming two acoustic paths are used to send and receive ultrasound simultaneously. The synchronization of the transducers can eliminate the influence caused by the inherent switch time in simple chord flowmeter. The distribution of the acoustic paths on the mechanical apparatus follows the Tailored integration, which could reduce the inherent error by 2–3% compared with the Gaussian integration commonly used in the ultrasonic flowmeter now. This work also develops timing modules to determine the flight time of the acoustic signal. The timing mechanism is different from the traditional method. The timing circuit here adopts high capability chip TDC-GP2, with the typical resolution of 50 ps. The software of Labview is used to receive data from the circuit and calculate the gas flow value. Finally, the two paths flowmeter has been calibrated and validated on the test facilities for air flow in Shaanxi Institute of Measurement & Testing.

1. Introduction

Compared with the traditional technologies (such as turbine, orifice, or vortex meters) , transit-time method ultrasonic flowmeter, possesses many merits [1]. This flowmeter has high accuracy and reproducibility. Moreover, containing no moving parts, it does not create extra pressure drop and allows bi-direction measurement. Finally this system can be conveniently maintained on-line without interrupting the fluid transport. Thus, the ultrasonic flowmeter has been more and more widely applied in the general field of process monitoring, measurement and control [2].

The transit-time ultrasonic flowmeter uses at least one pair of transducers with centerlines inclined at an angle to the axis of pipe containing the flow. Transducers on the same acoustic path send and receive ultrasound mutually. Then the path velocity is function of the different flight time of the sound transiting (TOF) in the flow direction and in the reverse direction. The flow velocity averaged over the entire cross-section can be computed with the path velocities according to certain integration. The principle is schematically illustrated in Fig. 1. The basic equations for a multipath flowmeter are given by following expressions:

$$v_i = \frac{L_i}{2\cos\theta}\left(\frac{1}{t_{i-\mathrm{up}}} - \frac{1}{t_{i-\mathrm{down}}}\right) \quad (1)$$

$$v = \sum_{i=1}^{n} \frac{L_i w_i}{2\cos\theta}\left(\frac{1}{t_{i-\mathrm{up}}} - \frac{1}{t_{i-\mathrm{down}}}\right) \quad (2)$$

Here, subscript i represents the path number, L_i denotes the distance between the two transducers achieved from the calibration process in Section 3.1, θ is the angle between the acoustic path and the pipe axis ensued from the meter construction. $t_{i-\mathrm{up}}$ and $t_{i-\mathrm{down}}$ are the flight times corresponding to an upstream sound propagation situation and a downstream sound propagation situation, respectively. v_i is the axial velocity average along the ith flight path. w_i is the matching weighting coefficient determined by the flowmeter integration.

The volume flow rate is then given by following equation:

$$Q_v = \pi R^2 \sum_{i=1}^{n} \frac{L_i w_i}{2\cos\theta}\left(\frac{1}{t_{i-\mathrm{up}}} - \frac{1}{t_{i-\mathrm{down}}}\right) \quad (3)$$

where Q_v is the volume flow rate and R is the internal radius of the pipe.

This paper designs a dual-path ultrasonic flowmeter adopting Tailored quadrature presented by Pannell et al. [3], and proposes a new timing circuit based on a high capability chip TDC-GP2. The timing resolution is about 50 ps. In addition other hardware and software is developed. Finally this system has been calibrated and tested on the standard air flow calibrating facilities in Shaanxi Institute of Measurement & Testing. Relevant experimental results are presented.

* Corresponding author.
E-mail address: jtwu@mail.xjtu.edu.cn (J. Wu).

0041-624X/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ultras.2013.06.001

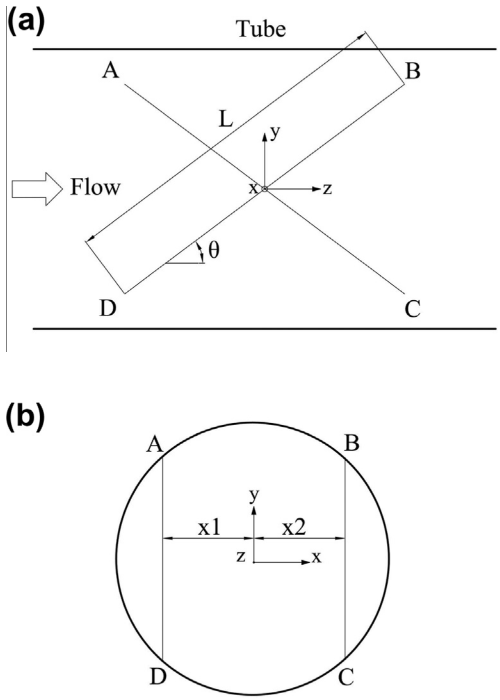

Fig. 1. Two pairs of transducers (A–D) are placed in the flowmeter body with the transducer centerlines inclined at an angle to the flow direction: (a) in the measuring plane and (b) in the projection on the tube cross section.

2. Design

The frame of ultrasonic flowmeter presented here is shown in Fig. 2. The system consists of flowmeter body, ultrasonic transducers, transmitter driving module, amplifier & filter module, comparator module, timing module, power module, control & data process module and storage & display module. Explanations of several modules are shown below.

2.1. Transducer and flowmeter body

Since the ultrasound sent and received from the transducer directly determines the flowmeter performance, ultrasonic transducer can be seen as the heart of the flowmeter. Several parameters need to be considered when selecting a suitable transducer for the flow measurement, including peak frequency, bandwidth, sensing range and maximum driving voltage. Peak frequency influences the sound attenuation and the signal to noise rate (SNR) [2]. Most flowmeter manufacturers typically choose the transducers in the frequency range from 40 kHz to 200 kHz.

The Airmar transducer (model AT200) chosen here has a peak frequency around 200 kHz. The active diameter is 16 mm, and the beam width is 14° ± 2° at −3 dB. The sensing range is 0.1-3m. The allowed driving voltage cannot exceed 500 V peak to peak (V_{pp}).

The basic principles of the ultrasonic flowmeter show the integration for the transducers' placement on the meter body introduces inherent error. Most researchers had compared this error among different integration techniques [3–5]. Published quadrature tables are always based on the optimal integration of some defined form of the integrand. For example, the well-known Gaussian quadrature is based on polynomials, the N-point rule being, in fact, exact for integrating any polynomial of order $(2N-1)$ or less over finite domains [6]. As emphasized in Ref. [3], the integrand of the ultrasonic flowmeter is not inherently polynomial-like, so it is not very suitable for this Gaussian quadrature. Based on the study to fitted flow-velocity function form, in particular its asymptotic behavior at the end-points of the domain, Pannell et al. presented the Tailored integration in 1990. Fig. 3 shows the Tailored integration could reduce 2–3% of the relative error on volumetric flow compared with the Gaussian integration.

This work introduces four transducers as two parallel chord paths according to Tailored integration. The arrangement type is shown in Fig. 4. The internal diameter of the flowmeter body is 100 mm, and the angle between the acoustic path and the pipe axis is about 45°. The abscissa of the two paths is 23.9 mm and −23.9 mm. According weights are the same value 0.8695.

2.2. Ultrasound emission and reception

In most ultrasonic flowmeters, a transducer emits acoustic signal to the other transducer on the same path, and the latter transducer emits ultrasound to the former after a switch time. Time of Flight (TOF) upstream and downstream in the flow is measured at different times. Therefore, the final calculated flow value cannot reflect the real flow rate, especially the pulsating flow in the pipe. To eliminate the influence caused by the inherent switch time in simple chord flowmeter, the technique presented here allows all the transducers emit and receive the ultrasound simultaneously.

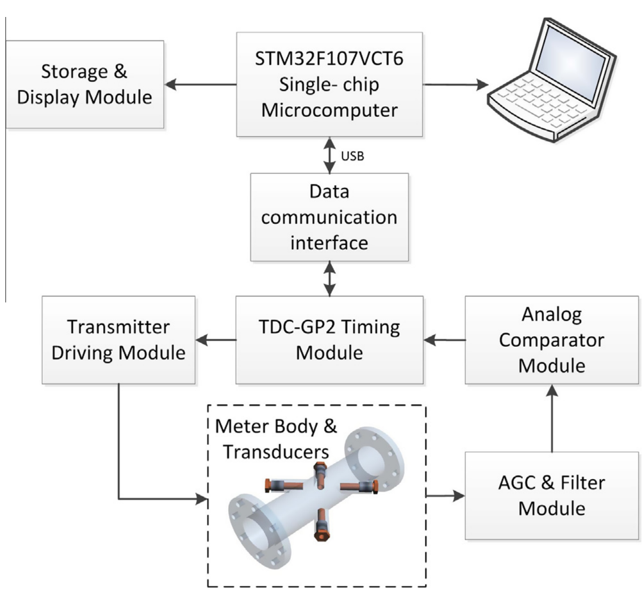

Fig. 2. Schematic diagram of the ultrasonic flowmeter system.

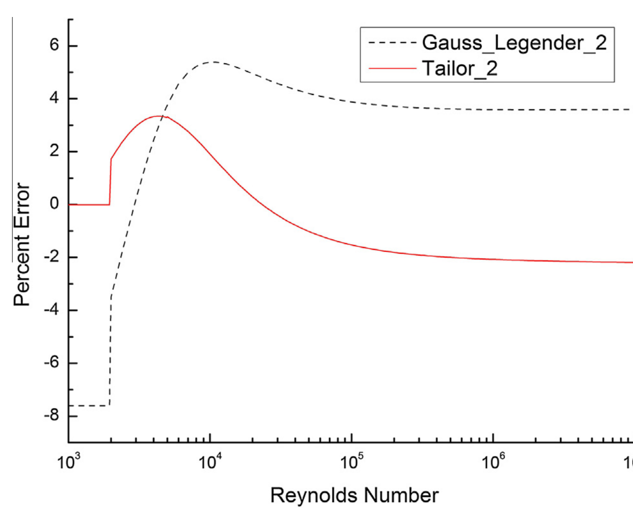

Fig. 3. Percentage error as a function of Reynolds number for 2-chord schemes.