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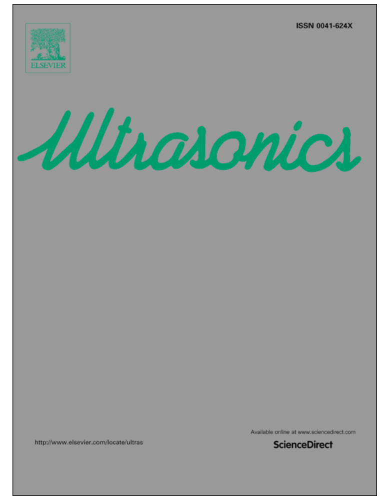

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Multipath ultrasonic gas flow-meter based on multiple reference waves

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Abstract—Several technologies can be used in ultrasonic gas flow-meters, such as transit-time, Doppler, cross-correlation and etc. In applications, the approach based on measuring transit-time has demonstrated its advantages and become more popular. Among those techniques which can be applied to determine time-of-flight (TOF) of ultrasonic waves, including threshold detection, cross correlation algorithm and other digital signal processing algorithms, cross correlation algorithm has more advantages when the received ultrasonic signal is severely disturbed by the noise. However, the reference wave for cross correlation computation has great influence on the precise measurement of TOF. In the applications of the multipath flow-meters, selection of the reference wave becomes even more complicated. Based on the analysis of the impact factors that will introduce noise and waveform distortion of ultrasonic waves, an averaging method is proposed to determine the reference wave in this paper. In the multipath ultrasonic gas flow-meter, the analysis of each path of ultrasound needs its own reference wave. In case study, a six-path ultrasonic gas flow-meter has been designed and tested with air flow through the pipeline. The results demonstrate that the flow rate accuracy and the repeatability of the TOF are significantly improved by using averaging reference wave, compared with that using random reference wave.

Keywords: Transit-time method; Cross correlation; Reference wave; Averaging method; Multipath ultrasonic flow-meter

1. Introduction

The measurement of gas flow rate in large-diameter gas pipelines has gained even more demands with the natural gas's wide use in china. The ultrasonic flow-meter (UFM) has many advantages over the traditional flow-meter in the field applications. Compared with other flow measurement techniques, the UFM does not contain any moving parts and will not cause the loss of pressure. It is easy to install and maintain. It can be applied in large-diameter pipelines with a rather high precision. Furthermore, the UFM allows bi-directional flow measurement [1].

UFM can be based on different principles, among which the transit-time method is one of the most widely adopted due to its numerous advantages [2-4]. In the transit-time UFM, at least one pair of transducers is applied with their centerlines inclined to the axis of gas pipeline at a designed angle. Transducers on the same acoustic path send and receive ultrasound alternately. Then the path velocity can be calculated by time of flight (TOF) of ultrasonic waves propagating in flow direction and reverse direction. The mean flow velocity over cross-section can be computed with path velocity according to certain integration algorithm. The upstream and downstream TOF can be calculated by following equations:

$$t_{up} = \frac{L}{c - v\cos\theta} \tag{1}$$

$$t_{down} = \frac{L}{c + v\cos\theta} \tag{2}$$

Where t_{up} and t_{down} are the TOF in upstream direction and downstream direction, respectively, L is the path length between the two transducers, v is the averaging flow velocity along the acoustic path, θ is the angle between acoustic path and the pipeline axis, and c is the speed of ultrasound in the profile, which can be calculated with the given temperature [5, 6], as shown in Eq. (3).

$$c = 331.45 \times \sqrt{\frac{T}{273.15}} \tag{3}$$

Where T is the thermodynamics temperature of the gas in the pipeline. The differential TOF of the acoustic path can be calculated by Eq. (4):

$$\Delta t = t_{up} - t_{down} = \frac{2Lv\cos\theta}{c^2 - v^2\cos^2\theta} \tag{4}$$

Since c^2 is much bigger than $v^2\cos^2\theta$ in normal atmospheric conditions (e.g. in natural gas or air), eq. (4) can be