

Journal of Vibroengineering

2000 No2 (3)

ISSN 1392-8716

Contents

23-40 Proceedings of the First International Anniversary Conference BALTIC-ACOUSTIC 2000 1-99



I-st INTERNATIONAL ANNIVERSARY CONFERENCE
BALTIC-ACOUSTIC 2000
17-21 September 2000 *VILNIUS* LITHUANIA



Contents

LITHUANIAN ACOUSTIC SOCIETY AND ITS FOUNDER	A-0
Acad. K. Ragulskis	
23. Activities in the First 10 Years of the Lithuania Acoustic Society	1
D. Gužas	
24. Vibration Excitation in a Cylindrical Shell by Concentrated Efforts and its Reduction Possibilities Under the Action of the Radial Force	13
D. Gužas, V.Yu. Kirpichnikov	
25. Environmental Acoustics Update	21
Z. Maekawa	
26. Efficient Method for Calculating the Sound Radiation of Vibrating Structures	29
U.-P. Svensson, K. Wendtlandt, U. Kristiansen, F. Goyard, P. Augereau	
27. Active Control of Noise Transmission of Double Wall Cylindrical Shells	33
R. Vaicaitis, C.-Y. Wang	
28. Digital Interferometry Method for Structure-Born Noise Examination	39
L. Ragulskis, M. Ragulskis, A. Palevičius, R. Maskeliūnas	
29. Experiences from Calibration of Noise Level Meters in 1999	45
A. Krukonis	
30. Ultrasonic System for Gas Flow Velocity and Flow Temperature Measurement	47
J. Butkus, L. Jakevičius, O. Tumšys	
31. Ultrasonic, Piezoelectric and Dielectric Properties of New Materials Exhibiting Cooperative Dipole Effects	53
V. Samulionis, J. Banys, Yu. Vysochanskii, V. Cajipe	
32. Peculiarities of Application of the Acoustic Correlation Method for the Gas Pipeline Hermeticity Control	63
L. Jakevičius, J. Butkus	
33. An Experimental Investigation of Acoustic Parameters of Reverberant Chambers for a Measurement of Sound Insulation of Building Elements	69
V. Dikavičius, R. Bliūdžius	
34. Investigation of Directional Characteristic of Concave Surface Acoustic Radiator	75
A. Petrauskas, V. Minialga	
35. Acoustic Gas Sensor	77
R. Giriuniene, E. Garška	
36. Relationship Between the Length of the Reverberation Time and Other Acoustic Parameter Distributions in the Field	81
A. Erdem Aknesil	
37. Platform Inspection in Turbid Water Using a 3D Acoustic Camera	85
E. Eknes, B. Wirzba, R.-K. Hansen	
38. The Application of Real Time 3D Acoustical Imaging	89
R.-K. Hansen, P.-A. Andersen	
39. Dynamic Range Compression (DRC)	93
OmniTech AS 8.11.99	
40. Ultrasonic Investigation of Betaine Compounds	95
V. Samulionis, J. Banys	

Ultrasonic System for Gas Flow Velocity and Flow Temperature Measurement

J. Butkus, L. Jakevičius, O. Tumšys
 Ultrasound Research Institute,
 Kaunas University of Technology, Lithuania

ABSTRACT: An ultrasonic system for laboratory and industrial measurement of gas flow velocity and temperature is described. More accurate basic algorithms for determination of sound velocity in the gas flow are proposed. It enables one to take into account the sound velocity and temperature of the gas flow when the flow velocity is determined. General layout of the ultrasonic system for practical realization of the proposed algorithms and principle of its operation is described too. An experimental results of the measurement of air flow velocity and sound velocity in the air flow and also of their pulsation's in the air flow conduit of 0.4m in diameter are presented. The results of experimental investigation of zero drift of the system are submitted too.

KEYWORDS: ultrasonic measuring system, gas flow velocity, flow temperature, sound velocity.

NOTATION

- c_v - sound velocity in the gas flow
- l - distance between transmitting and received surfaces of piezotransducers
- l_0 - length of measuring bases in the flowing medium
- Δl - difference $l-l_0$ in measuring direction
- R - universal gas constant
- T - absolute temperature
- v - gas flow velocity
- μ - molar mass
- γ - specific heat ratio, $\gamma = C_p / C_v$.

1. INTRODUCTION

The measurement of flow velocity, flow rate and temperature of natural and liquefied gas, oil products and other chemical materials is of prime importance in a modern technology [1]. High-rangeability of the gas flows and wide variation of the measuring conditions demands to create and to investigate a new ultrasonic methods for flow velocity and flow temperature measurement [2]. The high accuracy and small zero drift of the ultrasonic measuring systems are of great importance for assurance the leak-proofness of the pipeline as well as for performing of technological operations and satisfying the requirements of environmental protection [2,3].

The purpose of this investigation it was development of ultrasonic system for gas flow velocity and flow temperature measurement with the improved accuracy when high-rangeability gas flow is investigated.

The Journal was received on 7 July 2000 and was accepted for publication on 24 August 2000.

2. METHODOLOGY AND INSTRUMENTATION

Well-type transducer holders often are used when constructing an ultrasonic systems for gas flow velocity and temperature measurement. The spoolpiece is typically drilled through at 45° angle along a tilted diameter, creating a pair of opposite ports as shown in Fig.1.

With the purpose to avoid formation of the vortex and distortion of the gas flow thin metal nets covering the ports are used. In such a way, when measuring the flow velocity

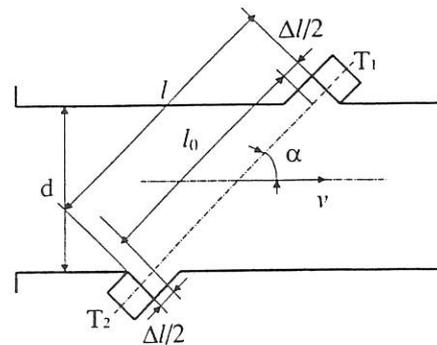


Fig.1. Well-type transducers arrangement on the spoolpiece.

and temperature the times which are needed for ultrasonic signals to travel from transmitter to receiver downstream the gas flow (τ_1) and upstream (τ_2) may be expressed:

$$\begin{cases} \tau_1 = \frac{l_0}{c + v \cos \alpha} + \frac{\Delta l}{c} + \tau_{el1}, \\ \tau_2 = \frac{l_0}{c - v \cos \alpha} + \frac{\Delta l}{c} + \tau_{el2}, \end{cases} \quad (1)$$

where l is the path length between transmitting and receiving surfaces of piezotransducers which in the flowing medium had a length l_0 ; Δl is the sum of the path lengths between active surfaces of the transducers and the inside surfaces of the measuring spoolpiece in the measuring direction; c is the sound velocity in the gas flow; v is the flow velocity; τ_{el1} and τ_{el2} are the delay times of the acoustic signal in electroacoustical and electronic circuits. In the (1) expression only delay times τ_{el1} and τ_{el2} are not dependent on the alteration of the gas flow parameters. Therefore, after the introduction of the replacement:

$$\begin{cases} \tau_1 - \tau_{el1} = t_1, \\ \tau_2 - \tau_{el2} = t_2, \end{cases} \quad (2)$$

expression (1) takes the shape:

$$\begin{cases} t_1 = \frac{l_0}{c + v \cos \alpha} + \frac{\Delta l}{c}, \\ t_2 = \frac{l_0}{c - v \cos \alpha} + \frac{\Delta l}{c}. \end{cases} \quad (3)$$

The system of obtained equations (3) has two unknown quantities: the sound velocity c and the flow velocity v . Other quantities are ascertained by parameters of the measuring channel. After the solving this system of equations the expressions of the sound velocity c_v and flow velocity v are obtained:

$$c_v = \frac{(t_1 + t_2)(l + \Delta l) + \sqrt{(t_1 + t_2)^2(l + \Delta l)^2 - 16t_1t_2\Delta l}}{4t_1t_2}, \quad (4)$$

$$v = \frac{l - t_1 c_v}{(t_1 - \frac{\Delta l}{c_v}) \cos \alpha}. \quad (5)$$

In the (4) and (5) the times t_1 and t_2 are defined by the (2) expression. How it is seen from Eqs. (4,5), the expression for calculation of sound velocity in the gas flow is enough complicated. Despite of that it enables one to calculate the sound velocity in the gas flow according to the delay times of acoustical signals propagating upstream (τ_2) and downstream (τ_1) the gas flow. On the other hand, the sound speed in an ideal gas at a constant pressure is:

$$c = \sqrt{\frac{\gamma RT}{M}}, \quad (6)$$

where γ , M , R and T are the specific heat ratio $\gamma=C_p/C_v$, molar mass, universal gas constant, and the absolute temperature, respectively. As can be seen from Eq. (6), the temperature of the gas flow may be calculated from the sound velocity if the composition of the gas is known. An expression:

$$c_0 = \frac{2l}{\tau_1 - \tau_{el1} + \tau_2 - \tau_{el2}}, \quad (7)$$

which was submitted in the [1,4] is valid only when the flow velocity is approaching the zero. Quantitative changes of the difference between the sound velocities in the gas flow calculated according to algorithms (4) and (7) enables one to discover the relative error:

$$\delta_c = \frac{c_v - c_0}{c_v} 100\%, \quad (8)$$

which will appear if the sound velocity it would be determined without consideration of the flow velocity. The alteration of this error, when the flow velocity is increasing, is shown in the Fig.2. The relative error of the algorithm for sound velocity determination in the gas flow is increasing markedly, when flow velocity is raised. It should be taken into account when the gas temperature is calculated from the sound speed in the gas flow.

Block diagram of the ultrasonic system for gas flow velocity and flow temperature measurement is shown in Fig.3.

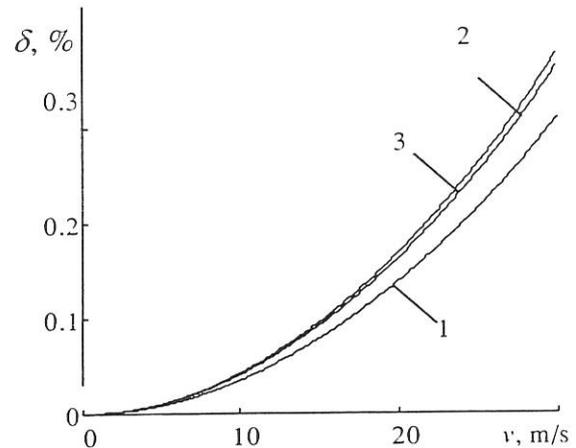


Fig.2. Increase of the relative error of the algorithm (7) when the sound velocity is determined without consideration the flow velocity: 1 - flow diameter $d=0.1$ m; 2 - $d=0.4$ m; 3- $d=1.0$ m.

The principle of action of the measuring system is based on the alternately contrapropagating ultrasonic pulse transit-time measurement. In accordance with (1-5) algorithms the flow velocity is obtained by the measuring of time delay of the single-beam contrapropagating ultrasonic pulses.

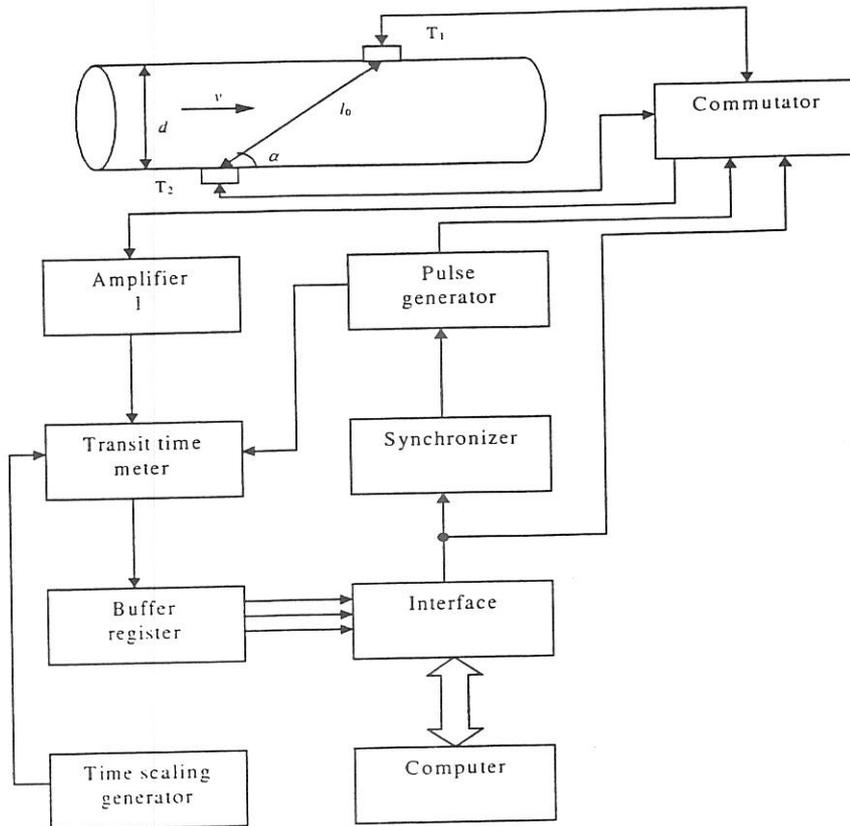


Fig.3. Block diagram of ultrasonic system for gas flow velocity and flow temperature measurement.

3. RESULTS AND DISCUSSIONS

An experimental investigation of ultrasonic system for gas flow velocity and temperature (sound velocity) measurement was carried out at the Heat-equipment research and testing laboratory of the Lithuanian Energy Institute. The velocity of airflow was measured in the test stand with diameter of the pipeline $d=0.4$ m. Before the measurement the flow was flattened by the confuser system to the value of about 0.98. The results of flow velocity measurement carried out by the ultrasonic measuring system, reference turbine meter and Pitot tube showed a good agreement in the range from 0.1 m/s to 16 m/s [5].

With the purpose to evaluate the stability of parameters of the measuring system and reliability of the obtained results the zero drift of the measuring system was investigated. The zero error is related to the resolution of the travel time measurements and small offsets in the travel time measurement. This could introduce a travel time difference being measured even when the gas flow velocity is zero. The results of investigation are presented in Fig.4. How one can see from Fig.4. the zero drift of ultrasonic

system for gas flow velocity measurement was less than $\pm 1,0$ mm/s within 24 hour period.

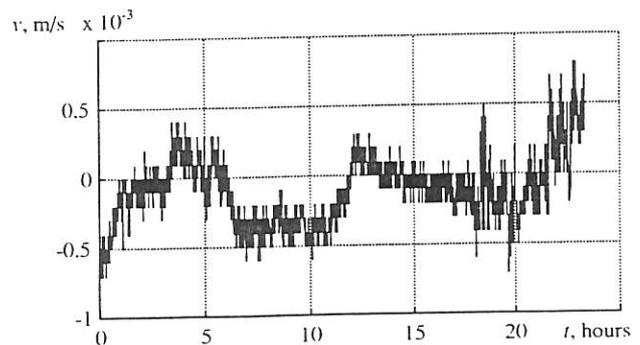


Fig.4. The dependence on time of the zero drift of ultrasonic system for gas flow velocity measurement.

Despite of the means, which were used for flow velocity stabilization, pulsations of the flow velocity were sensed in all the region of air flow under investigation. Especially it was seen when the mean value of the flow velocity was varied in the region of (2...4) m/s (Fig.5.6).

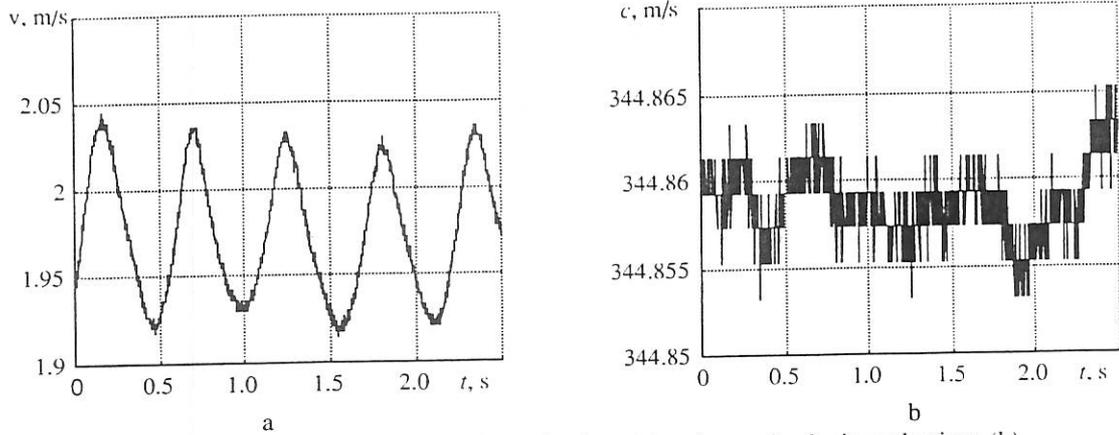


Fig.5. Distribution of flow velocity pulsations (a) and sound velocity pulsations (b) on time in the air flow.

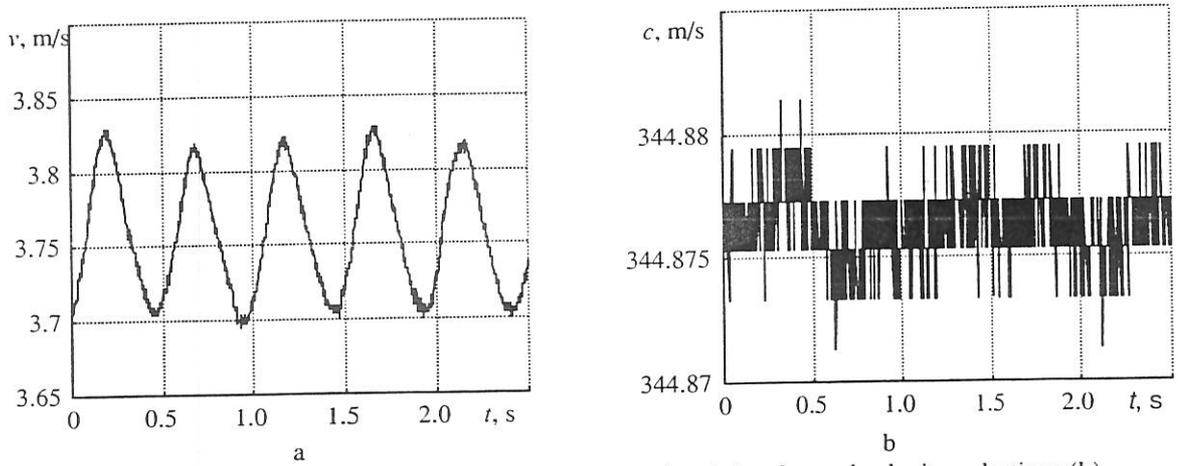


Fig.6. Distribution of air flow velocity pulsations on time (a) and sound velocity pulsations (b).

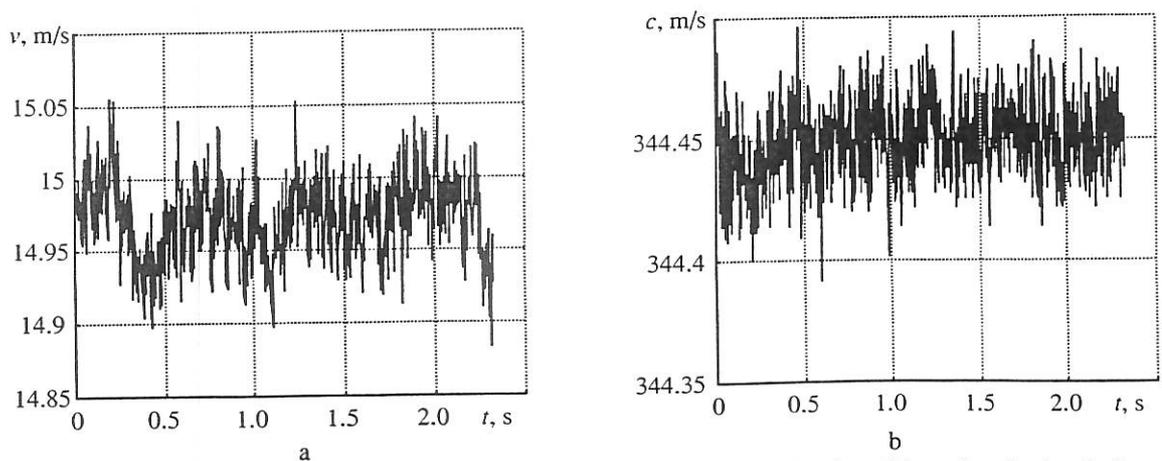


Fig.7. Distribution of flow velocity pulsations (a) and sound velocity pulsations (b) on time in the air flow.

These pulsations, in our opinion, were created by the rotational frequency of the vanes of turboblower. When the flow velocity was increased to 10...15 m/s the magnitude of the oscillations it was about 0,5...1 % of the mean value of flow velocity. The magnitude of the sound velocity pulsations increased from a few millimeters per second, when the flow velocity was 2...4 m/s to the 8...10 cm/s when the flow velocity was raised to the 10...15 m/s (Fig.7). Small magnitude of the sound velocity pulsations, which always was 3...10 times less than the magnitude of

during the experiment. The values of the sound velocity in the air flow obtained by the algorithm (7) always were less than the corresponding values of the sound velocity in the air flow obtained by the algorithm (4) at the same temperature (curve 2 in Fig. 8). How it is seen from Fig. 9 the relative noncoincidence between the sound velocity obtained by using algorithms mentioned above is rapidly increasing when the flow velocity is raised. It might be useful when the flow temperature and velocity is measured with the highest achievable accuracy.

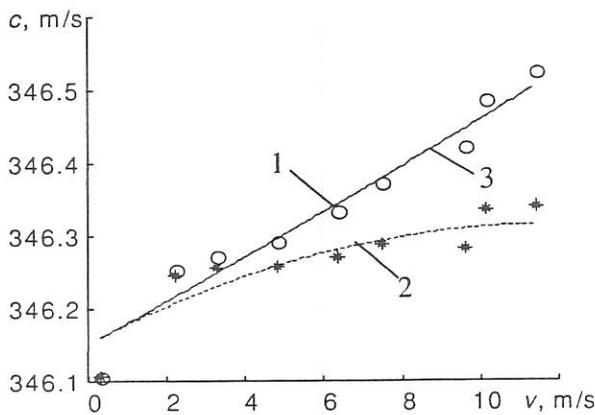


Fig.8. Variation of sound velocity in the airflow: 1- sound velocity determined by algorithm (4), 2- sound velocity determined by algorithm (7).

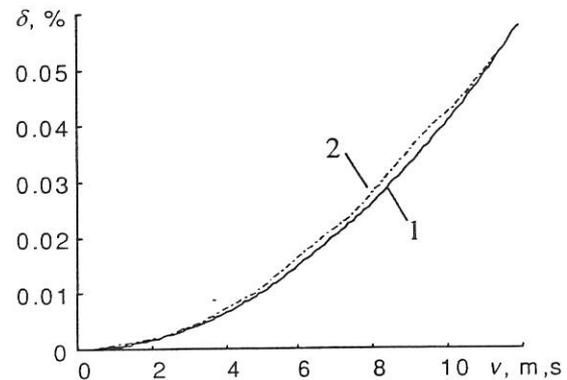


Fig.9. Relative noncoincidence of the sound velocity in the airflow determined by the algorithm (4) and (7): 1-theory, 2-experiment.

the flow velocity pulsations, shows a good stability and noise-immunity of the ultrasound system. The amplitude range of the sound velocity pulsations was less than one centimeter per second, when the flow velocity achieves 3,75 m/s (Fig.6) and 16 cm/s, when the mean flow velocity reaches 15 m/s (Fig.7).

High sensitivity and measuring resolution of the proposed system allowed us to check experimentally the algorithms (4) and (7) for determination of sound velocity in the gas flow. With the purpose to estimate an influence of the temperature change during the experiment, the sound velocity was determined before, during and after the experiment when the mean flow velocity was being zeroed (line 1 in the Fig.8). During the experiment the gas flow velocity was increased from 0.3 to 12m/s and the sound velocity was determined by using the algorithms (4) (denoted by the "o" in Fig.8) and (7) (denoted by the "*" in Fig.8). How it is seen from Fig 8, the values of the sound velocity obtained by the algorithm (4) (which evaluates the flow velocity), may be approximated by the straight line 3 which was in good agreement with those obtained before, during and after the experiment when the flow rate was zero. The growth of sound velocity (lines 1 and 3) is connected with positive temperature gradient about 0.6° C

4. CONCLUSIONS

1. More accurate basic algorithm for sound velocity determination in the gas flow is proposed. It enables one to determine the gas temperature from the ultrasound velocity and to take into account the sound velocity in the gas flow when the flow velocity is measured.
2. An ultrasonic system for realisation in practice of these more accurate basic algorithms for sound velocity determination in the gas flow and for gas flow velocity and temperature measurement is described.
3. It is shown that the zero drift stability of the ultrasonic measuring system is one of the most important requirements for a large dynamic range gas flow velocity meters.
4. An experimental investigation of the measuring system showed that the zero drift of the system was less than $\pm 1\text{mm/s}$ within 24 hour period and that the system is capable to record the flow velocity and sound velocity pulsations from a few millimeters per second to a few meters per second when the mean flow velocity changes from zero to 10...15 m/s.

5. With the purpose of revealing the capabilities of the measuring system in the range of low velocity ($v \leq 0.5$ m/s) the stability of the measuring stand is to be increased and the sampling rate of the ultrasonic system raised to 100 MHz.

References

- 1 L. C. Lynnworth. Ultrasonic Flowmeters// Physical Acoustics/ N. Y. Academic Press, 407-519 (1979).
- 2 K. C. Mylvaganam. High-Rangeability Ultrasonic Gas Flowmeter for Monitoring Flare Gas// IEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, Vol.36, No.2, 144-149 (1989).
- 3 J. Butkus, L. Jakevičius, O. Tumšys, G. Gudavičius. Flow velocity measurement by coherently modulated ultrasound// Ultragarsas (Ultrasound), Nr.1.(26), 17-21 (1996).
- 4 J. Butkus, L. Jakevičius, O. Tumšys. Flow velocity measurement by the pulse acoustical signals// Ultragarsas (Ultrasound), Nr.2(30), 25-29 (1998). (In Lithuanian)
- 5 J. Butkus, L. Jakevičius, O. Tumšys. An experimental investigation of the ultrasonic system for measurement velocity of gas flows// Ultragarsas (Ultrasound), Nr.1(31), 15-18 (1999). (In Lithuanian)