GAS FLOW MEASUREMENT WITH CROSS CORRELATION FUNCTIONS OF ULTRASONIC SIGNALS TAKING ADVANTAGE OF ARTFICIALLY GENERATED VORTICES

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Introduction

In spite of many advantages ultrasonic gas flow meters are not generally accepted in the market of flow measuring instruments. Most of them are operating with ultrasonic impulses using the principle of time-of-flight measurement. Vortex frequency measurements up to now don't use ultrasound for the detection of frequency although the sensitivity can be increased up to ten times and analogue signal processing is very easy [1]. Cross correlation measurements with two ultrasonic barriers are only used in a few cases on account of difficult signal processing, misunderstood physics and nonlinear calibration. To consider even unsymmetrical flow profiles multi-path arrangements of ultrasonic sensors have been applied. These disadvantages can be avoided by the combination of cross correlation measurements with small artificially generated vortices.

Vortex Measurement

In the following a self-monitoring system based on vortex and cross-correlation measuring method shall be presented. For vortex measurements usually pressure sensors or the change of capacity of a paddle oscillating with vortex frequency in the wake of the bluff body are applied for the detection of vortex frequency which is proportional to the average flow velocity. They presuppose big bluff body sizes on account of the low sensitivity of pressure sensors. In literature a bluff body height of 24 - 28% of the pipe diameter is recommended [2]. They result in big pressure losses. The high sensitivity of ultrasound to all kinds of turbulences in a streaming fluid admits a drastic reduction of the bluff body size and pressure losses to be neglected. Further advantage is that the sensitivity of the measuring system increases with decreasing bluff body size.

For triangular bluff bodies it became apparent that it is advantageous if the tip of the bluff body faces the inflow and not the flat side as for measurements with pressure sensors.
Only primary vortices are generated in the wake of the bluff body. They result in a nearly sinusoidal modulation of the ultrasonic signal. The sensitivity E referring to the number of vortices per meter is defined as

$$E = \frac{df}{du} \qquad \text{in m}^{-1}. \qquad (1)$$

For bluff bodies with the tip facing the inflow the sensitivity is $E=223d^{-0.89}$. Figure 1 shows this characteristic [1].

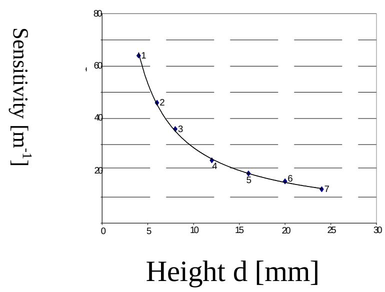

Fig.1 Sensitivity E as characteristic of bluff body height d

Correlation measurements

In conventional cross-correlation measurements the flow velocity is determined by the time shift of the peak of the cross-correlation function between two ultrasonic barriers. The deviation of this method from the real average flow velocity is mostly explained by the measurement of the difference of a line integral of the ultrasonic beam to the area integral of the flow in the pipe. But this hypothesis presupposes that the distribution of the velocity components is symmetric and is described by a Gaussian normal distribution. Experiments have shown that this distribution is skewed so that average value and the most frequent value (modal value) are not identical. Examinations have shown that in correlation measurements only the modal value is determined. That means that the velocity of the most frequent flow velocity components in the fluid is measured which depends on the velocity dependent flow profile. This is the real explanation for the deviation from the average flow velocity and shows the necessity of calibration [4].

Combination of vortex and correlation measurement

The disadvantage of calibration stated above can be avoided by a combination of vortex and cross-correlation measurement. In the wake of a bluff body symmetrically distributed vortices are generated which can be detected as a symmetric pattern between two ultrasonic barriers. The transit time of a group of vortices in the cross-correlation function corresponds to the average flow velocity. Measurement results show the superiority of this method to the measurement of natural turbulences in the fluid without bluff body. The uncertainty of the new method decreases in comparison to the conventional method, figure 2.

The combination of vortex and correlation measuring methods results in a self-monitoring system because the two measuring systems are independent of each other. If one method fails the other method continues working.

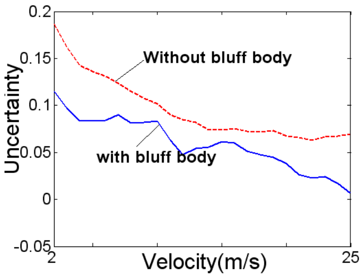

Fig.2 Uncertainty of measured velocity with and without bluff body

Measurements

Measurements have been made in a pipe with 100 mm diameter. The distance between the two ultrasonic barriers was 90 mm. The gas was air of 1 bar pressure. The flow velocity range was 2 – 25 m/s corresponding to Reynolds number from 13000 to 163000.

Figure 3 shows the characteristic cross-correlation functions for a gas flow velocity of v = 25 m/s for the same arrangement.

It can be seen that the natural turbulent flow has a higher stability than the vortices in the wake of the bluff body. It is remarkable that the peak of the cross correlation function

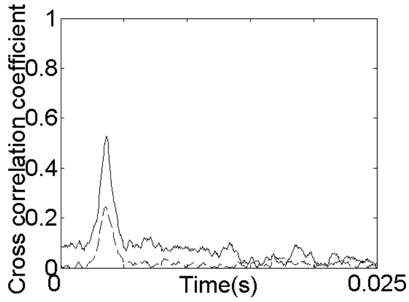

Fig.3 Cross-correlation function of gas flow at v =25 m/s.
Dash line: with bluff body, solid line: natural turbulences.

with vortices behind the bluff body is clearly lower than that of natural turbulences. That shows that the vortices are dissipating more quickly than natural turbulences within the measuring distance of 90 mm.

Conclusion

Conventional ultrasonic cross correlation measurements of turbulent gas flow require calibrations with nonlinear characteristic on account of velocity dependent flow profiles. Using artificially generated vortices in the wake of a small bluff body the real average gas flow velocity can be measured directly. Additionally the system can be used as self-monitoring system.

References

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