ISSN 1392-2114 ULTRAGARSAS, Nr.4(37). 2000.

Peculiarities of slow rate gas flow velocity measurement

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Introduction

The measurement of slow rate gas flow velocity is one of the most actual problems of modern industry. It is concerned with the wide use of such gas flows in various technological processes of industry and when creating the systems of maintenance of microclimate, ventilation and air heating [1]. In such cases, when seeking to decrease acoustical noises which appears when the systems of air heating and ventilation are operating, the velocity of air motion is decreased. The control of such systems demands to measure small velocity ($v \leq 0.5$m/s) of gas motion. Slow gas flows, through the natural convection and through the technological peculiarities of their generation, frequently are not enough stabile. This is the main reason burdening their experimental investigation while theoretical modeling of influence of multiple external factors is very complicated. All wide known methods, except laser based methods, are insensitive in the low velocity region ($v \leq 0.2 \ldots 0.3$m/s) and dos not ensure the required accuracy. Laser based methods for gas flow velocity measurement are distinguished by high accuracy, but they are very expensive and are hardly applied under industrial conditions [2]. Ultrasonic methods due to their simplicity and cheapness are widely applied in the gas flow velocity measurement, but in the range of slow rate flow they are investigated insufficiently. Therefore the aim of this investigation was to reveal some peculiarities of slow gas flow velocity measurement.

Measurement methods

The slow rate gas flows due to the natural convection and technological peculiarities of their generation are not distinguished by stability. Therefore when seeking to achieve the improved accuracy it is necessary:

1. To decrease formation of the vortex and distortion of the gas flow in the measuring region when ultrasonic measuring channel is installed.
2. To increase the measurement rate and to ensure the continuity of measuring process with the aim of revealing the dynamic process which takes place in the gas flow.
3. To reduce the zero drift of the measuring system and to decrease the influence of environmental conditions on it.

When measuring the gas flow velocity the difficulties attending ultrasonic transmission across the gas, at pressure near atmospheric, must be considered. The losses due to absorption and turbulence must be taken into account too [3,4]. These reasons do not allow for gas flow velocity measurement to use the clamp-on ultrasonic transducers. Only electroacoustical transducers with the direct contact of the piezoelectric transducer with the gas media or transducers with the direct contact through the intermediate matching layers can be used [3,4]. With the purpose to avoid distortion of the gas flow and to improve the matching of acoustical resistances of electroacoustical transducers with the gas media the transducer holders are mounted in the spoolpiece at 45° angle along a tilted diameter creating a pair of opposed ports (Fig.1). To avoid formation of the vortex and distortion of the gas flow thin metal nets covering the ports are used [5]. The surfaces of the metal nets are grinded and accurately adjusted to the internal surfaces of the spoolpiece. The introduction of such nets leads to a 4…8 dB loss of signal at each side the path of acoustic measuring channel, but distortion of the gas flow at the measuring region is minimized.

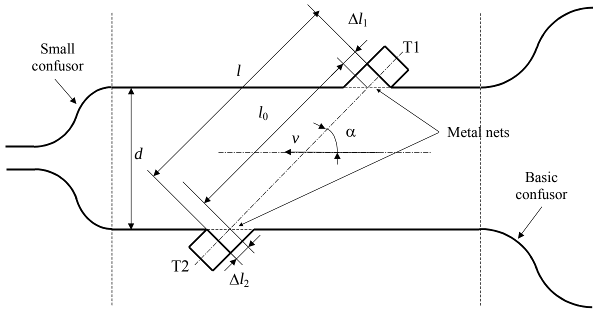


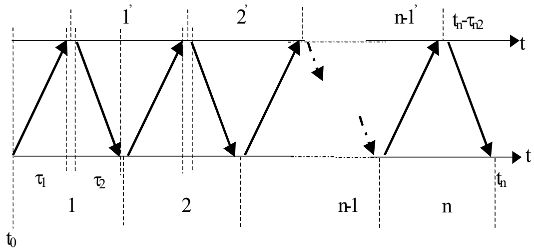
Fig.1. **The arrangement of ultrasonic measuring channel**

Phase shift method for measuring the slow rate gas flow velocity is more sensitiv when compared with another one. It allows one to achieve the measurement rate up to $\omega/2\pi$ measurement values per second [6], where ω is the angular frequency of acoustical signal. But the duration of measurement cycle of the phase shift method is limited by the reflection of acoustic signal in the measuring channel and is less than $\tau_m \leq 2\tau_c$ [6], where τ_c is the time required for ultrasound to propagate from transmitter to the receiver. With the purpose to avoid effect of the standing wave the another cycle of measurement should not be started earlier than 3…5 τ_c after the end of the previous cycle [6]. During this time the parameters of the gas flow may be changed and the fast dynamic variations may be missed. In addition, when measuring by the phase shift method, the measurement range of the flow velocity is limited from the upper values, as maximal phase shift should not exceed the value of π. In other case the ambiguity indications of flow velocity, which is characteristic feature of the phase shift method, should be displayed. The sensitivity of the phase shift method is increased when the frequency of acoustical signal is raised. But the measurement range of flow velocities, which are measured unambiguously, is reduced. When a single measuring channel is used, the stability of frequency of acoustic signal is very important. The influences of instability of frequency of the measuring signal may be diminished when two separate measurement channels upstream and downstream the flow are used. But the parameters of the gas flow, simultaneously measured in both separate channels, may differ and the error of measurement may be increased.

The sing-around method is not applicable too. It is impossible to measure accurately the small change of frequency during the short period of time [6]. Besides, if the single acoustic measuring channel is used, it is impossible to sound the flow simultaneously in both directions. When measuring the flow velocity by this method, ultrasound path informational frequencies F_1 and F_2 are obtained alternately and are separated in time. During this time interval between measurement in both directions the flow velocity may be changed and the errors of measurements should be increased. When using the different channels the measurements may be performed simultaneously in both directions. But the channels are separated in space and so flow parameters may be different. Therefore, the additional measurement errors, appear the magnitude of which depend on the mean flow velocity and on its alteration rapidity. In addition, when using the sing-around method, the parameters of the gas flow are averaged in time and the information about the dynamic parameters of the gas flow is lost.

When applying the pulse method and seeking to increase the measurement accuracy it is expedient to sound the gas flow in both directions simultaneously. In such a way the wideband well-damped electroacoustical transducers are to be used. The vibrations inside such transducer should be extinguished faster than the signal propagates from the transmitter to the receiver. Besides that, the separate electronic measuring unit for everyone probing direction is needful. The metrological characteristics of both channels must change identically when the temperature, the nominal voltage and other parameters of environment are changed. Because of the poor impedance matching of transducers with the gas media the amplitude of the transmitted signal must be about 10^6 times bigger than the amplitude of the received signal. Therefore the problem of switching of wide dynamic range electrical signals occurs, when the direction of probing is changed [7]. The problem of sufficient acoustical isolation of electroacoustical transducers from the pipe wall remains too [6,7].

The requirements for electroacoustical transducers, equipment for commutation and for other arrangement are slightly diminished when the pulse measuring method is applied. Using this method the ultrasonic pulse is sent upstream the gas flow and, when it arrives to receiver, it is immediately sent in downstream direction. Therefore, when sounding the gas flow at equal time intervals alternately in both directions, the rate of flow velocity measurement may be increased almost twice. After the performing of n measurements in each direction it is possible to obtain $2n$-1 results of measurement. For that purpose once the flow velocity measurement values are obtained by measuring the time propagation of signal downstream the gas flow and immediately after it following values of time propagation of signal upstream the gas flow. Another values of flow velocity are obtained by measuring at first the time propagation of acoustical signal upstream the gas flow and immediately after it following values of time propagation of signal downstream the gas flow (Fig.2).



By using this measuring method it is possible to achieve rather big measuring rate and to fix enough dynamic alterations of gas flow parameters. For example, if the sound velocity of the air flow c=340m/s, diameter of the gas flow d=0.4m, and the angle between the sounding path and the centerline of the pipe α=45°, the average measurement rate, even when using the sing-around method, may achieve only 574 measurements per second. Therefore, when using the pulse method and probing the flow in succession in both directions, theoretically it is possible to reach the measurement rate up to 287 measurements per second. The system described in [8,9] when the results of measurement are processed by customary method, enables one to achieve the measurement rate up to 200 measurements per second. When using the proposed method for processing of measurement results it may be reached the measurement rate up to 400 measurements per second. By using this method a lot of information may be obtained in a short time period. It is possible to average the results of many measurements. It enables one to minimize random errors of measurement with no loss of information about the measured changes. The block diagram of the measuring system for realization of the proposed method of data processing is shown in Fig.3. The gas flow velocity v and sound velocity c at the gas flow it may be expressed:

$$v = k\frac{l - \Delta l_1 - \Delta l_2}{2\cos\alpha}\left(\frac{1}{\tau_1 - \frac{\Delta l_1 + \Delta l_2}{c} - \tau_{el1}} - \frac{1}{\tau_2 - \frac{\Delta l_1 + \Delta l_2}{c} - \tau_{el2}}\right), \quad (1)$$

$$c = \frac{l}{2}\left[\frac{\tau_1 - \tau_{el1} + \tau_2 - \tau_{el2}}{(\tau_1 - \tau_{el1})(\tau_2 - \tau_{el2})}\right], \quad (2)$$

where k is the factor which compensates the variation in flow profile with Reynolds number Re; l is the path length between transmitting and receiving surfaces of piezotransducers; Δl_1 and Δl_2 are the distances between the active surfaces of electroacoustical transducers and the inside surfaces of the measuring spoolpiece in the measuring direction; τ_1 and τ_2 are the times propagation of signals in the gas flow and in the electroacoustic and

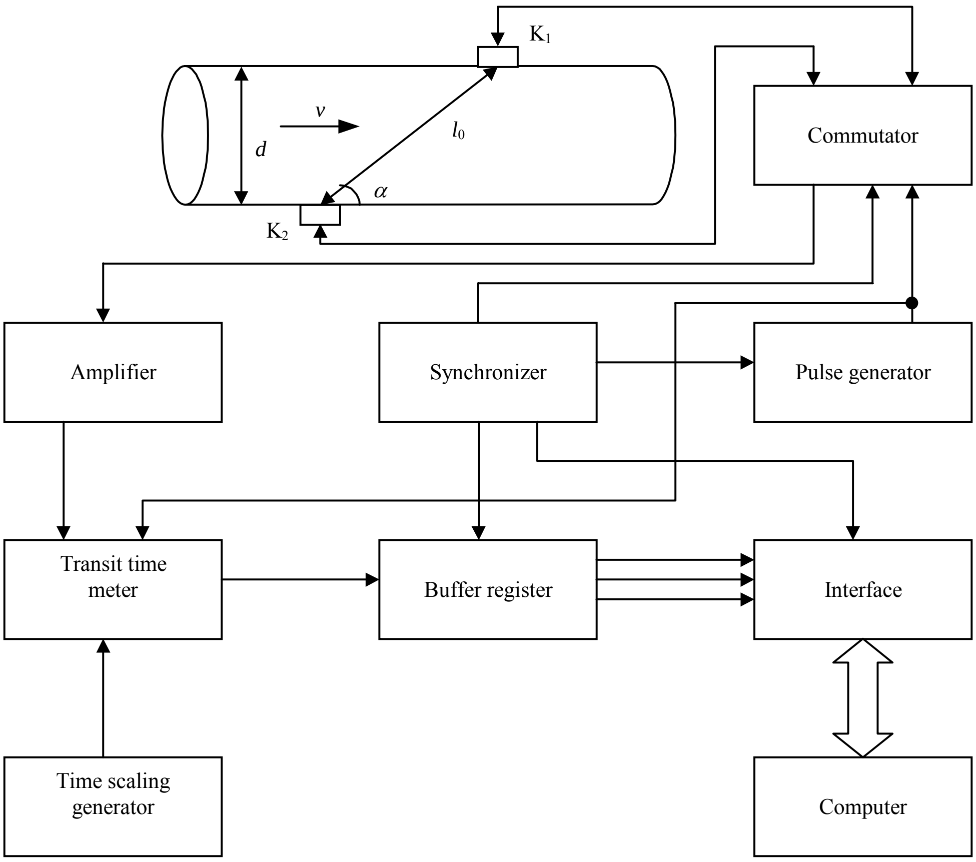


Fig.3. Block diagram of ultrasonic system for gas flow velocity measurement

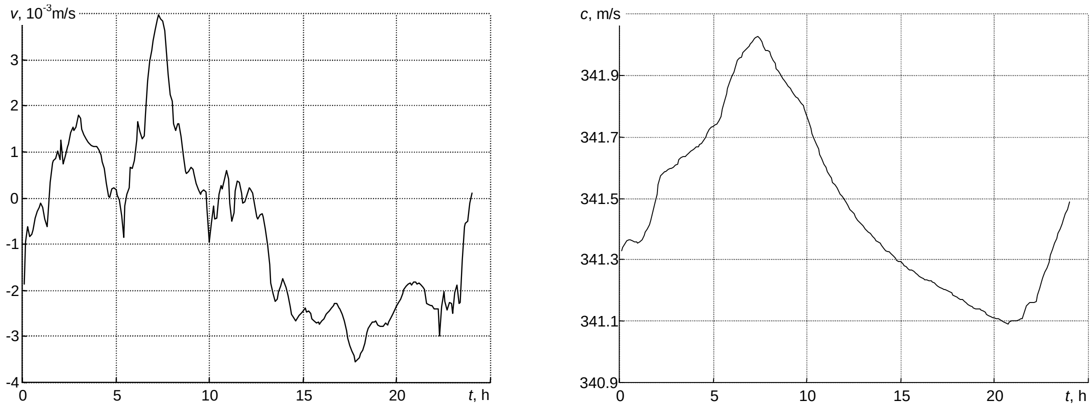
electronic circuits when sounding downstream and in opposite direction; τ_{el1} and τ_{el2} are the delay times of the signal in the electroacoustical and electronic circuits when probing downstream and upstream the gas flow.

When measuring the low flow rate of the gas flow and in order to reach the high rangeability of measurements small zero drift of the ultrasonic measuring system is needful. The zero drift is related to the travel time difference being measured even when the flow velocity is zero. The zero drift depends on many factors and the investigation of influence of which is rather complicated. In practice it is difficult to maintain the measuring conditions stabile during the long period of time (few hours or few days) therefore durable investigations are required.

Results and discussion

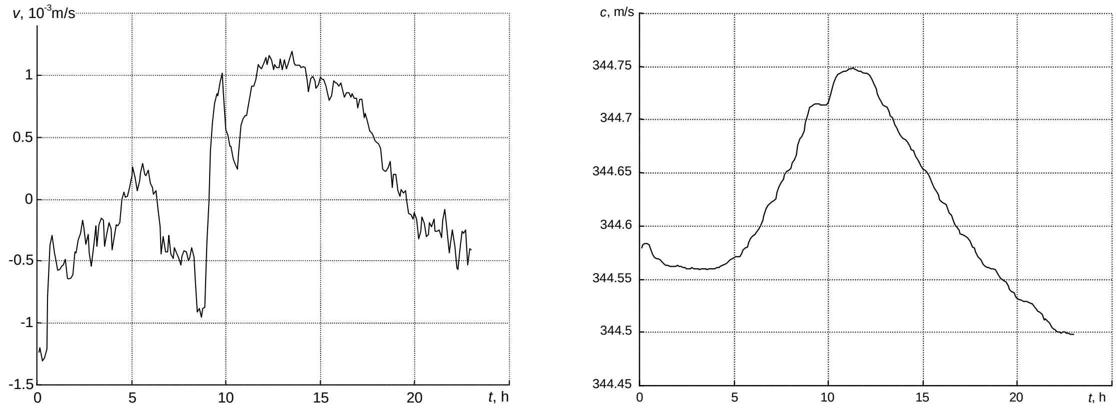
An experimental investigation of ultrasonic system for gas flow velocity measurement was carried out at the Lithuanian Energy Institute. The results of investigation were provided in [8-10] and showed that one of the most influential factor which acts the zero drift of the ultrasonic measuring systems is the instability of environmental temperature. This instability is sufficiently well reflected by the sound velocity values obtained at the gas flow measuring section (Fig.4).

How it is seen from this figure, the character of change of the zero drift of the ultrasonic measuring system is similar to the character of change of sound speed determined in the measuring section. It is unambiguously related with the gas temperature at the measuring section. This shows quite possible cross correlation between the zero drift of the system and the ambient temperature. After the stabilization of temperature of the electronic unit at ±0.1°C limits, the zero drift of the system decreased till the value less than ±2mm/s (Fig.5). For more accurate evaluation of this dependence, long-term investigations of zero drift of the gas flow velocity measuring system is indispensable. It is needful to note that the influence of the zero drift, when measuring the sound velocity at the spoolpiece with diameter $d \geq 0.4$m, is insignificant. The zero drift may influence only 5…6 significant digit of sound velocity value. Because there was no possibility to measure precisely the absolute values of the measuring base l, the probing angle α and the delay times of signals in the electroacoustical circuits τ_{el1}, τ_{el2}, the absolute values of sound velocity, presented here, may differ from their true values by 10…12cm/s. It can change the measured value of the sound velocity at the gas flow only by the few millimeters per second. It is indispensable to note that the rise of temperature by 1°C increases the sound velocity at the airflow by the 0.59m/s [11]. At such a way the variation of sound velocity values caused by the zero drift is able to alter the gas temperature change, determined according to the sound velocity, to 0.01…0.02°C. Besides the influence of environmental temperature, the zero drift of ultrasonic system depends on the gas motion inside the measuring section caused by the natural convection. It is evidently seen from Fig.6 and Fig.7.



a b

Fig.4. **The dependence on time of the zero drift of measuring system (a) and sound velocity (b) when the ambient temperature is changed**



a b

Fig.5**. The dependence on time of the zero drift of ultrasonic measuring system (a) and sound velocity (b) when the temperature of electronic unit is stabilised**

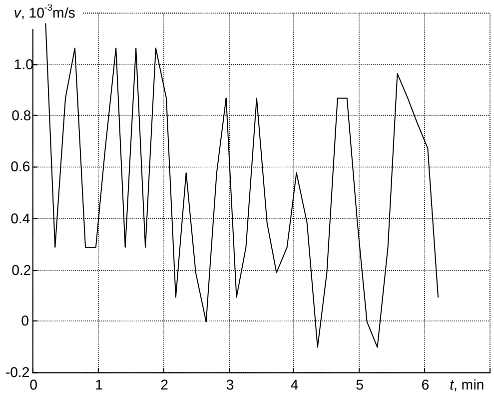


Fig.6. **The instability of zero gas flow when only one end of the measuring conduit is disclosed**

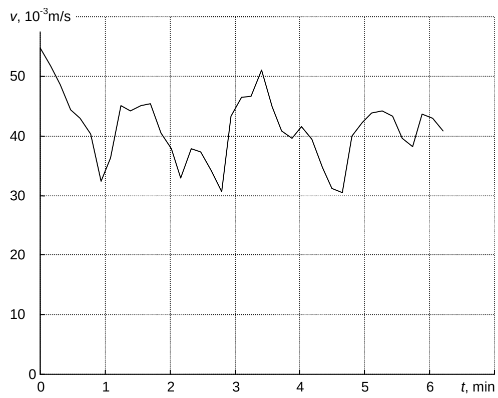


Fig.7. **The zero flow instability when both ends of the spoolpiece are disclosed**

How one can see from Fig.6, after the opening the measuring channel connecting the spoolpiece with the confusor system and turboblover, the zero velocity pulsation became a few times bigger when compared with the case when the spoolpiece was closed. When the both ends of the measuring section ere disclosed the pulsation of zero velocity became about 10 times bigger (Fig.7). The steady component of gas flow velocity $v \approx 0.04$m/s appeared (Fig.7). When the opened end of measuring spoolpiece was closed by the small confusor, the steady component of the gas flow decreased about 6 times to the value of 7mm/s (Fig.8).

Therefore the investigation of zero drift of the gas flow velocity meter became considerably difficult. Since in practice it is difficult to close the measuring spoolpiece completely, the dry calibration of ultrasonic gas flow velocity meters is proposed [12]. During the dry calibration the measurements of geometrical dimensions of spoolpiece and metrological characteristics of electronic equipment are investigated. In accordance with the results of these investigations the uncertainty of gas flow velocity measurement is determined. However this method is applied only for calibration of ultrasonic gas flow rate meters of serial production, the metrological characteristics and working conditions of which are widely investigated [12].

Therefore the influence of zero drift of ultrasonic measuring system on accuracy of low rate gas flow velocity measurement it would be estimated after the program of investigation of the measuring stand it would be fulfilled. This program is being carried out at the Heat-equipment research and testing laboratory of Lithuanian Energy Institute where Lithuanian national gas flow velocity standard is being created [13].

Conclusions

It is revealed that the slow rate gas flow velocity it is purposive to measure by the continous ultrasonic pulse measuring method. It is proposed to probe the gas flow at equal time intervals simultaneously or alternately in both directions. In order to diminish the random errors it is suggested to increase the measuring rate and to average the results of many measurements. The increase number of measurements it may be achieved by using adjacent values of time propagation of signals upstream and downstream the gas flow. Another values of flow velocity it may be obtained by using the values of time propagation of signals downstream the flow and adjacent values of time propagation upstream the gas flow. On the basis of experimental investigation it is shown that the instability of temperature of electronic unit is the main influential factor which acts the zero drift of the ultrasonic measuring system. For minimisation of zero flow instability it is not enough to stop the natural convection of the gas by closing of only one end of the measuring spoolpiece. The gas motion is to be stopped at the both ends of the measuring section. Otherwise, the influence of natural convection it may be bigger than the zero drift of the ultrasonic measuring system and the results of investigation it would be distorted.

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Dujų srautų mažų greičių matavimo ypatumai

Reziumė

Parodoma, kad mažo greičio dujų srautų greitį tikslinga matuoti nepertraukiamu ultragarsiniu metodu. Siūloma srautą zonduoti tuo pat metu abiem kryptimis arba pakaitomis abiem kryptimis. Atsitiktinėms paklaidoms sumažinti siūloma spartinti matavimus ir vidurkinti daugelio matavimų rezultatus. Matavimų skaičiui padidinti, apdorojant informaciją apie srauto greitį, pradžioje tikslinga poromis imti gretimas perėjimo prieš ir pagal srautą laikų vertes, paskui - perėjimo pagal srautą laikų ir tuoj po jų einančias perėjimo prieš srautą laikų vertes. Eksperimentiškai tiriant, kaip keičiasi ultragarsinės dujų srauto greičio matavimo sistemos nulio dreifas, atskleista, kad vienas svarbiausių nulio dreifui įtakos turinčių veiksnių yra elektroninio duomenų apdorojimo bloko nestabilumas dėl temperatūros. Stabilizavus šio bloko temperatūrą ±0,1°C ribose, nulio dreifą pavyko sumažinti keletą kartų, t.y. iki ±1…2 mm/s. Nustatyta, kad, tiriant matavimo sistemos nulio dreifą, nepakanka dujų judėjimą sustabdyti tik viename matavimo sekcijos gale. Jį būtina apriboti abiejuose matavimo sekcijos galuose. Kitu atveju dujų judėjimas dėl natūralios konvekcijos gali būti keletą kartų didesnis už ultragarsinės matavimo sistemos nulio dreifą ir padidinti srauto greičio matavimo neapibrėžtį.

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