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The influence of flattened flow profiles to the airflow velocity measurement by ultrasound

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Introduction

The measurement of airflow velocity is one of the most actual problems of modern industry. It is due to wide use of such gas flows in various technological processes of industry and when developing the systems of maintenance of microclimate, ventilation and air heating [1-4]. Ultrasonic methods due to their simplicity and low-cost are widely applied for gas flow velocity measurements [3, 4]. Usually a transit-time method and path through the pipe centre from transmitting to receiving sensors are applied for flow velocity measurement [3-8]. However in the transit time method only the average flow velocity along an acoustic path is determined [6]. In order to determine the mean axial flow velocity over the cross-section and therefore the volume flowrate, the velocity distribution correction factor must be known [6-7]. The value of the velocity distribution correction factor is a function of the Reynolds number (Re_D) and can be calculated approximately for fully developed velocity distribution in the axi-symmetric nonswirling flow. This correction factor cannot be defined without solution of ambiguity for the transition from a laminar to a turbulent flow [6]. If the pipe flow distribution in a pipe is assumed to be uniform, then positive errors will occur [5]. These errors will range from 2…3% to 5…6 % of the true value, depending upon which model for the ideal flow distribution is selected [5,6]. These errors depend on the Reynolds number, pipe roughness, inlet flow conditions, the distance from an inlet, etc. For fully developed pipe flow distributions these errors decrease monotonically with the Reynolds number [5-8].

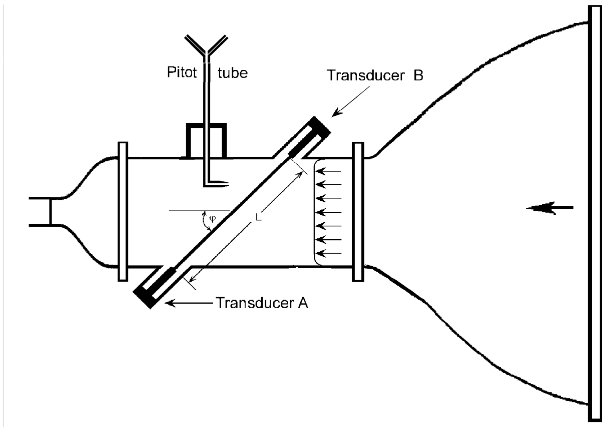

Fig.1. **The measurement section with the special form convergent nozzle for air flow flattening**

In our case the gas flow was formed by use of the air velocity national standard [9]. The Lithuanian national standard is intended to reproduce air velocity units in the range from 0.2 up to 60 meters per second with uncertainty accordingly less than ±(7.0-1.0)%. For improvement the parameters of a gas flow, the convergent nozzle of special form was used. This allowed to increase the flattening of the airflow to the value of about 0.98, (Fig.1). The airflow velocity measurement is based on the 3 static Pitot tubes, 3 convergent nozzles and an ultrasonic airflow velocity meter [10-12]. Because the convergent nozzle was used and airflow was flattened, the velocity profiles in the measuring section are different from the profiles usually obtained in the airflow channels. The parabolic velocity distribution for a laminar and power low for a turbulent flow, which are usually used for evaluation of flow profiles [4-8] in our case are not accurate enough. Therefore the aim of this investigation was evaluation of the influence of flattened airflow profiles to the flow velocity measurement by ultrasound.

Theoretical investigation

The calculation of the velocity distribution factor is based on the Reynolds number, the assumed flow profile and the integration technique used [6]. However, errors in the correction factor may cause non-linearity or systematic error when determining the volume flowrate. For evaluation of the influence of the velocity distribution factor to the flow velocity value, determined by ultrasound, let us to analyse it more detail.

The volume flowrate Q of the gas flow, when the pressure and the temperature of the gas are constant, may be expressed by equation

$$Q = V/t, \tag{1}$$

where V is the volume and t is the time. The volume of the gas, which passes through the cross-section S of the measuring section during the time t is given by

$$V = S\bar{v}_S t, \tag{2}$$

where $\bar{v}_S$ is the mean axial flow velocity over the cross-section S of the measuring section. Therefore the volume flowrate is

$$Q = S\bar{v}_S. \tag{3}$$

However, the shape of the axial velocity distribution profile in the cross-section of the measuring channel depends on the flow velocity, the distance from the pipe inlet, pipe wall roughness, variations of the pipe geometry, gas chemical composition and other parameters. For these reasons let us consider that the distribution of a flow velocity in the cross-section of the measurement section is axially symmetrical. When the distribution of the gas flow velocity *v(r)* in the radial direction is known, the flowrate *Q* of the gas flow in the measuring section may be determined by equation

$$Q = 2\pi \int_0^R r v(r) dr . \qquad (4)$$

Then the mean gas flow velocity $\bar{v}_s$ in the cross-section *S* of the measuring section is given by

$$\bar{v}_s = \frac{2}{R^2} \int_0^R r v(r) dr . \qquad (5)$$

When the gas flow velocity is measured by ultrasound, the ultrasound signal propagates up and down the flow at an angle through the pipe centre. In this case only the average flow velocity along the acoustic path v_i is determined

$$\bar{v}_i = \frac{\int_0^R v(r) dr}{R} . \qquad (6)$$

But when measuring the volume flowrate, the mean axial flow velocity v_s over the cross-section *S* of the measuring section is to be determined. Therefore, for determination of the mean axial flow velocity $\bar{v}_s$, after the measurement of the gas flow velocity $\bar{v}_i$ along the pipe diameter by ultrasound, the velocity distribution correction factor *k* can be determined

$$k = \bar{v}_s / \bar{v}_i . \qquad (7)$$

After the substitution of Eq. 5 and 6 to the Eq. 7, the flow velocity distribution correction factor *k* can be determined

$$k = \frac{2\int_0^R r v(r) dr}{R \int_0^R v(r) dr} . \qquad (8)$$

Knowing the value of the correction factor *k*, the volume flowrate of gas through the cross-section *S* of the measuring section can be calculated

$$Q = k \pi R^2 \bar{v}_i . \qquad (9)$$

Experimental results and discussion

An experimental investigation of the ultrasonic system for airflow velocity measurement was carried out at the Heat-Equipment Research and Testing laboratory of Lithuanian Energy Institute. The velocity of the airflow was obtained by the turbo-blower in the test wind tunnel with the diameter of the measuring section *D* = 0.40 m. A special form convergent nozzle was used for flattening of the airflow to the value of about 0.98. The results of the airflow velocity measurement, carried out by the reference turbine meter AAT-60 (calibrated in PTB, Germany), static Pitot tubes and the ultrasonic measuring system showed a good agreement in the range from 0.2 m/s to the 10…13 m/s [9-12]. In the range of an airflow velocity from 3 m/s to 10 m/s the profiles of the airflow velocity distribution through the diameter of the measuring section were obtained. The static Pitot tubes of 1.0 mm in the diameter were used for measurements. The static Pitot tubes were shifted from the inside wall of the round measuring channel to its centre by the use of transversing mechanism. The steps of displacement of the static Pitot tubes were 0.1 mm in the boundary layer of the measurement section (at the distances from 0.5 mm to about 10-15 mm from the measuring channel wall). When the probe crossed the boundary layer and was approaching the centre of the measuring channel, the steps of the displacement were increased to the values 5 – 10 mm (Fig.2).

How one can see from Fig.2, the profiles of the airflow

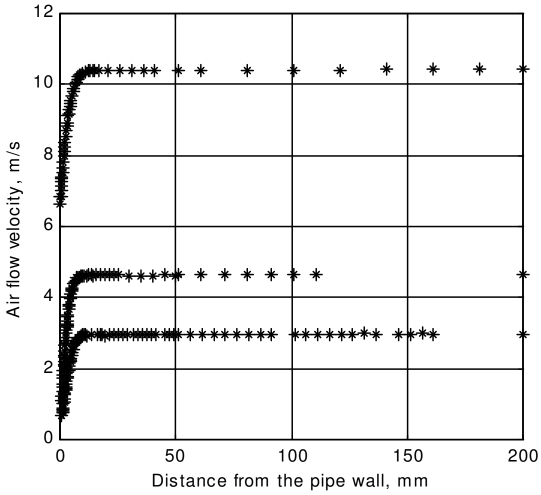

Fig.2. **Profiles of the airflow in the measuring channel measured by static Pitot tubes**

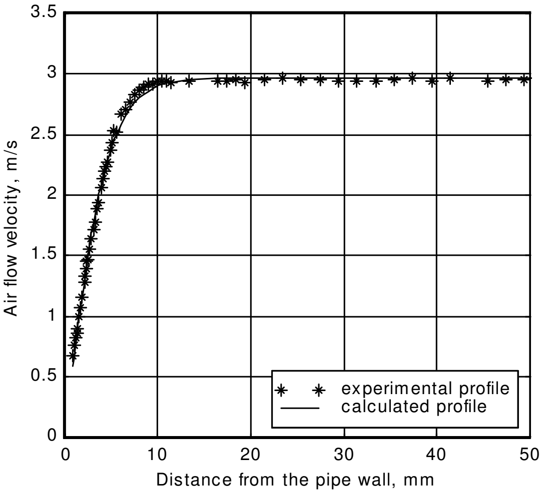

Fig.3. **Distribution of the airflow velocity near the wall of a circular measuring channel**

velocity, obtained by the use of the special form convergent nozzle, were sufficiently flattened. They were different from these usually obtained at the same conditions without flattening [7, 8]. Generally the laminar gas flow profile is described by a parabolic low, but turbulent flow velocity distribution usually coincides with the power low [7, 8]. On the basis of experimental results was seen that, profiles of the airflow velocity distribution in the measuring channel may be described by the hyperbolic tangent law (Fig.3)

$$v = v_m \,\mathrm{th}\left[(R-r)\alpha\right], \qquad (10)$$

where v_m is the maximal value of flow velocity in the centre of measurement section; α is the factor of flow profile flattening. How one can see from Fig.3, the coincidence of measured and calculated profiles in the measuring channel was enough tolerable. The factor α of flow flattening shows the maximal curvature of the flattened flow profile in the region of a boundary layer in the measuring channel. It depends on the Reynolds number of the flattened flow, pipe wall roughness, change of the pipe geometry, gas chemical composition and other parameters. The dependence of the factor of flow profile flattening on the flow velocity is shown in Fig.4.

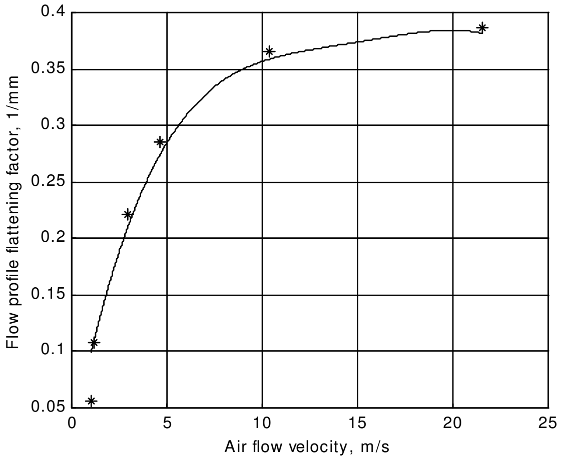

Fig.4. **Dependence of flow flattening factor α on a flow velocity in the measuring channel**

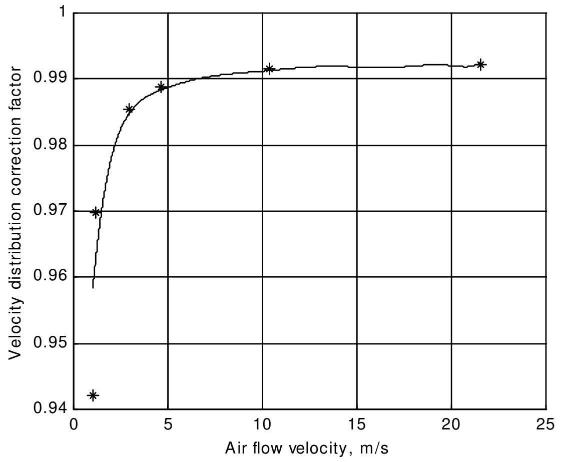

Fig.5. **Dependence of the airflow velocity distribution correction factor k on a airflow velocity in the measuring channel**

Then the gas flow velocity distribution correction factor k may be determined by equation

$$k = \frac{2\int_0^R r\,\mathrm{th}\left[(R-r)\alpha\right]dr}{R\int_0^R \mathrm{th}\left[(R-r)\alpha\right]dr}. \qquad (11)$$

The results of calculation of the values of the flow velocity distribution correction factor k are presented in Fig.5.

Conclusions

The results of investigation show that the methods, usually used for evaluation of the influence of flow profiles, are not sufficiently accurate when the flow velocity is measured by ultrasound and the flow profile is flattened by special shape convergent nozzle.

On the basis of measurement of airflow velocity profiles is proposed to use the hyperbolic tangent for description of flow velocity profiles in the measuring circular channel.

For evaluation of change of a flattened flow profile across the measuring channel diameter it is proposed to introduce the factor of flow profile flattening. The value of this factor corresponds to the value of maximal curvature of the airflow profile in the region of boundary layer in a circular measuring channel.

The accuracy of a gas flow velocity measurement by ultrasound may by increased after evaluation of the flow flattening factor as well as the flow velocity distribution correction factor.

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Išlygintojo srauto profilio įtaka ultragarsiniu metodu matuojant oro srauto greitį

Reziumė

Ultragarsiniu metodu matuojant dujų debitą vamzdynuose, būtina įvertinti jų srauto greičio pasiskirstymo profilį. Dujų srauto, išlyginto specialios formos konfuzoriumi, greičio pasiskirstymo profilis iš esmės skiriasi nuo dujų greičių profilių paprastuose vamzdžiuose. Išmatavus išlyginto konfuzoriumi oro srauto greičio pasiskirstymo profilį statiniu Pito vamzdeliu, nustatyta, kad jis labai artimas hiperbolinio tangento funkcijai. Hiperbolinio tangento kitimo ir srauto greičio profilio kitimo apvalaus kanalo skerspjūvyje atitikimą, lemia srauto profilio išlyginimo veiksnys. Pateikiamos srauto profilio išlyginimo ir srauto greičio pasiskirstymo apvalaus kanalo skerspjūvyje korekcijos veiksnių priklausomybės nuo ultragarsiniu metodu išmatuoto srauto greičio matavimo kanale. Parodoma, kad, norint padidinti srauto greičio ultragarsinio matavimo tikslumą, būtina įvertinti srauto profilio išlyginimo ir srauto greičio pasiskirstymo korekcijos veiksnių įtaką matavimo rezultatams.

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