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DESIGN ASPECTS OF ULTRASONIC MEASUREMENT CONFIGURATION IN VORTEX SHEDDING FLOW-METERS

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Abstract: The high sensitivity of ultrasound on small turbulences leads to new considerations on the dimensioning of bluff-bodies and the positioning of the ultrasound beam. Smaller dimensions cause smaller pressure loss, higher vortex frequencies and higher signal resolution. The high sensitivity of ultrasound on modulating influences admits the measurement not only behind but also in front of the bluff-body with the advantage of better signal-to-noise ratio.

Keywords: bluff-body geometry, ultrasound, flow measurement

1   INTRODUCTION

Many problems in technical process require volume- or mass-flow data for its quantitative solution. Therefore many flow-measurement-systems basing on different principles have been developed. This paper presents investigations on vortex shedding flow-meter combined with an ultrasound barrier for detecting the vortex frequency.

Commercial flow-meter use a large variety of bluff body shapes depending on the kind of sensors for signal processing. Mostly pressure sensors are applied. Using the modulation of ultrasound by vortices new dimensions and shapes of bluff bodies have been developed adapted for simple and cost saving digital signal processing. The location of the ultrasound barrier was varied to get an optimised signal without any secondary effects for the whole velocity range. Actual investigations have shown that the fluid even in front oft the bluff body is pulsating with vortex frequency. This effect can be used for modulating the ultrasound, too.

2   SIGNAL PROCESSING

The ultrasound wave is modulated by vortices in amplitude and phase. The carrier frequency can be eliminated by undersampling [1,2]. 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 [3]. For that method well defined vortices must be generated. Neither secondary vortices are allowed nor any other disturbing effects. Therefore great importance has to be attached to the shape of the bluff body.

3   EXPERIMENTAL SETUP

The vortex flowmeter uses the separation of vortices at the backside of a body well known as the Karman vortex street. The frequency of the vortex street depends on the mean flow velocity and the shape of the bluff body. Preferably the vortex frequency should depend linearly on the mean flow velocity for a wide range of Reynolds number. 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:

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

(1)

The vortex frequency is defined by the separation of a pair of vortices.

In most commercial vortex flow meters the vortices are detected by pressure sensors fixed on the pipe wall or inside the bluff body. The sensitivity of pressure sensors is rather low. So the vortices must be strong, big dimensions of the bluff body are required. By the way of contrast ultrasound is

very sensitive to inhomogenities in the fluid. As mentioned it is modulated in phase and amplitude and signal processing for detecting the vortex frequency depends on well defined vortices but not on the pressure level primarily. These facts result in smaller bluff body dimensions and smaller pressure loss in the pipe.
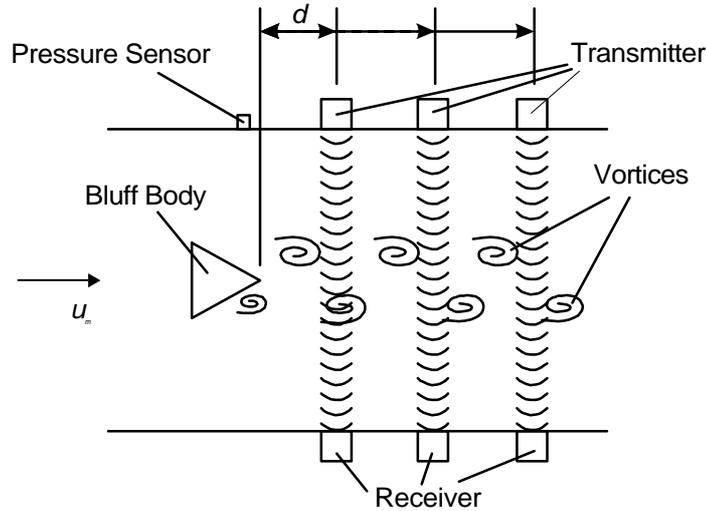

Figure 1: Principle of a vortex shedding flowmeter with three positions of ultrasonic vortex detection.

Present investigations were made on a test arrangement with a pipe diameter of 100 mm. The used testfluid was air at 1 bar static pressure. The test rig is fully automated and velocity controlled. The range of the mean flow velocity reaches from 1 m/s up to 30 m/s. The reference measurement was done by a calibrated turbine gas meter. For various configurations of the bluff bodies and the ultrasonic beam a special measuring chamber was built to investigate various types of bluff bodies and to vary the location of the ultrasonic beam. The distance d from the back side of the bluff body to the ultrasonic beam can be changed from direct contacting the shape up to 150 mm. The ultrasonic beam could be placed also direct in front of the bluff body. The present measurement was executed with a configuration of four ultrasound barriers in the measurement device. The first transmitter receiver pair was located close to the front of the bluff body, the second one right behind. The third and fourth barrier were placed each with a further distance of 40 mm. The signals were sampled at the same time to guarantee identical conditions and the same set of vortices at each of the ultrasonic barriers. The signal processing was done on a personal computer using a demodulation algorithm for the inphase and quadrature modulation, reconstructing phase shift and amplitude of the ultrasonic signal and detecting the characteristic vortex frequency.

4   MEASUREMENT RESULTS

Various shapes of bluff bodies have been tested with regard to their dominant frequency signal for the whole velocity range. In this paper the results of three different bodies are shown. For all off the presented shapes the vortex frequency to mean flow velocity ratio is highly linear.
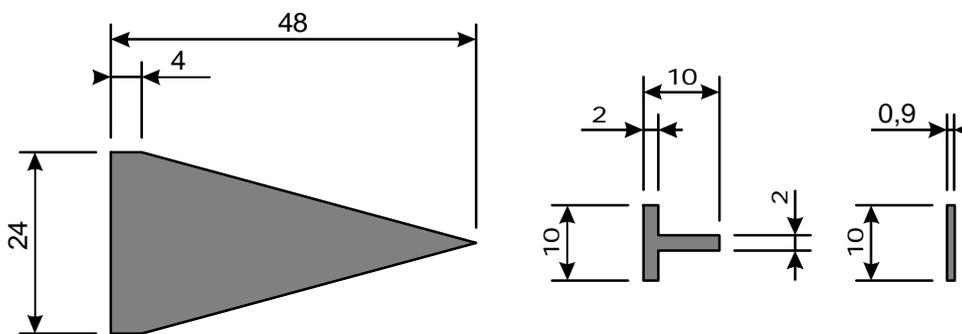

Figure 2: Design of the bluff body shapes.

4.1 Downstream measurement

4.1.1 Triangular Bluff Body

In Figure 3 a-c are shown the vortex frequency over the mean flow velocity for the triangular bluff body with a width of 24 mm and a length of 48 mm facing the flat side to the inflow. The three diagramms belong to different positions in which the ultrasonic barrier is located. The first beam is installed directly at the back side of the bluff body. It shows a very linear carateristic curve from zero up to 200 Hz. The second and the third measurements were made in a distance of 40 and 80 mm. Here also a lot of measured values correspond to the characteristic with a upward gradient of 6.67 Hzper m/s. All other measured values belong to another curve with a gradient, which is twice as large. In the third diagramm all values for higher velocity correspond to the upper straight line with the higher gradient.
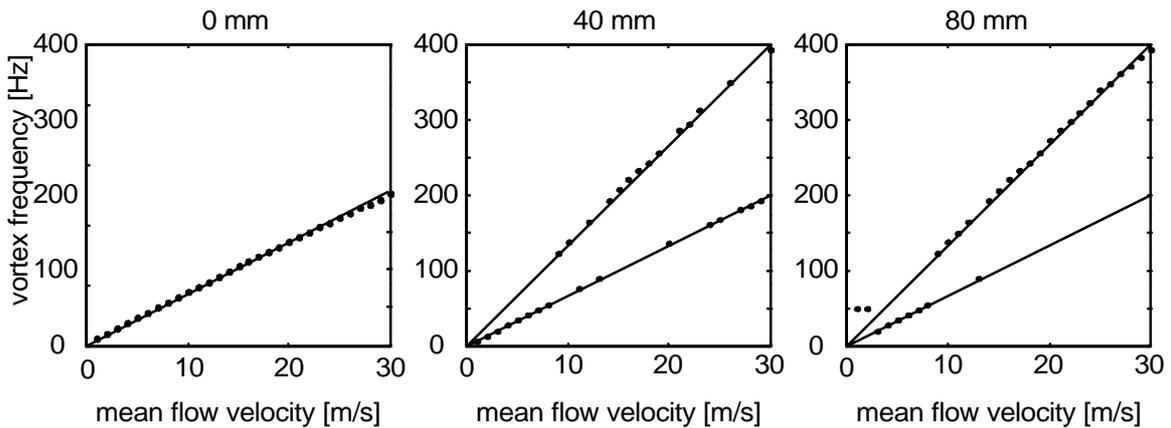

Figure 3: Vortex frequency over mean flow velocity for three different positions of the ultrasonic beam behind a triangular bluff body.

Detecting the vortices by a pressure sensor inside the wall at various distances to the bluff body leads to the same characteristic curve as shown in Figure 3a. But the error rate for low velocities is much higher as sampling the vortices by ultrasound.
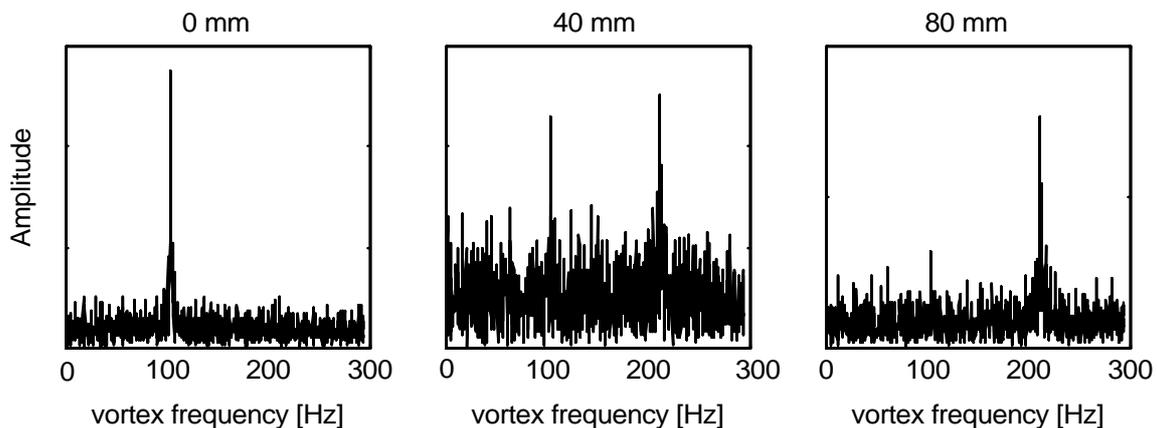

Figure 4: Frequency spectrum of amplitude modulation of a triangular bluff body, u=16 m/s.

In Figure 4 the frequency spectrum of the triangular bluff body is shown at a mean flow velocity of 16 m/s. The ultrasound barrier is positioned 0, 40 and 80 mm behind the body. The frequency spectrum of the first position shows a dominant frequency of about 100 Hz having a high signal to noise ratio. At a distance of 40 mm the amplitude of the ultrasonic barrier is also modulated with a frequency of 200 Hz. 80 mm behind the bluff body a frequency of 200 Hz is dominating. In general two frequency components occur. The magnitudes of these frequencies change depending on the position of the sensors and the mean flow velocity. Dissipation of the vortices are responsible for this effect.

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4.1.2   T-Shaped Bluff Body

Using a T-shaped bluff body with a width of only 10 mm for the vortex generation the vortex street downstream the profile is developed with much higher vortex frequencies for the same Reynolds numbers. This also means a much higher signal resolution.
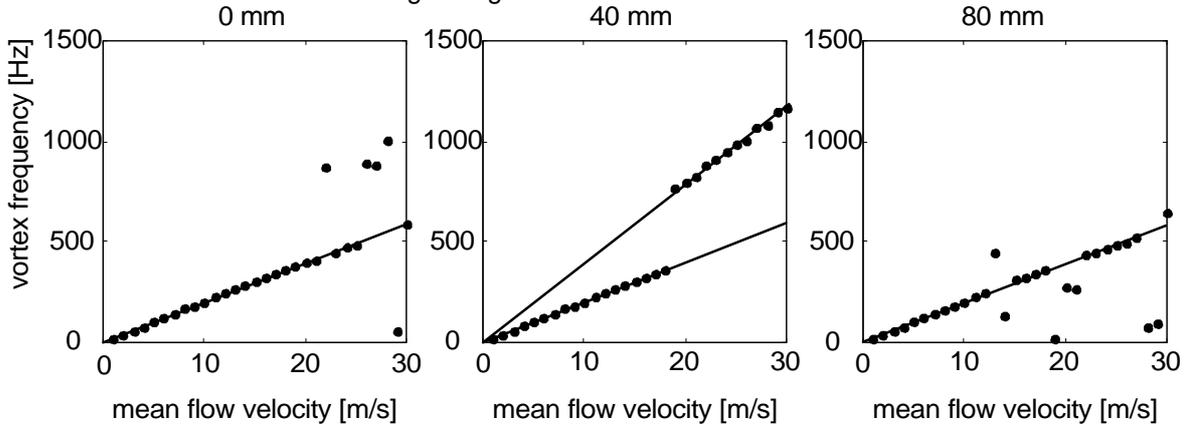
Figure 5: Vortex frequency over mean flow velocity for three different positions of the ultrasonic beam behind a T-shaped bluff body.

At a distance of 40 mm the characteristic curve shows a linear dependence of the vortex frequency on the mean flow velocity for a lower velocity range from zero up to 18 ms. All values belong to a straight line with an upward gradient of 20 Hz per m/s. At the upper velocity range from 19 to 30 m/s the vortex frequency also depends linearly on the mean flow velocity but the upward gradient has changed. All values belong to a straight line with an upward gradient which is twice as large. At the other positions of the ultrasonic beam, direct behind the bluff body and at a distance of 80 mm the diagram shows only one characteristic curve with the minor upward gradient but the measurement is disturbed for a higher mean flow velocity.
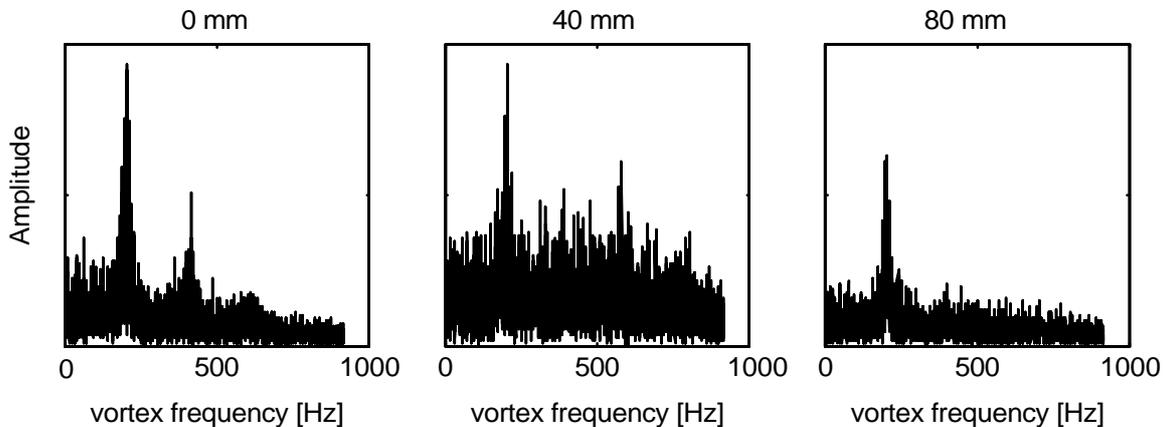
Figure 6: Frequency spectrum of amplitude modulation of a T-shaped bluff body, u=10 m/s.

At a mean flow velocity of 10 m/s in the frequency spectrum of the modulated amplitude there is one dominant maximum at about 200 Hz at all of the three positions (Figure 6) Sampling the Vortex frequency direct behind the bluff body the frequency spectrum of the demodulated signal shows a secondary maximum at about 400 Hz. The physical effects of two frequency components are the same as shown for the triangular bluff body.

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4.1.3 Rectangular Bluff Body

Measuring the vortex frequency downstream of a rectangular bluff body with a length of 0.9 mm and a width of 10 mm the behaviour can be noticed in a similar way as the triangular and the T-shaped one has shown.
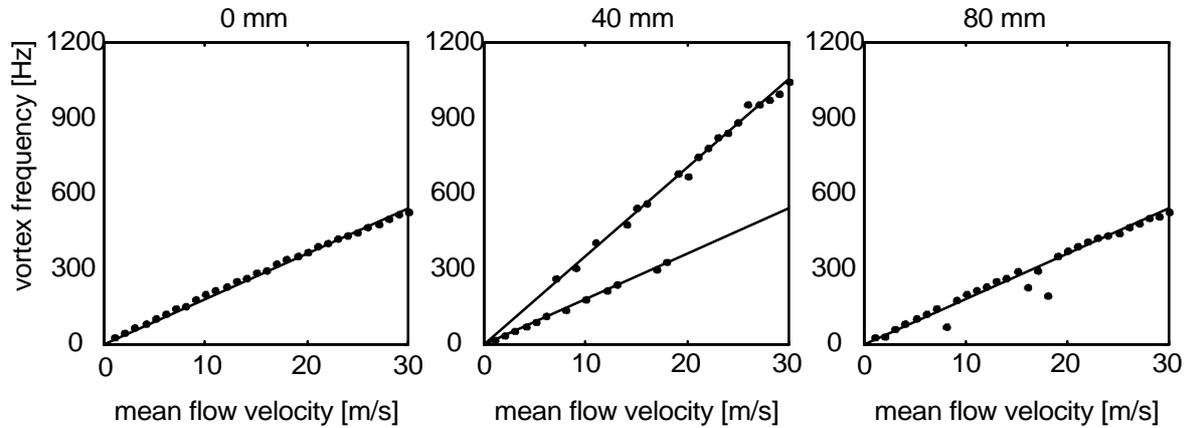

Figure 7: Vortex frequency over mean flow velocity for three different positions of the ultrasonic beam behind a rectangular bluff body.

Direct at the back of the body there is only one characteristic curve of the dominant frequency for the whole velocity range. The frequency spectrum for a mean flow velocity range of 18 m/s (Figure 8) shows only one maximum overtopping the noise. At a distance of 40 mm the ultrasonic barrier is modulated by two different frequencies. Both depend linearly on the mean flow velocity. The lower one corresponds to the defined vortex frequency. The higher one is caused by secondary effects.
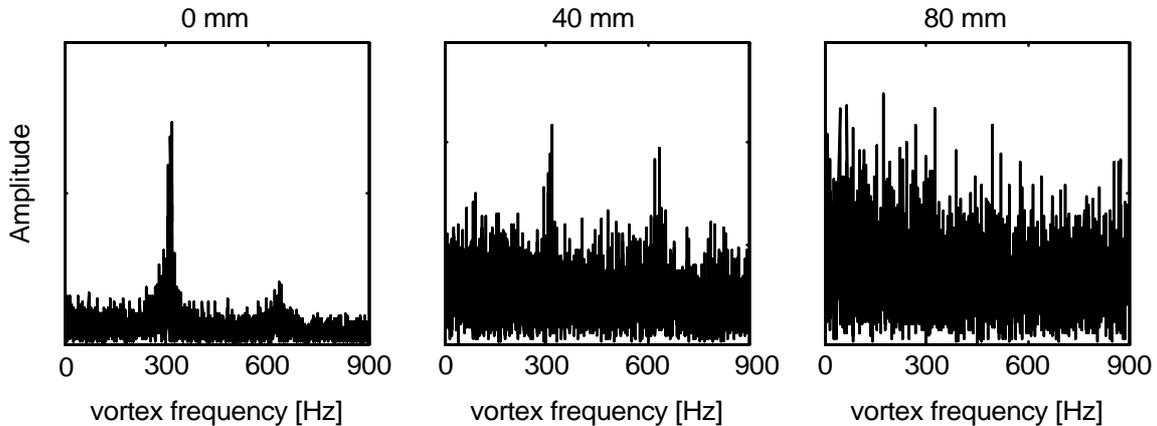

Figure 8: Frequency spectrum of amplitude modulation of a rectangular bluff body, u=18 m/s.

80 mm downstream of the bluff body the detection of the vortex frequency becomes unreliable. Most of the measured values belong to the characteristic curve but the signal to noise ratio has decreased to a minimum. The separating vortices dissipate so the noise of the turbulent flow becomes a stronger impact on the modulation as the vortex frequency.

4.2 Upstream measurement

Simulating the flow around the bluff body has shown a strong upwind influence of the separating vortices on the inflow [2]. So alternatively the ultrasonic beam was placed direct in front of the bluff body to measure the upwind influence of the vortices upstream the body. The upwind influence modulates the phase of the ultrasonic signal with the same frequency as it could be determined downstream.
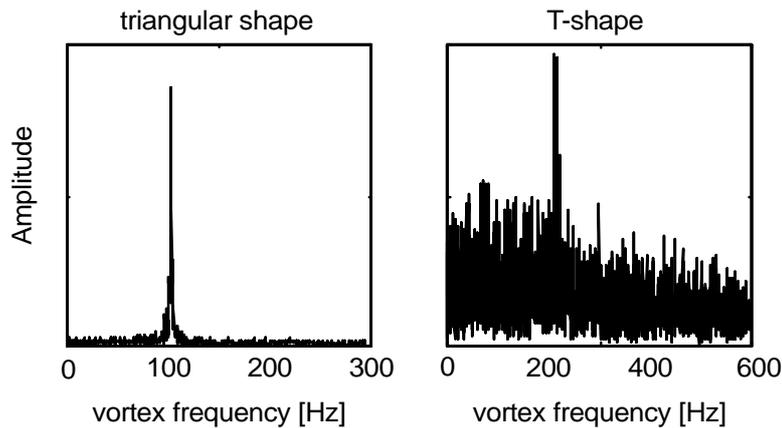
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triangular shape   T-shape

Figure 9: Frequency spectrum of phase modulation, measurement in front of the bluff body, u=13 m/s.

In Figure 9 the frequency spectrum of the triangular and the T-shaped bluff body is shown for the in front measuring configuration. In the frequency spectrum of the triangular bluff body there is only one dominant frequency. Secondary effects have no influence on the spectrum. The signal to noise ratio has increased. The frequency spectrum of the T-shaped body has also only one dominant frequency. The signal to noise ratio is much smaller but it enables also a reliable detection of the vortex frequency without secondary frequencies for the whole velocity range. For a lower mean flow velocity the detection of the vortex frequency can also be done in front of a small rectangular bluff body. But at higher flow rates the detecting of the vortices becomes unreliable. The frequencies caused by the noise of the turbulent inflow get a much higher intensity as the vortex frequency.

5   CONCLUSION

Using ultrasound in a vortex shedding flowmeter the configuration of the measurement device is not only done by improving the shape of the bluff body but also by selecting the ideal position of the ultrasonic barrier for the detection of the separating vortices. The location of the ultrasonic beam in the measurement device has a strong impact on the quality of the measurement result. A high signal to noise ratio is needed for a reliable signal processing. Placing the barrier close to the bluff body leads in most cases to reliable signals. In a distance of about 40 mm behind the bluff body the influence of secondary vortices increases and the characteristic curve switches from the vortex frequency to the double frequency. Very far behind the body there are also both frequencies in the spectrum and the error rate increases. The implementation of the ultrasonic beam in front of the bluff body leads to reliable results and a high signal to noise ratio for larger shapes. For smaller geometries the upward influence of the vortices is less strong and the detection of the vortices becomes more difficult.

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