The Use of Multifrequency Binary Sequences MBS Signal in the Anemometer with Thermal Wave

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Abstract. *Measurement of the very low air flow velocity by means of the spectral analysis of the thermal wave was described. The method is based on the relationship between the phase shifts of the thermal wave's harmonic components in the function of frequency. Experimental research conducted in a wind tunnel was presented and discussed. In this paper applying of multi frequency MBS signal as a source of thermal wave was investigated.*

Keywords: Air Flow Velocity Measurements, Thermal Wave, MBS Signal

1. Introduction

Thermal wave propagation in a flowing gas can be used to measure flow velocity. The method is based on the dispersion of wave, which means that waves of different frequency travel at different phase velocities. Intermittently heated thin wire is used to generate a hot spot in the flowing medium that is convected past temperature sensors placed downstream. Several types of anemometers with thermal wave have been reported in the literature. A broad description was provided by Lomas [1]. Rachalski [2] developed a method that is based on applying a series of sinusoidal waves with different frequencies and measuring phase shifts of the relevant harmonics. A square wave also can be applied [3]. In this paper, we propose the use of Multifrequency Binary Sequences signal MBS [4] as a source of thermal wave.

2. Subject and Methods

Spatial configuration of the proposed system that consists of a three thin, parallel and coplanar hot-wire transducers supplied from the electronic circuit was presented on the Fig. 1. One of them is the thermal wave transmitter. The two remaining wires, placed downstream are wave receivers. The idea is to measure the time of wave passage within the flow at known distance. Simple relation between the phase shift and velocity of the wave is given by Eq. 1.

$$\Delta\varphi = \frac{\omega \Delta x}{V_T} \tag{1}$$

where

Δx the distance between the two receivers

ω angular frequency of the thermal wave

V_T velocity of the thermal wave

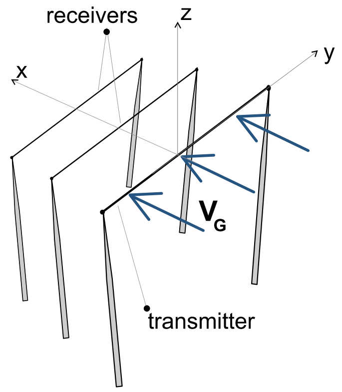

Fig. 1. Spatial configuration of the transmitter and receivers in the air flow.

Kielbasa [5] provided analytical solution for the phase shift *Δφ* of the sinusoidal wave in the flowing medium at known distance (Eq. 2). It can be noticed from Eq. 1 and Eq. 2, that velocity of the flowing gas is lower than velocity of the thermal wave. For low velocities below 30 cm/s, thermal diffusion of air affects the temperature wave propagation.

$$\Delta\varphi\left(\Delta x,\omega,\kappa,V_G\right)=\frac{V_G\Delta x}{2\kappa}\sqrt{\frac{1}{2}\left(\sqrt{1+\frac{16\kappa^2\omega^2}{V_G{}^4}}-1\right)} \tag{2}$$

where

κ thermal diffusivity of air

V_G gas flow velocity

Velocity of the flowing gas V_G can be obtained by solving the set of equations (Eq. 3), by means of nonlinear estimation. Applying a series of waves at different frequencies f_i allow to determine the phase shift φ_i for each frequency [6]. However, the sinusoidal wave has one dominant harmonic on the power spectrum. Here, we propose application of the multi frequency Stratchclyde MBS signal on the transmitter. First eight harmonic of that signal contain 76.6% of the power spectrum [7].

$$\Delta\varphi_i=\frac{V_G\Delta x}{2\kappa}\sqrt{\frac{1}{2}\left(\sqrt{1+\frac{16\kappa^2\omega_i^2}{V_G{}^4}}-1\right)} \tag{3}$$

3. Results

The experimental research was conducted in a wind tunnel. The probe in the configuration presented in Fig. 1. was inserted in a test section. The distance between the transmitter and the first receiver was set to 3.0 mm, while the distance between two receivers 2.0 mm. The diameter of the transmitter was 8 μm, while the receivers 5 μm. The transmitter operated in the constant temperature anemometer (CTA) system, which forces the temperature of the source to be a time dependent function for a given frequency and amplitude. The system was controlled by non-bridge constant-temperature anemometer circuit [8]. The temperature was varied by modulating the overheating ratio of the transmitter wire ±25% from 1.5. The voltage signals from the wires were acquired by an analog to digital converter. In order to compute the phase shift, signals on the receivers were analyzed via Fourier transform.

Two periods of the MBS waveform on the transmitter and receivers was presented on the Fig. 2. The voltage spikes, related to the change in the overheating ratio, can be found. Thus, short electrical transients in voltage do not affect the signal obtained on the receivers. It can be noticed, that temperature signal diffuses, as the thermal wave is transported simultaneously through convection and thermal diffusion. This effect increases with a decrease in gas velocity. On the Fig. 3 amplitude spectrum of received signal was shown. It can be observed that applying of multi frequency signal allows determining phase shift for several harmonics simultaneously.

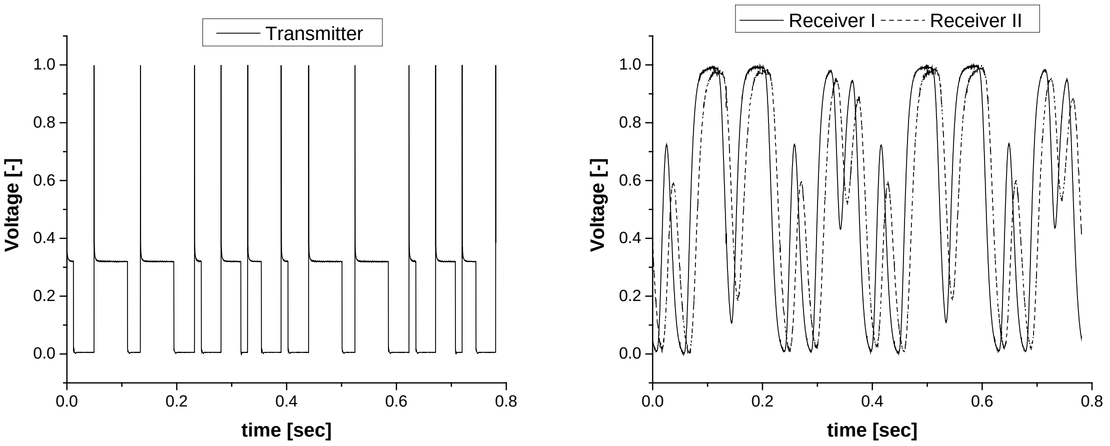

Fig. 2. Two periods of the normalized voltage waveform on the transmitter (left) and receivers of the thermal wave (right) for V_G = 18.48 cm/s (right).

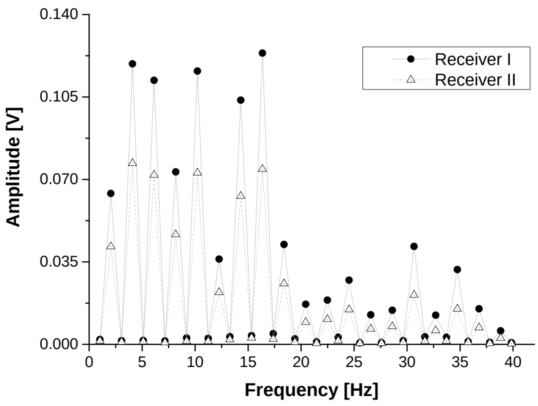

Fig. 3. Amplitude spectrum of temperature signal on the receivers for V_G = 18.48 cm/s.

Measured phase shifts as a function of frequency for four flow velocities was presented on the Fig. 4. The results were compared with the phase shifts obtained from sinusoidal wave. A good agreement between two different waveforms can be found. The result of the air flow velocity estimation and corresponding error of fitting was presented in Tab. 1.

Table 1. Measured velocity of the air flow using the sinusoidal and MBS wave.

Velocity from the sinusoidal signal [cm/s]	Standard Error [cm/s]	Velocity from the MBS signal [cm/s]	Standard Error [cm/s]
7.44	0.05	7.68	0.09
18.21	0.26	18.48	0.17
24.06	0.25	24.00	0.14
30.55	0.23	30.02	0.14

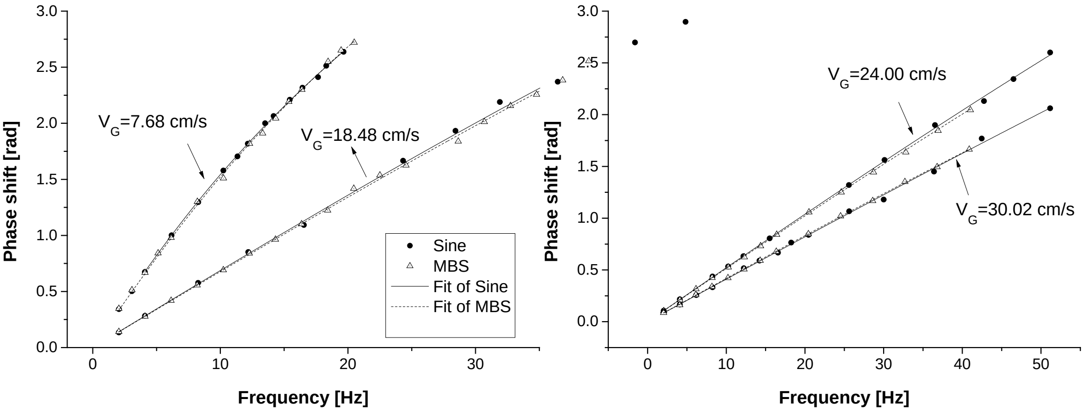

Fig. 4. The measured phase shift as a function of the frequency for the sine and MBS wave.

4. Discussion

Thermal wave propagation in a flowing gas can be used to measure velocity in the very low range. Presented method is restricted to laminar flow conditions. In this paper, the MBS signal on the transmitter of the wave was applied. The experimental results were compared with sinusoidally heated wire. The main advantage of using the MBS signal is that one can obtain phase shift for several harmonics simultaneously, which reduces the measurement time.

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