EXPERIMENTAL OPTIMISATION OF BLUFF BODIES IN ULTRASOUND VORTEX SHEDDING FLOW-METERS

H. Windorfer, V. Hans
Institute of Measurement and Control, University of Essen, D-45117 Essen, Germany

Abstract: Using ultrasound in vortex shedding flow-meters is a powerfull combination. The high sensitivity of ultrasound to the vortex structures enables a compleatly new design of the measuring system. Smallest bluff-bodies can be used generating a regular and well defined vortex street. At the same time the pressure loss caused by the bluff-body is minimised. The high sensitivity of ultrasound to the vortex structures and the secondary vortices requires the design of a special shaping with new properties.

Keywords: Ultrasound, Vortex Flow-Meter, Bluffbody Optimisation

1 INTRODUCTION

Most commercial vortex-shedding flow-meters rely on a well known relationship between the vortex shedding frequency an the mean flow velocity. Pressure sensors are almost used in the wall of the pipe or inside the bluff body for the detection of the separating vortices. Various shapes of bluff bodies are designed creating a regular and well defined vortex structure and pressure signal at the sensor for a reliable, simple and cost saving signal processing. Alternatively to the pressure sensors ultrasonic sound can be used for detecting the vortex street downstream the bluff body. The ultrasonic barrier behind the body is modulated in phase and amplitude [1]. Undersampling the signal and reconstructing phase shift and amplitude of the ultrasound by using the inphase and quadrature demodulation leads to reliable and cost saving evaluation methods with a simple microcontroller [2] however, the signal processing requires well defined vortices at only one dominant frequency, without any secondary effects. An economic signal processing is only feasible with an optimised shape of the vortex body.

Bluff bodies as they are designed for vortex flow-meters using pressure sensors do have the major disadvantage of their large dimensions. Mostly they have a width of 24 percent of the pipes diameter [3] covering an area of more than 30 percent of the pipe profile and cause an immense pressure loss. Investigations on vortex shedding flow meters combined with ultrasound have shown a much higher sensitivity for the detection of the vortices, so much smaller geometries can be used. The installation of bluff bodies with a width of only ten percent of the pipes diameter and the excellent measurement results have already been shown [4].

2 MEASUREMENT-PRINCIPLE

The vortex frequency measuring principle uses the separation of vortex structures at the backside of a body that is flowed around. This effect is well known as the Karman vortex street. The frequency of the vortex separation depends nearly linearly on the mean flow velocity. The dependence of the vortex frequency f, the mean flow velocity u_m and the diameter of the bluff body d is expressed by the dimensionless Strouhal number:

$$Sr = \frac{f \cdot d}{u_m}. \tag{1}$$

Most commercial vortex shedding flow-meters use pressure sensors for the detection of the separating structures fixed inside the pipe wall or at the backside of the bluff-body. The low sensitivity of the pressure sensors requires strong vortices generated by large bluff bodies. An alternative method is the use of an ultrasonic barrier behind the bluff-body perpendicular to the pipe axis and the bluff-body measuring the vortex frequency. This technique is much more sensitive to the inhomogeneous structures that modulate the ultrasonic signal in phase and amplitude. This modulation is not only caused by the pressure fluctuations but also by other parameters of the fluid as speed of sound and the velocity components.

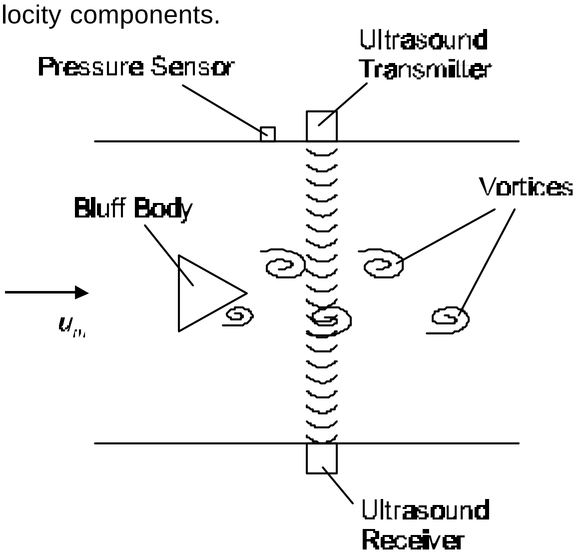

Figure 1: Principle of vortex shedding flowmeter.

The present measurement was done in a prototype measuring chamber that enables various configurations of the vortex measuring system and the use of different shapes of bluff bodies. The pipe of the test arrangement has a diameter of 100 mm. The used test fluid was air at 1 bar static pressure. The flow is velocity controlled in a range of 1 up to 30 m/s. A turbinegasmeter is used as reference measuring system with deviation less than 1 percent of the mean flow velocity. For the generation of the ultrasonic beam ultrasound tranceducers are used with a diameter of 13 mm at a carrier frequency of 220 kHz. The location of the ultrasonic beam was selected by the demand for the most sinusoidal timesignal of the demodulated amplitude in a range of ten to eighty millimetres behind the bluff-body.

3 SIGNAL PROCESSING

The ultrasound wave is as mentioned above modulated by the vortices in amplitude and phase. The carrier frequency can be eliminated by an undersampling technique [1,3]. The sideband contains the information of the amplitude and phase. The demodulation technique uses the inphase and quadrature modulation sampling reconstructing phase shift and amplitude of the modulated ultrasonic signal and detecting the characteristic vortex frequency [4].

4 MEASUREMENT

Presently tests have been performed with bluff-bodies of a width up to 12 times smaller than the bodies used in many commercial vortex shedding flow-meters combined with pressure sensors. Measurements of high quality have been executed with these bluff-bodies using the high sensitivity of the ultrasonic barrier. Conjunct with that the disturbing impact of the high pressure loss of the measuring systiem was reduced. A very high dependence of the vortex frequency and the mean flow velocity could be determined for all of the geometries. In this paper the measurement results of three different bluff-bodies are presented as shown in Figure 2.

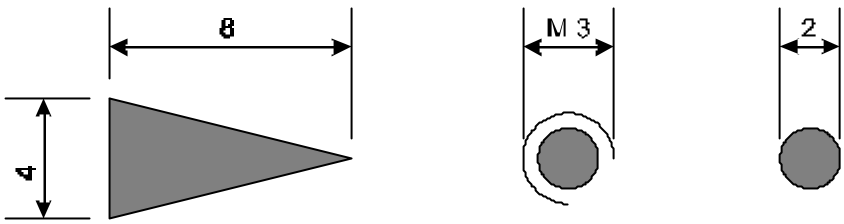

Figure 2: Presented bluff-bodies: Triangular form with 0.5 with to length ratio, threaded control rod M3 and circular bar 2 mm diameter.

In comparison to a common bluff body used in many commercial vortex shedding flow-meters the width could be minimised to only 1/12. The critical behaviour of the measuring system with lock-in of the vortex frequency at the natural frequency of the small bluff-body was eliminated by raising up the eigenfrequency of the bluff-body by putting it on tensile stress.

4.1 Triangular Form

Many commercial vortex shedding flow-meters combined with pressure sensors use a triangular bluff-body with a width of 24 percent and a length of 48 percent of the pipes diameter generating well defined pressure signals. The shape of the first presented bluff body is similar to this form with a width to length ratio of 0.5 but the dimensions are six times smaller as for the known shape. This form shows also a better resistance to oscillation with the eigenfrequency as the circular forms. In figure 3 is shown the vortex frequency and the dimensionless Strouhal number versus the mean flow velocity. The measured values follow a curve with an upward gradient of about 26 Hz per m/s. At a low mean flow velocity below 5 m/s the measurement becomes less reliable by strong deviations.

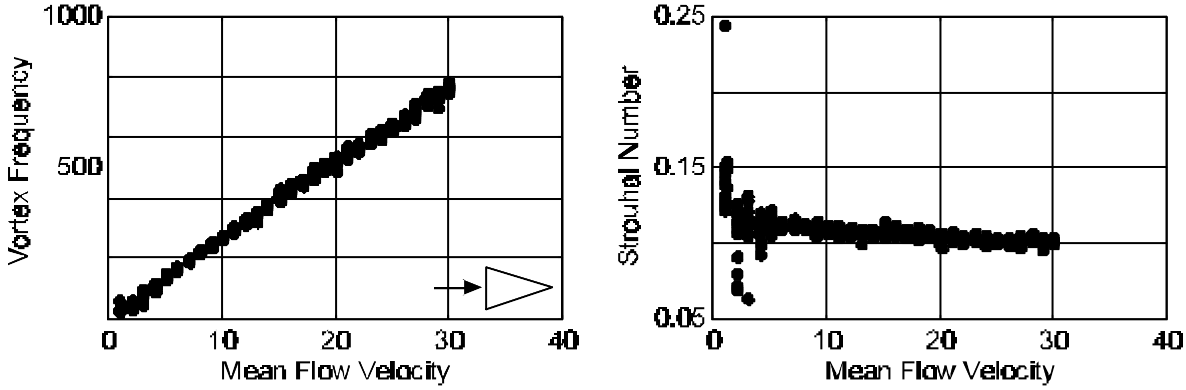

Figure 3: Vortex Frequency and Strouhal Number versus mean flow velocity for the triangular bluff-body facing the flat side to the inflow measured 80 mm behind the bluff-body.

In the time domain (Figure 4) the demodulated amplitude of the ultrasonic signal is displayed at a velocity of 10 m/s. It shows a primary periodic progression but also disturbances caused by secondary effects. These effects have already been shown for this form of bluff-bodies with larger dimension in combination with ultrasound. The frequency spectrum shows a strong maximum at the vortex frequency with a high signal to noise ratio. A secondary maximum with the doubled frequency but a lower amplitude can also be noticed.

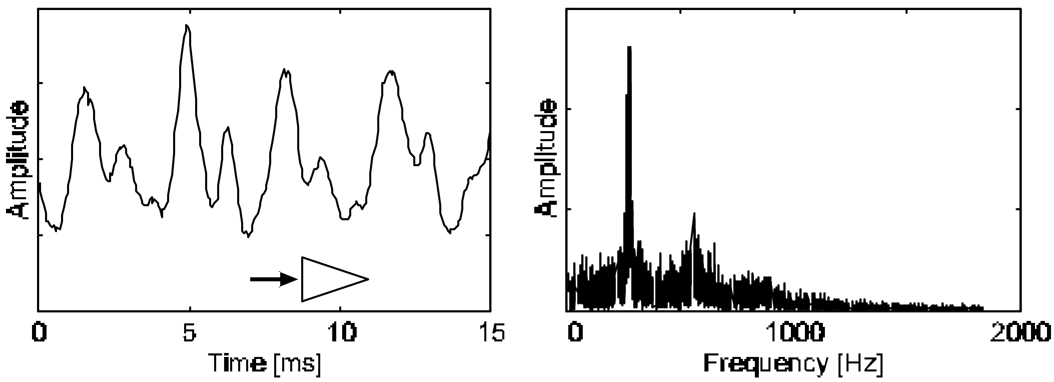

Figure 4: Timesignal and frequency spectrum of the triangular bluff-body facing the flat side to the inflow.

Using the same bluff-body turned around facing the edge to the inflow leads to very different but better results. The diagram of vortex frequency versus mean flow velocity (Figure 5) shows an upward gradient that is about twice as large as shown for the first kind of usage. This improves the quality of the measurement by a better frequency resolution. The linearity displayed by the Strouhal number is also much higher especially for the lower velocity range.

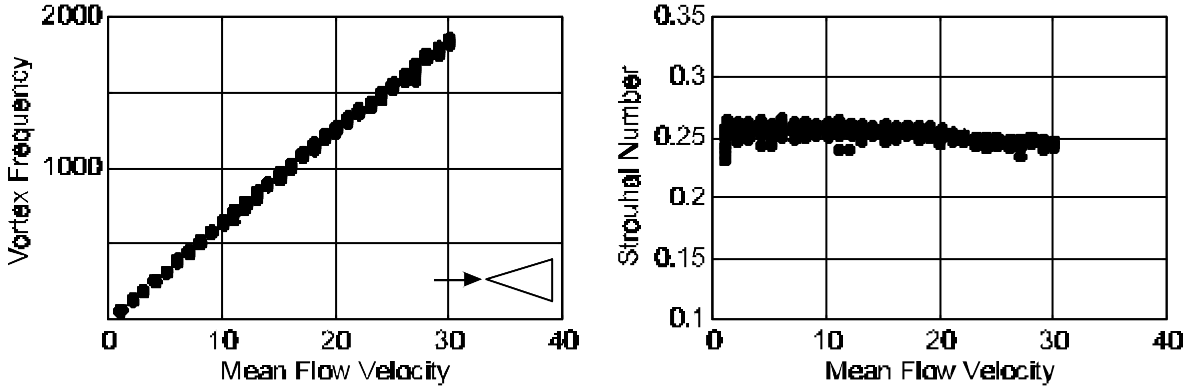

Figure 5: Vortex Frequency and Strouhal number versus mean flow velocity for the triangular bluff-body facing the edge to the inflow.

The influence of secondary effects could be reduced. The timesignal became less disturbed and more sinusoidal but the amplitude variates still strongly. The signal to noise ratio of the vortex frequency in the frequency spectrum was increased but still a secondary much smaller maximum at the double frequency can be noticed.

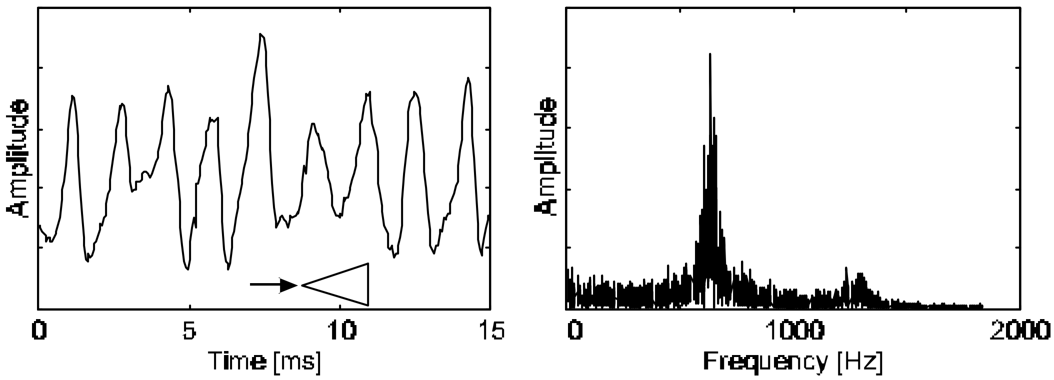

Figure 6: Timesignal and frequency spectrum of the triangular bluff-body facing the edge to the inflow at a velocity of 10 m/s.

4.2 Threaded control rod M3

Further investigations have shown that special shaping of the bluff-bodies almost leads to higher linearity of the measuring system and more reliable vortex-signals for the whole velocity range.

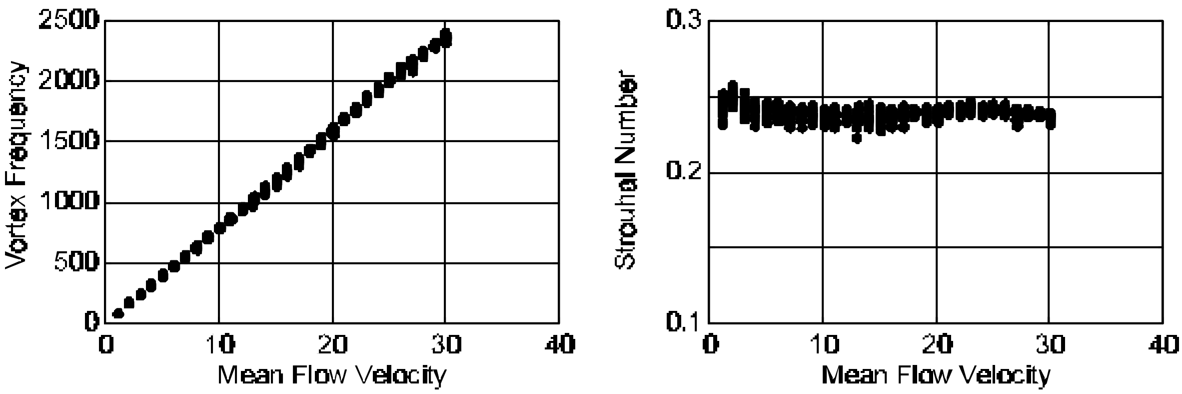

Figure 7: Vortex Frequency and Strouhal number versus mean flow velocity for the M3 threaded control rod.

Manipulating the surface of the bluff-body is one further more way to improve the signal-generation. The use of an M3 threaded control rod suppresses highly the development and separation of secondary structures and leads to a very harmonic and steady signal of the demodulated amplitude. No secondary frequency can be noticed in the frequency spectrum anymore.

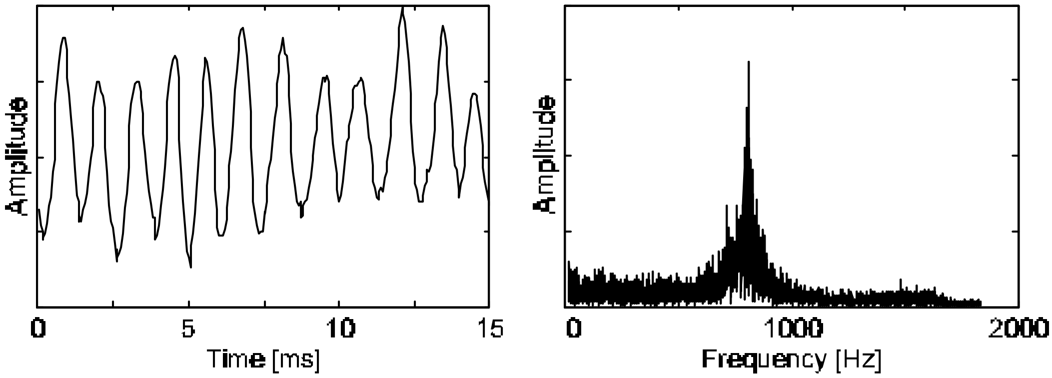

Figure 8: Timesignal and frequency spectrum of the M3 threaded control rod at a velocity of 10 m/s.

The high decrease of the vortex frequency to mean flow velocity characteristic and the strongly sinusoidal demodulated amplitude enables a simple and fast signal processing for the measurement of the mean flow velocity.

4.3 Circular 2 mm form

Optimising the vortex measuring system with regard to reducing the pressure loss caused by the vortex meter requires smallest bluff-body geometries. The minimisation of the bluff-bodies is not restricted by the form's stability but by the signals amplitude. As to the vortex structures the ultrasonic signal is as sensitive to the natural structures of the turbulent flow. The useful signals are covered by the noise of the streaming fluid. One of the smallest bluff-bodies that have been investigated in the test arrangement is a circular bar with a diameter of 2 mm.

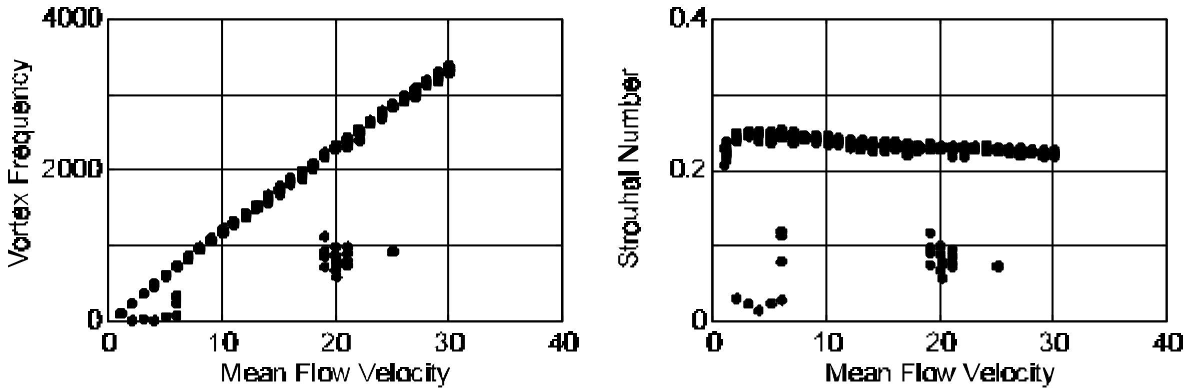

Figure 9: Vortex Frequency and Strouhal number versus mean flow velocity for the circular bluff-body with a diameter of 2 mm.

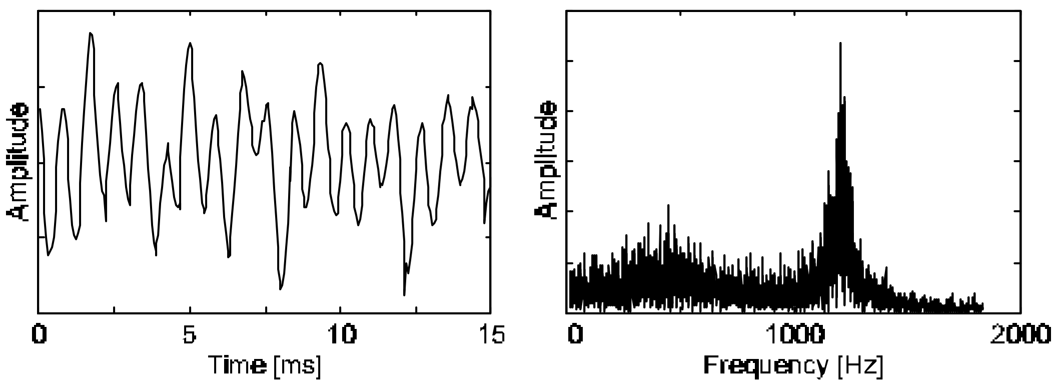

Figure 10: Timesignal and frequency spectrum of the circular bluff-body with 2 mm diameter at a velocity of 10 m/s.

The vortex frequency to mean flow velocity characteristic shows a very good linear behaviour with an extremely high upward gradient of 110 Hz per m/s.
The primary vortex frequency is overlaid by disturbances caused by the inhomogeneous structures of the turbulent flow. In the frequency spectrum the rate of lower frequencies increases.

5 CONCLUSION

The use of ultrasound in vortex shedding flow-meters is a powerful combination. The ultrasonic detection method requires a complete new design of the measuring system. The high sensitivity of the ultrasound barrier to the vortex structures needs a special shaping of the bluff-bodies so that they will generate a well defined vortex street suppressing any secondary effects. The high sensitivity enables the application of smallest bluff-bodies, too, with the advantage of less pressure loss. The combination of ultrasound and vortex metering requires simple and easily producible bluff-body geometries.

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AUTHORS:

Dipl.-Ing. Harald Windorfer, Prof. Dr.-Ing. Volker Hans
- Institute of Measurement and Control -
University of Essen, D-45117 Essen
Tel.: ++49 183 2969
Fax.: ++49 183 93 2969
Email: harald.windorfer@uni-essen.de
volker.hans@uni-essen.de