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Computer model of acoustic link in a pipe with a flowing gas medium, Part II: Accuracy improvement of medium flow velocity determination

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ABSTRACT

While constructing medium flow velocity meters with the use of the ultrasonic method, it is assumed, that the deviation of the ultrasonic beam caused by medium flow, is insignificant. The assumption seems to be correct, because the average flow velocity is usually much smaller than the ultrasonic wave velocity in a medium. Basing on the assumption, we can use a known expression, which makes it possible to calculate an average medium flow velocity through run-time measurement from the transmitter to the receiver and in an opposite direction. In the paper, it is shown, that the average flow velocity determined in this way, using the computer model of acoustic link in a pipe with a flowing gas medium, is measured with a significant error. This error depends on the flow pipe diameter, the transducer diameters and the means of placing the transducers in the pipe.

Properly modifying the expression for ultrasonic run-time through flowing gas medium and taking into account the means of transducer placing in the pipe, we can eliminate the error related to the measurement geometry and we can find an optimum ultrasonic wave propagation angle.

WPROWADZENIE

In the hitherto existing realisations of the ultrasonic measurement of gas flow velocity, the error in measurement of the average flow velocity connected with the deviation of the ultrasonic beam has not been taken into consideration. This error can be significant for the measurement results at small angles of placing the transmitting and receiving transducers with regard to the pipe axis. The development of the computer model of the acoustic link in the flowing conditions made it possible to calculate the average gas velocity measurement error, brought about by the ultrasonic beam deviation and to find the way to improve the measurement accuracy.

DETERMINATION OF THE AVERAGE VELOCITY OF THE MEDIUM FLOW

The computer model presented in the paper [4] takes into consideration the possibility of determining the average medium flow velocity on the basis of the calculated run-time from the transmitting to the receiving transducers. When constructing medium flow velocity meters with the use of the ultrasonic methods, the assumption is usually adopted that the deviation of the ultrasonic beam brought about by the medium flow is insignificant [1]. The assumption seems to be correct because the average flow velocity of the medium is usually much smaller than the velocity of the ultrasonic wave propagation in the medium. Adopting such an assumption, it is possible to calculate the relationships which make it possible to determine the average medium flow velocity by the run-time measurement from the transmitter to the receiver and in the opposite direction [2,3]. Having adopted the aforementioned assumption it is possible to use the projection of the resultant vector of the ultrasonic wave propagation velocity c_w taking into account the flow to the straight line passing through the surface centres of the transducers (fig.1). Then the run-time from the transmitter to the receiver can be determined from the expression:

$$t_1 = \frac{D_k}{(c+V_{sr}\cos\alpha)\cdot\sin\alpha} \quad , \tag{1}$$

and the run-time in the opposite direction from the expression:

$$t_2 = \frac{D_k}{(c-V_{sr}\cos\alpha)\cdot\sin\alpha} \quad , \tag{2}$$

In the both equations V_{sr} is the average velocity of the medium flow in the pipe. Converting two equations to the expressions:

$$c + V_{sr}\cos\alpha = \frac{D_k}{t_1 \sin\alpha} \quad , \tag{3}$$

$$c - V_{sr}\cos\alpha = \frac{D_k}{t_2 \sin\alpha} \quad , \tag{4}$$

and substracting them on the sides, we get the average medium flow velocity:

$$V_{sr} = \frac{t_2 - t_1}{t_1 \cdot t_2}\,\frac{D_k}{2\sin\alpha\cos\alpha} \quad for\ \alpha \neq 90° \quad . \tag{5}$$

The equation (5) is mainly used to determine the average flow velocity of the medium in the ultrasonic flow velocity measurements [1,2,3].

The relationship (5) does not take into consideration the connectors length with the transducers (fig.1) where the medium flow velocity is insignificant (however it should be stressed that the size of the connector cavity influences much the formation of whirls and turbulence). Thus V_{sr}, determined by means of the equation (5) will be underrated value. A more accurate equation can be made taking into account the distances in the connectors as $h/\sin\alpha$ (fig.1) in the equations (1) and (2) and using the time difference $\Delta t = t_2 - t_1$. In this way a new expression is obtained for the average medium flow velocity, which does not depend on the connectors length:

$$V_{sr} = \frac{D_k - \sqrt{D_k^2 + \Delta t^2 c^2 \sin^2\alpha}}{\Delta t \cos\alpha\ \sin\alpha} \quad for\ \alpha \neq 90° \quad . \tag{6}$$

In the computer model two expressions (5) and (6) are used.

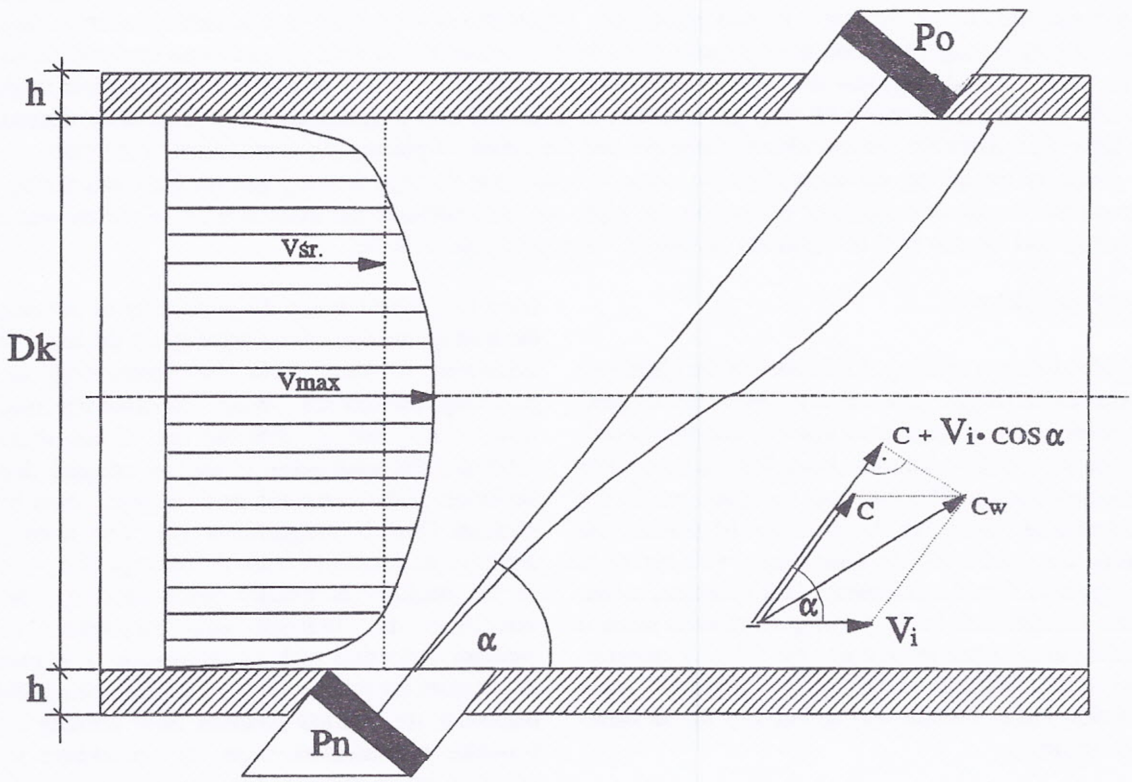

Fig.1. Projection of the resultant velocity of the ultrasonic wave to the straight line linking the surface centres of the ultrasonic transducers in the measurement V_{sr} in the axial-symmetric pipe.

ANALYSIS OF THE MEASUREMENT ACCURACY OF THE AVERAGE FLOW VELOCITY

Having the possibility of determining the average velocity of the flow (V_p - according to the equation (5) and $V_{\_p}$ - according to the equation (6)) the accuracy of the simulated measurement of the average air velocity in the pipe was analysed on the basis of the pseudo-real values of run-times t_p (the time of running of ultrasonic wave on the way L_α in the direction from the transmitting to the receiving transducers) and t_p' (similarly as in t_p but in the opposite direction), calculated by the computer model keeping the relationships (5) and (6). The analysis results are shown in figs.2÷5.

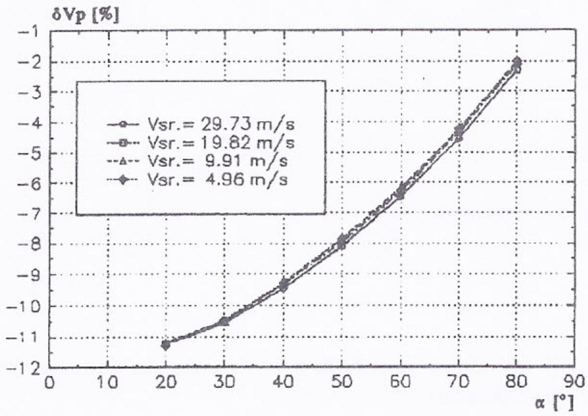

Fig.2. The measurement error of the average air flow velocity in relation to the angle of placing the transducers with regard to the pipe axis for D_n=7 cm and D_k=0.5 m (the velocity calculated from the eq. (5)).

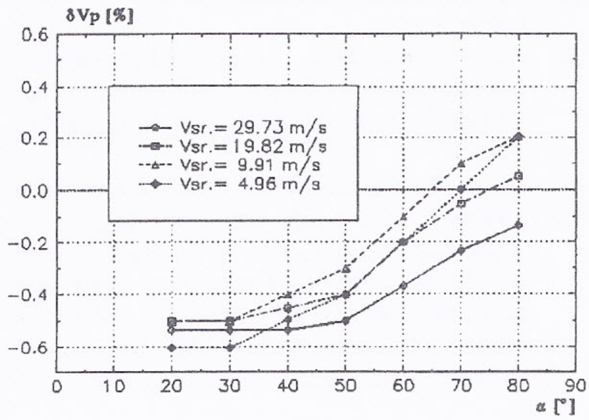

Fig.3. The measurement error of the average air flow velocity in relation to the angle of placing the transducers with regard to the pipe axis for D_n=7 cm and D_k=7 m (the velocity calculated from the eq. (5)).

The values of the errors presented in figures 2,3 and 4 were calculated as $(V_p\text{-}V_{śr})/V_{śr}\cdot 100\%$, whereas the errors shown in the figure 5 were calculated as $(V_{\_p}\text{-}V_{śr})/V_{śr}\cdot 100\%$. The velocity $V_{śr}$ denotes the average flow velocity on the pipe calculated by averaging the flow profile. The relationships presented in figs.2÷4 show that the equation (5) depends much on the ratio of the transducer diameter to the pipe diameter D_n/D_k, which can be explained with the distance influence in the connectors. The bigger ratio is, the bigger measurement errors $V_{śr}$ are.

It was determined that the errors brought about by the influence of the transducer diameter can be overlooked if $D_n/D_k \leq 0.005$. The eq. (5) also depends much on the angle of placing the transducers in the pipe, which in the case of the ratio $D_n/D_k > 0.005$ is caused by the influence of the distance in the connectors and in the case of $D_n/D_k \leq 0.005$, it is the assumption about the omission of the beam shift. On the basis of the graph presented in fig.4 it can be noticed that it is possible to determine the optimum measurement angle $\alpha \approx 35°$ for which having satisfied the condition $D_n/D_k \leq 0.005$ the relative errors of determining the average flow velocity are the smallest, of the order 0.1%.

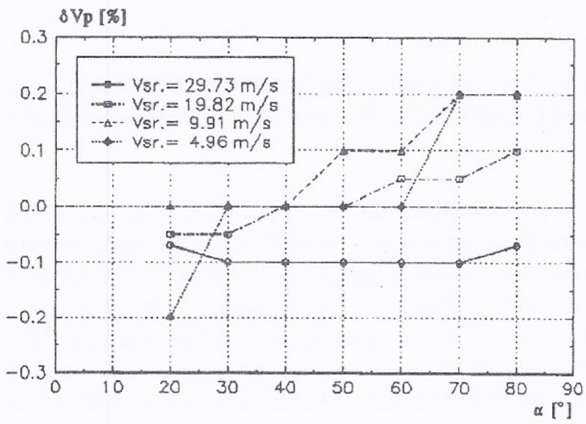

Fig.4. The measurement error of the average air flow velocity in relation to the angle of placing the transducers with regard to the pipe axis for D_n=3.5 cm and D_k=7 m (the velocity calculated from the eq. (5)).

Fig.5 presented the error values determined for D_n=3.5 cm and D_k=0.5 m, however it turns out that they do not change for other values D_n and D_k, which speaks for the independence of the equation (6) of the pipe diameter and transducers and at the same time of the connectors length. The error dependence on the angle is more significant for bigger flow velocities, which is brought about by the assumption about the omission of the beam deviation. It seems that upon the fig.5 it is also possible to determine the optimum angle α=35°.

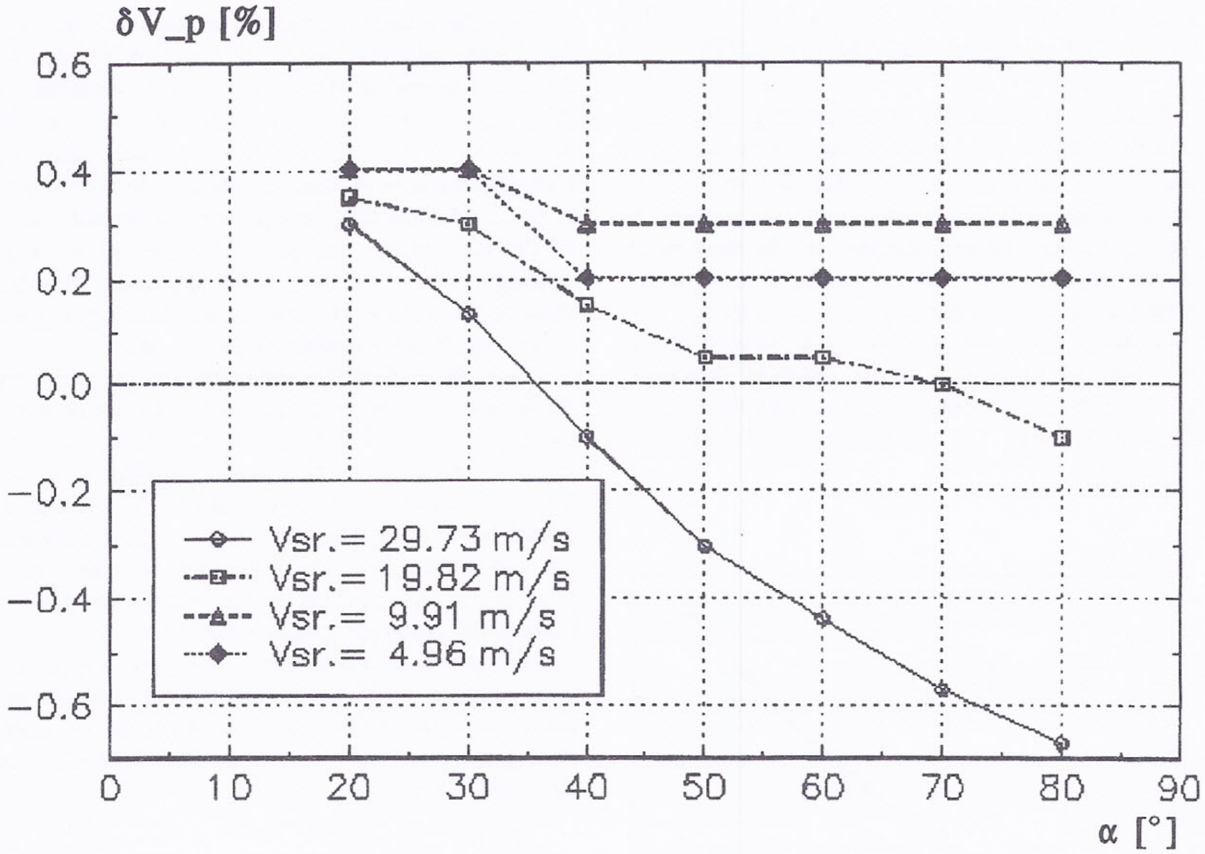

Fig.5. The measurement error of the average air flow velocity in relation to the angle of placing the transducers with regard to the pipe axis (the velocity calculated from the equation (6)).

The sensitivity of the equations (5) and (6) on the change of air temperature and resultant change of the ultrasonic wave propagation velocity in the medium was also examined. The changes of temperature by tens of degrees according to the equation (5) (high velocity of flow 30 m/s) brought about the errors of the order of 0.01m/s whereas according to the equation (6) the errors of the order of 0.03m/s.

CONCLUSIONS

Modification of the relationship determining the run-time of the ultrasonic wave through the flowing medium taking into consideration the way of placing the transducers in the pipe made it possible to eliminate the error connected with the geometry of measurement. The value of the ultrasonic wave propagation angle was also optimised.

The considerations indicate high usefulness of the equation (6), which so far has not been used in practical realisations of the gas flow velocity measurements.

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