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IMPROVEMENT OF ULTRASONIC CROSS-CORRELATION MEASUREMENT OF GAS FLOW BY BLUFF BODY GENERATED VORTICES

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Abstract: Ultrasonic cross-correlation flow meters using natural turbulences in a fluid must be calibrated. The reason is that the most frequent components in the fluid are determined by this method deviating from the average flow velocity. The calibration characteristic is nonlinear and depends on the flow velocity and profile, respectively. This disadvantage can be avoided by small artificially generated vortices combined with cross-correlation measurement. In this case the vortices are travelling with average flow velocity. The detection of travelling time of a group of vortices between two ultrasonic barriers by cross correlation admits the direct determination of the average flow velocity. Furthermore, the combination of vortex and correlation measurement results in a self-monitoring system.

Keywords: flow measurement, vortex measurement, cross correlation, self-monitoring system**.**

1. 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.

2. 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. As shown in figure 1 the Strouhal number of the bluff body with the flat side to the inflow $S_r = 0.16$ increases to $S_r = 0.32$ for the same bluff body turned around 180 degrees. Correspondingly the sensitivity increases by the factor 2. The bluff body diameter was d = 24 % of the pipe diameter of D = 100 mm.

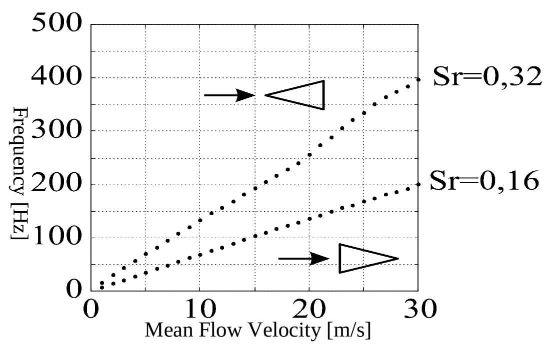

Fig.1. Characteristics of vortex flowmeter with different bluff body arrangement. Bluff body diameter d = 24 mm

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

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

It represents the periodic length of vortices. In the case of flat side facing the inflow the sensitivity can be described as $E = 77d^{-0.79}$. The characteristic is shown in figure 2 [3].

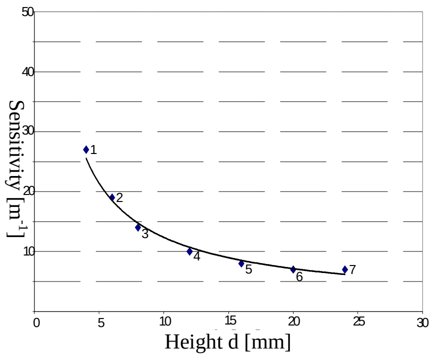

Fig.2. Sensitivity E as function of bluff body height d

For bluff bodies with the tip facing the inflow the sensitivity is $E=223d^{-0.89}$. Figure 3 shows this characteristic.

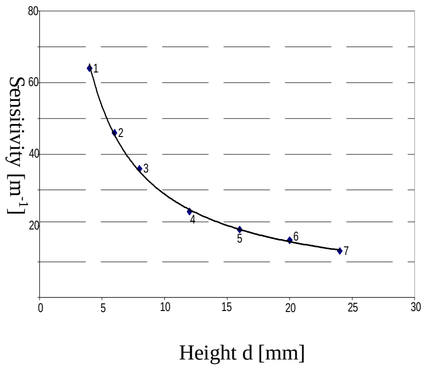

Fig.3. Sensitivity E as characteristic of bluff body height d

3. 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].

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, figure 4. In the wake of a bluff body symmetrically distributed vortices are generated which can be detected as a symmetric pattern

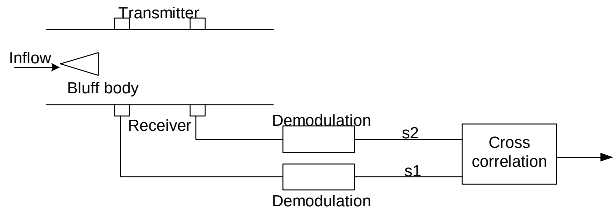

Fig.4. Combination of vortex and correlation measurement system

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. Consequently the uncertainty of the new method decreases in comparison to the conventional method, figure 5.

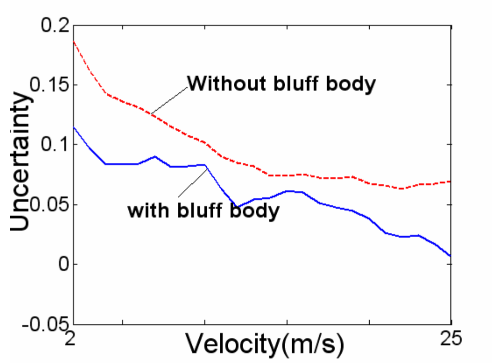

Fig.5. Uncertainty of measured velocity with and without bluff body

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.

5. MEASUREMENT RESULTS

The measurement set up is shown in figure 6.

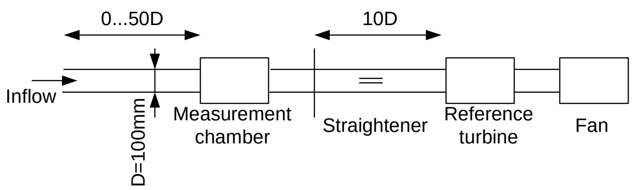

Fig.6. Measurement set up

Measurements have been made in a pipe with 100 mm diameter. The length of the pipe was 5 m ensuring a stationary turbulent flow with fully developed flow profile. 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.

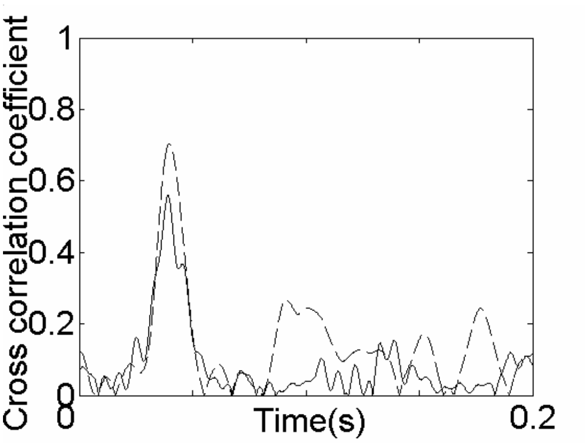

**Fig.7. Cross-correlation function of gas flow at v=2 m/s.
Dash line: with bluff body; solid line: natural turbulent flow**

Figure 7 shows the measurement result for a flow velocity of 2 m/s with (dashed line) and without bluff body (solid line). The time shift of the peak of both curves is small but clearly visible.The peak of the dashed line shows the correct time shift of the cross-correlation function representing the average flow velocity. The peaks show different heights. They represent the similarity of the pattern between the two ultrasonic barriers in a distance of 90 mm.

Figure 8 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

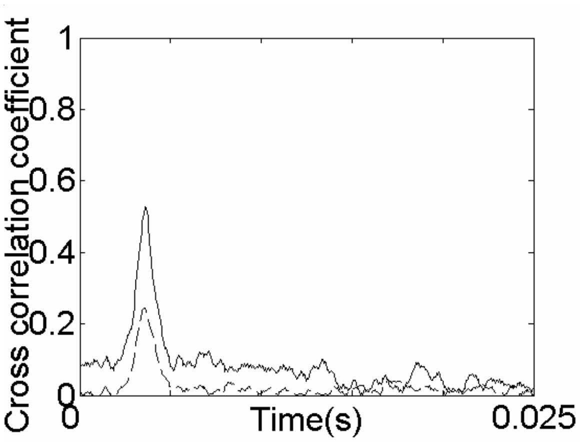

**Fig.8. Cross-correlation function of gas flow at v=25 m/s.
Dash line: with bluff body, solid line: natural turbulencs.**

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.

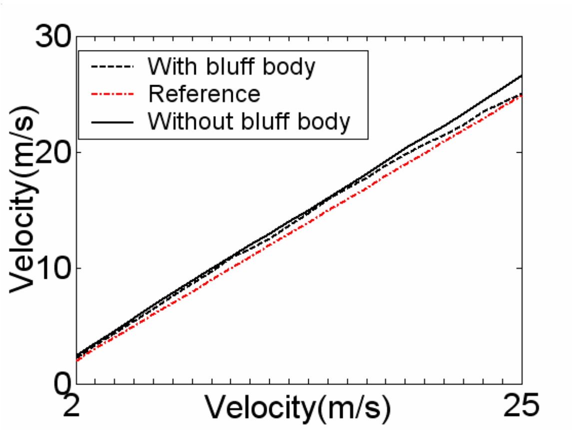

Fig.9. Calculated results from cross correlation measurements versus reference flow velocity

Figure 9 shows the calculated results from measured cross correlation functions with and without bluff body. Especially in the range of higher flow velocities the arrangement with bluff body shows advantages.

6. CONCLUSION

Measurement of velocity of a natural stationary turbulent flow by ultrasonic cross correlation functions result in the determination of the most frequent velocity components in the fluid. On account of a skewed density distribution of the velocity components in the fluid the modal value deviates from the average flow velocity. It is dependent on the flow profile and the flow velocity. For this reason a calibration of the measuring system is necessary. Measuring the velocity of vortices, generated by a small bluff body, between two ultrasonic barriers the average flow velocity can be detected directly. The combination of vortex and correlation measurement results in a self-monitoring flow measurement system.

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