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New algorithms for evaluation parameters of the gas flow

L. Jakevičius, J. Butkus

Prof. K.Baršauskas Ultrasound Institute

Kaunas University of Technology

Introduction

At present for measurement of gas flow velocity, flow rate and other parameters in most cases acoustic transit time measuring methods are used. However, differently from liquids, only invasive methods may be used because there is a great difference of acoustical impedances of the pipe wall and the gaseous medium under investigation [1]. In such a way a direct contact between the radiating (receiving) surface of the acoustical transducer and the media under the investigation is ensured. But such a measuring channel has one principal shortcoming: there are ports where transducer holders are mounted. In the vicinity of these ports the vortexes are created when the gas flows in the measuring spoolpiece. The form and the size of these vortexes depend on a lot of factors, which are individual in each separate case and are indescribable mathematically in practice. It makes a great influence on the accuracy of measurement results. This problem may be solved partially when covering the ports of the transducer holders with a metal net [2]. When the gas flow velocity is small and the ports are covered with nets, the vortexes usually do not appear and the velocity of gas flow in the ports is equal to zero. However, certain difficulties remain even in such conditions. An acoustical signal in the measuring channel propagates in the gas filling the spoolpiece and the pockets of the transducer holders from the transmitting to the receiving transducer (Fig.1). For the calculation of a gas flow velocity v the following algorithm is usually used [3]:

$$v = \frac{l}{2\sin\beta} \frac{t_2 - t_1}{t_1 t_2}. \quad (1)$$

Here l is the distance between the point A and B (Fig.1); t_1 and t_2 are the times of propagation of acoustical signals between the points A and B upstream and downstream the gas flow respectively.

On the other hand, the propagation time of acoustical signal from one electroacoustical transducer to the another is usually measured. Here one can see that real measured times of propagation of acoustical signals differ from those used in the algorithm (1) by the delay times of acoustical signals in the ports of transducer holders. Therefore in order to calculate a gas flow velocity in the pipe it is necessary to eliminate the time's of propagation of acoustical signals in the pockets of transducer holders. However, the propagation time in the ports of transducer holders are variable quantities, which depend on the sound velocity in the gas filing the pipeline. If the composition, the temperature or other parameters, which influence the velocity c of acoustical signal propagation in the gas, change, the time of propagation of the acoustical signals in the pockets of transducer holders changes too. Therefore, the correction coefficients, which are inserted in the algorithm (1), have a multiparametric functional dependence on the speed c of acoustical signals propagation [4]. One can see that the exact evaluation of time's of propagation of acoustical signals in the ports of transducer holders is very complicated or absolutely impossible. That decreases the accuracy of measurements of the gas flow velocity in a pipeline.

Mathematical model

In order to increase the accuracy of calculation of the gas flow velocity v and the velocity c of acoustical signal propagation in the gas filling the pipeline, the new algorithms were developed. When using these algorithms the changes in duration of acoustical signal's propagation in the ports of transducer holders do not influence the results of measurements.

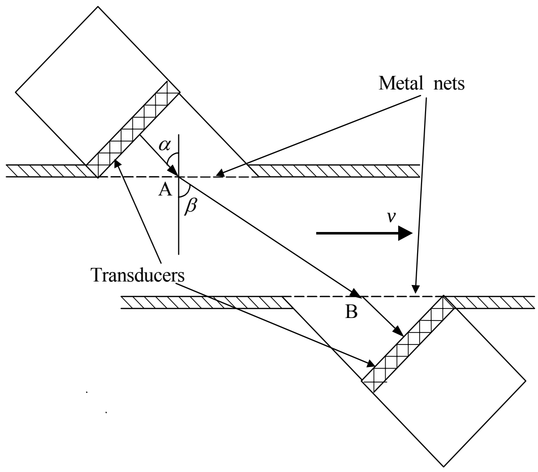

Fig.1. **An electroacoustical measurement channel**

Let us consider that the beam of the acoustical signal starting from any point of the transmitting electroacoustical transducer reaches the analogical point of the receiving transducer (Fig.2). The beam of the signal starting from the centre of the transmitting transducer will be received by the centre of the receiving transducer, from one side to the an other side and so on. Because the active surfaces of the electroacoustical transducers are parallel to each other, so the projection of sum of paths, covered by acoustical signals transmitted from any points of the transducer, in the ports of transducer holders, to the axis Y, is the constant quantity:

$$y_n = y_{n1} + y_{n2}. \quad (2)$$

Here y_{n1} and y_{n2} are the projections of tracks on the axis Y covered by acoustical signals propagating in the first and second ports of the transducer holders respectively. How it is seen from Fig.2, when the flow velocity v is constant, the projections of displacement of acoustical signals on the axes of coordinates, when passing the distance from one transducer to another, are the constant quantities independent on their points of radiation x and $y=y_v+y_n$. Here y_v is the projection of track of acoustical signal in the pipe to the axis Y. When taking into account these geometrical peculiarities, the propagation of acoustical signals in the electroacoustical measuring channel may be depicted structurally like in Fig. 3.

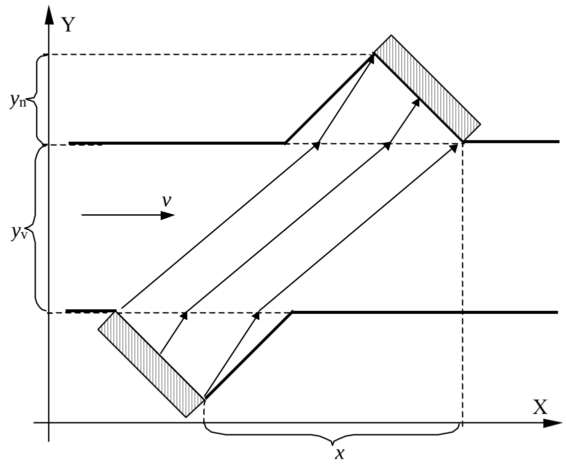

Fig.2. **Propagation of an acoustic signal in the measuring channel**

Let us consider that an acoustical signal is being radiated down stream at an angle α_1. In the pipe the acoustical signal is carried by the flow and is propagating at an angle β_1 with respect to the axis Y (with respect to the external coordinate system). Since the gas flow velocity is small ($v<<c$), the index of refraction of acoustical signals, which appears due to motion of environment, might be considered equal to one. Then the projections of the propagation velocity c on the axes of coordinates with respect to the gas will be equal quantities in the ports of transducer holders as well as in the pipe. Therefore the projection of the displacement of the acoustical signal in the measuring channel on the Y-axis is

$$y = t_1 c \cos\alpha_1 . \tag{3}$$

Here t_1 is the duration of propagation of acoustical signals downstream the flow in the measuring channel. Within this time the acoustical signal will move in the direction of X-axis at the distance

$$x = x_{1c} + x_{1v} = t_1 c \sin\alpha_1 + t_{1v} v . \tag{4}$$

Here x_{1c} and x_{1v} are the projections of components of displacement on the axis X, which appeared because of propagation of the acoustical signal and the motion of medium respectively; t_{1v} is the time of propagation of the acoustical signal in the pipe. During this time the acoustical signal will move in the direction of Y-axis at a distance

$$y_v = t_{1v} c \cos\alpha_1 . \tag{5}$$

From Eq. 3 and 5 it is seen that

$$t_{1v} = \frac{y_v}{y} t_1 . \tag{6}$$

After inserting Eq. 6 to Eq. 4 it is obtained

$$x = t_1 c \sin\alpha_1 + \frac{y_v}{y} t_1 v . \tag{7}$$

Analogically are obtained the expressions for displacement projections of the acoustical signal, propagating upstream. In such a case only the incidente angle α_2 and the duration of propagation t_2 of acoustical signal in the measuring channel are changed. It may be written by the system of equations

$$\begin{cases} y = t_1 c \cos\alpha_1 \\ x = t_1 c \sin\alpha_1 + \dfrac{y_v}{y} t_1 v \\ y = t_2 c \cos\alpha_2 \\ x = t_2 c \sin\alpha_2 - \dfrac{y_v}{y} t_2 v \end{cases} . \tag{8}$$

After the reconstruction of the first equation in the system it is obtained

$$\sin\alpha_1 = \sqrt{1 - \left(\frac{y}{t_1 c}\right)^2} . \tag{9}$$

By analogy the Eq. 3 of the system is reconstructed. After the insertion of these expressions to Eq. 8 it is obtained

$$\begin{cases} x = \sqrt{(t_1 c)^2 - y^2} + \dfrac{y_v}{y} t_1 v \\ x = \sqrt{(t_2 c)^2 - y^2} - \dfrac{y_v}{y} t_2 v \end{cases} . \tag{10}$$

We need to obtain the equation of the gas flow velocity v, which is described by geometrical parameters of the measuring channel and by times of propagation of acoustical signals upstream and downstream the gas flow. Therefore, the velocity c of propagation of acoustical signals must be eliminated from Eq. 10.

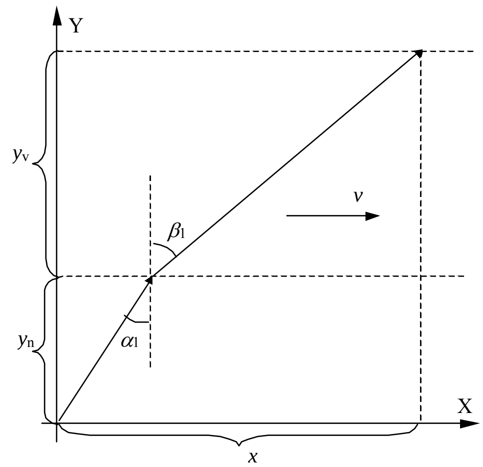

Fig.3. **The equivalent diagram of propagation of acoustical signal in the measuring channel**

For this purpose the system of Eq. 10 is rearranged:

$$\begin{cases} \dfrac{x^2}{t_1^2} - \dfrac{2xy_v v}{yt_1} + \dfrac{y_v^2 v^2}{y^2} = c^2 - \dfrac{y^2}{t_1^2} \\ \dfrac{x^2}{t_2^2} + \dfrac{2xy_v v}{yt_2} + \dfrac{y_v^2 v^2}{y^2} = c^2 - \dfrac{y^2}{t_2^2} \end{cases}. \quad (11)$$

After subtraction of the second equation from the first one we obtain

$$x^2\left(\frac{1}{t_1^2} - \frac{1}{t_2^2}\right) - \frac{2xy_v v}{y}\left(\frac{1}{t_1} + \frac{1}{t_2}\right) = -y^2\left(\frac{1}{t_1^2} - \frac{1}{t_2^2}\right). \quad (12)$$

Performing the mathematical reconstruction of Eq.12 leads to

$$\frac{2xy_v v}{y} = \left(x^2 + y^2\right)\frac{t_2 - t_1}{t_1 t_2}. \quad (13)$$

The gas flow velocity in the pipe is given by

$$v = \frac{\left(x^2 + y^2\right)y}{2xy_2}\frac{(t_2 - t_1)}{t_1 t_2}. \quad (14)$$

In order to describe the speed c of propagation of acoustical signals in the gas by geometrical parameters of the measuring channel and by the times of propagation of acoustical signals upstream and downstream the flow the system of Eq. 10 may be rewritten.

$$\begin{cases} \dfrac{x^2}{t_1} - \dfrac{2xy_v v}{y} + \dfrac{y_v^2 v^2 t_1}{y^2} = c^2 t_1 - \dfrac{y^2}{t_1} \\ \dfrac{x^2}{t_2} + \dfrac{2xy_v v}{y} + \dfrac{y_v^2 v^2 t_2}{y^2} = c^2 t_2 - \dfrac{y^2}{t_2} \end{cases}. \quad (15)$$

When summarizing termwise the both equations it is obtained

$$x^2\left(\frac{1}{t_1} + \frac{1}{t_2}\right) + \frac{y_v^2 v^2}{y^2}(t_1 + t_2) = c^2(t_1 + t_2) - y^2\left(\frac{1}{t_1} + \frac{1}{t_2}\right). \quad (16)$$

After performing the mathematical reconstruction Eq.16 may be written

$$c^2 = \frac{x^2 + y^2}{t_1 t_2} + \frac{y_v^2 v^2}{y^2}. \quad (17)$$

When describing the velocity c of propagation of acoustical signal by Eq.17, the gas flow velocity v in the pipe is necessary. With the purpose to avoid this dependence, the Eq.14 is substituted to Eq.17:

$$c^2 = \frac{x^2 + y^2}{t_1 t_2} + \frac{x^2 + y^2}{4x^2}\frac{(t_2 - t_1)}{t_1^2 t_2^2}. \quad (18)$$

After performing the mathematical reconstruction the expression for description of the propagation velocity c of acoustical signals in a gas flowing in a pipe is obtained

$$c = \sqrt{\left(\frac{x^2 + y^2}{t_1 t_2}\right)\left(1 + \frac{\left(x^2 + y^2\right)(t_2 - t_1)}{4x^2 t_1 t_2}\right)}. \quad (19)$$

On the basis of the results obtained it is seen that for calculation of the gas flow velocity, according to Eq.14 and Eq.19, it is not necessary separately to evaluate the duration of propagation of acoustical signals in the ports of transducer holders. It enables to avoid the difficulties mentioned above and to avoid errors, due to variations of propagation velocity c of acoustical signals in the measuring channel during measurements. In this case the accuracy of measurements is determined by the accuracy of measurement of the geometrical parameters of the measuring channel and by the accuracy of measurements of propagation duration of acoustical signals between the transducers.

Conclusion

When measuring a gas flow velocity v and sound speed c in it is often attempted to evaluate the time of propagation of acoustical signals in the ports of transducer holders and to eliminate it. The new algorithms (14) and (19) enables one to calculate the velocity of a gas flow and sound velocity in it not taking into account the duration of propagation time of acoustical signals in the ports of the transducer holders. This enables us to avoid the measurement error, which appears when the duration of time of propagation of acoustical signals in the ports of transducer holders is changing. In this case the accuracy of measurements depends only on the accuracy of measurement of geometrical parameters of measuring channel and on the accuracy of measurement of duration of propagation of acoustical signals in the gas flow between the transducers.

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Nauji algoritmai dujų srauto parametrams įvertinti

Reziumė

Parodyta, kad, taikant invazinius akustinius matavimo metodus dujų srauto ir akustinių signalų sklidimo jame greičiams apskaičiuoti, vienas iš paklaidų šaltinių yra akustinių signalų sklidimo elektroakustinių keitiklių tvirtinimo nišose trukmė. Ši trukmė priklauso nuo daugelio veiksnių ir matavimo metu gali kisti. Todėl tiksli jo vertė, o kartu ir įtaka matavimo rezultatams sunkiai nustatoma. Darbo metu gauti nauji algoritmai dujų srautui ir akustinių signalų sklidimui jame apskaičiuoti. Taikant šiuos algoritmus, nereikia iš anksto įvertinti akustinių signalų sklidimo elektroakustinių keitiklių tvirtinimo nišose trukmės. Dujų srauto ir jame sklindančių akustinių signalų greičiai apskaičiuojami įvertinus elektrokustinio matavimo kanalo geometrinius parametrus ir išmatavus akustinių signalų sklidimo tarp keitiklių trukmes.

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