

# CORRELATION OF ULTRASOUND AND PRESSURE IN VORTEX SHEDDING FLOW-METERS

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*Abstract: Using ultrasound for the detection of vortex frequency in a vortex shedding flow-meter is a powerful combination. The demodulated timesignal of the ultrasound differs from the known timesignal received by the pressure sensor. The optimisation of bluff-bodies for the generation of well defined vortices requires a visualisation of the vortex street and the correlation of pressure and ultrasound for the enlightenment of the differences. Measuring the time-dependent pressure plot around the bluff body shows the correlation between the modulation of the ultrasonic signal and the pressure structures separating from the bluff body.*

*Keywords: Vortex Flow-Meter, Pressure Plot, Ultrasound*

## 1 INTRODUCTION

The vortex frequency measurement system is based on the well known relationship of mean flow velocity and vortex frequency. Most commercial vortex flow-meters use pressure sensors fixed inside the pipe wall or inside the bluff body for the detection of vortices. This technique requires strong pressure fluctuations generated by bluff bodies with large dimensions [1]. The vortices can be sampled by an ultrasonic barrier in a short distance behind the bluff body, too. The ultrasound is modulated in phase and amplitude [2]. In contrast to the pressure measuring method the ultrasonic measurement system is much more sensitive to the vortex structures separating from the backside of the bluff body. This leads to the advantage of smaller geometries and from this follows less pressure loss [2]. Investigations on the ultrasonic signal have shown differences between the two measuring techniques. The development of special shaping for the bluff body in the ultrasonic measurement system becomes necessary. The optimisation of the bluff-body requires the investigation of the vortex street downstream the body and the parameters of separating vortices. Some investigations were made by simulating the flow [3] and visualisation of the simulated parameters. Small pressure sensors enable the examination of the pressure inside the vortex street. To show the correlation between the vortex structures and the ultrasonic beam the whole time-dependent pressure field around the bluff body was measured and reconstructed to a pressure plot.

## 2 MEASUREMENT-PRINCIPLE

Vortex flow-meters use the separation of vortices at the backside of a bluff-body that is flowed around for the calculation of the volume flow. The bluff-body persuades the pipe perpendicular to the axis. The vortices separate periodically from both sides of the body. This phenomenon is well known as the Karman vortex street that develops downstream the body. Simple and cost saving signal processing require well defined vortex structures and a regular vortex frequency for a reliable measurement system. Special shaping of the bluff-body has an influence on the linearity of the characteristic of vortex frequency  $f$  versus mean flow velocity  $u_m$  expressed by the dimensionless Strouhal number:

$$Sr = \frac{f \cdot d}{u_m} . \quad (1)$$

where  $d$  is the diameter of the bluff body. The vortex frequency is defined as the frequency given by a pair of vortices, one from the upper side, one from the lower side, separating from the bluff-body.

In between the two measuring principles pressure and ultrasound there are many strong differences. The pressure sensor inside the wall samples directly one physical parameter: the pressure of the fluid at one discrete location. A capable application of the sensor minimises the influence of other secondary effects.

The ultrasound measurement principle is an integrating method along the ultrasonic beam. Various structures along the profile have an influence on the modulation of the carrier frequency. There are not only effects adding each other but also those mutually influencing or nullifying in the receipt signal. .

Further more there is a more complex interrelation between the fluid parameters and the modulation components.

As mentioned above ultrasound is modulated in phase and amplitude. Both modulation components include various effects caused by the fluids parameters. The phase modulation is a measure for the transmission time of the sound waves. It is primarily caused by the velocity components of vortices along the ultrasonic beam and the local speed of sound. There is a phase shift caused by the local speed of sound along the ultrasonic ray, too. The amplitude modulation reflects the intensity of the ultrasound at the receiver. Not only an attenuation can be noticed in the timesignal of the amplitude but also an amplification pushing the amplitude up over the value in undisturbed state. As influencing factors refraction of sound and drift of the ultrasonic beam are mentioned.

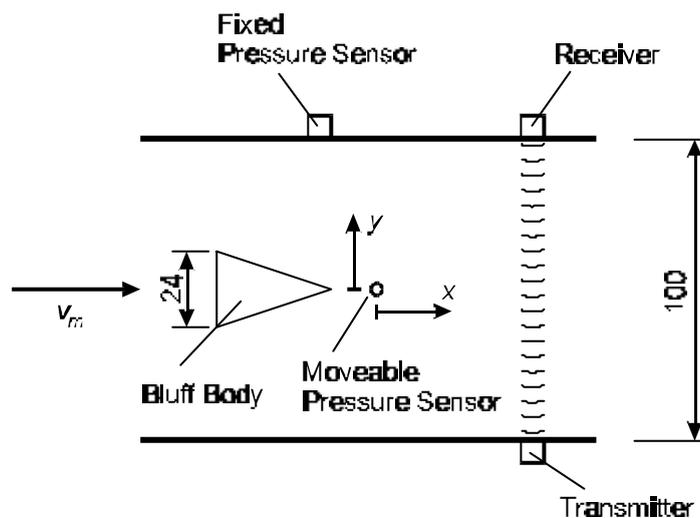
### 3 MEASUREMENT-SETUP

The present measurement was done in a test arrangement with a pipe diameter of 100 mm. The flow is velocity controlled in a range from 1 m/s up to 30 m/s. A turbinegasmeter with a deviation of less than 1 percent is used as reference measuring system for the velocity control. Furthermore each measuring point was sampled at the same velocity calculated by the measured vortex frequency to ensure equal flow conditions that are prerequisite for the signal processing.

The pressure sensor was moved in a two dimensional layer perpendicular to the bluff body on the layer that includes the pipe axis (Figure 1). The investigated area ranges over 80 x 80 mm. The backside of the bluff-body reached for 20 mm into the measuring field. The head of the pressure probe was orientated parallel to the bluff-body to ensure that the velocity components in the measurement layer have no influence on the pressure signal.

A second pressure sensor was included into the pipe wall used as a reference to shift each of the measurements into the right phase angle and create the pressure plot.

The ultrasonic beam was inserted at the physically distance  $x=50$  mm, 30 mm behind the bluff body.

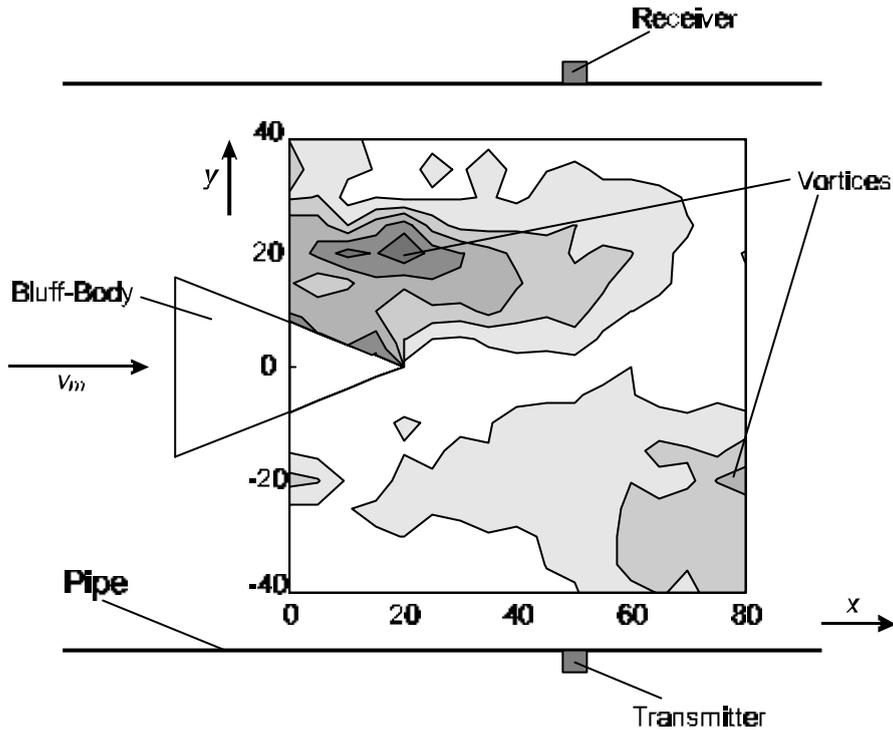


**Figure 1:** Schematic measurement set-up.

In this paper the measurement results are shown for a triangular bluff-body that is used in many commercial vortex shedding flow-meters combined with pressure sensors. The body has a width of 24 mm and a length of 48 mm. The used pressure sensors were miniaturised probes with a diameter of only 1.6 mm to have least reaction on the flow and the vortex street.

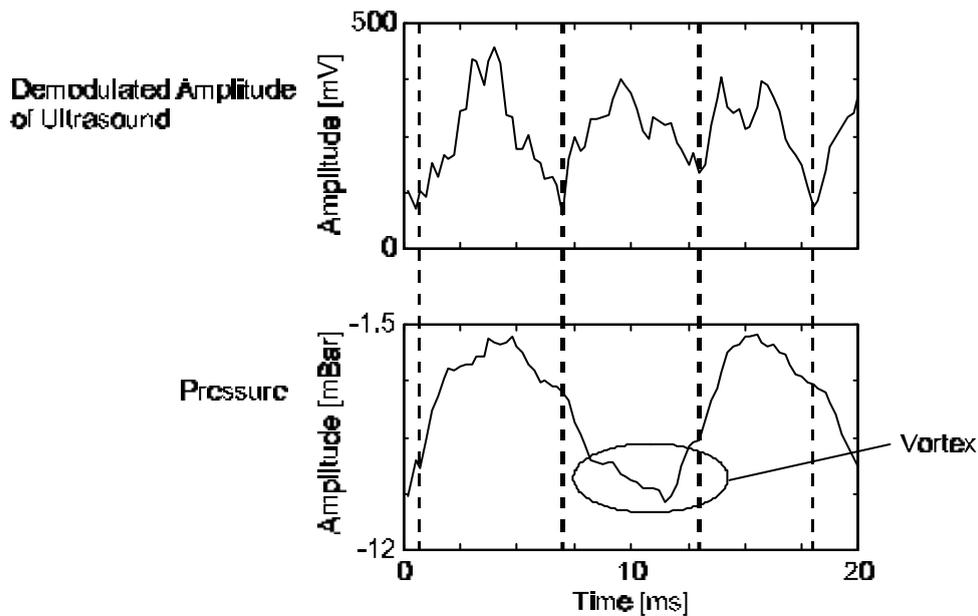
### 4 MEASUREMENT RESULTS

The current measurement was done at a mean flow velocity of 15 m/s. In figure 2 is shown the vortex measurement configuration with the enclosed measurement layer with the pressure plot downstream the bluff body. The pressure signal at each discrete point was calculated by the time average of the periodic signal over 128 measurements to suppress the influence of the structures of the turbulent inflow. The correct phase relation of the samples was ensured by use of a second pressure sensor as reference. The pressure is presented in an isobar plot. Light grey equals high pressure, dark grey equals low pressure.



**Figure 2:** Measured pressure plot of a Karman vortex street behind a bluff body.

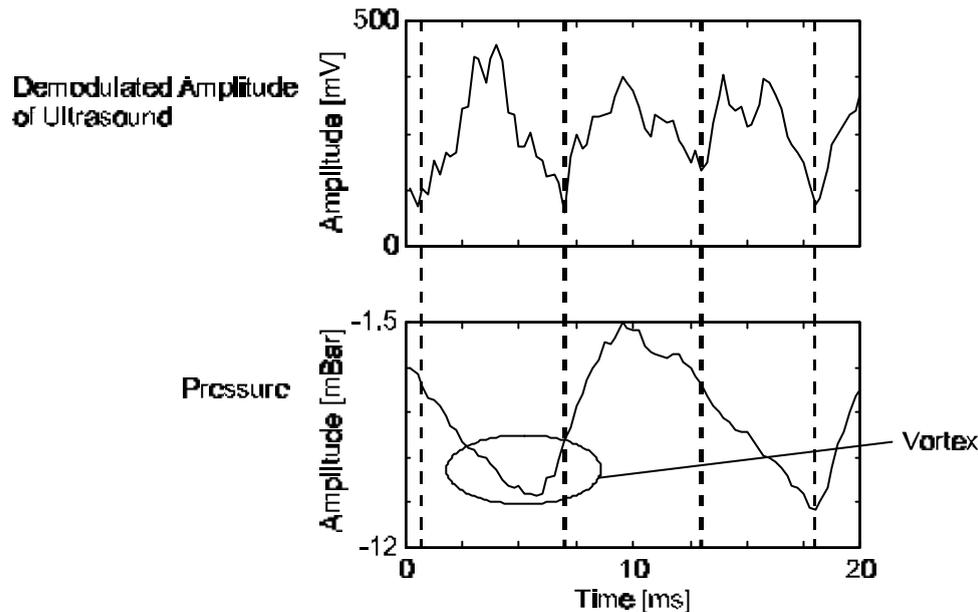
The picture shows only a few details of the vortex street because of the low resolution of only 17 x17 points and the reaction of the structures on the pressure sensor but there are still several characteristics played back. The vortices enter the image at the left side in the height of the upper and lower separation point at the front side of the bluff-body. They increase their speed after fully separation from the body and move towards the pipe walls. At the backside of the body develops a very high pressure gradient while the separation process of the vortices observable by four isobars ending at one point at the backside edge of the bluff- body. Not only the pressure plot presents information about the vortex street but also the comparison of the ultrasonic and pressure timesignals.



**Figure 3:** Top: Timesignal of the ultrasonic barrier at the position  $x=50$  mm. Bottom: Timesignal of a pressure sensor at the location  $x=50$ mm,  $y=20$  mm.

Figure 3 shows in the upper picture the averaged timesignal of the demodulated amplitude of the ultrasonic signal at a velocity of 15 m/s.

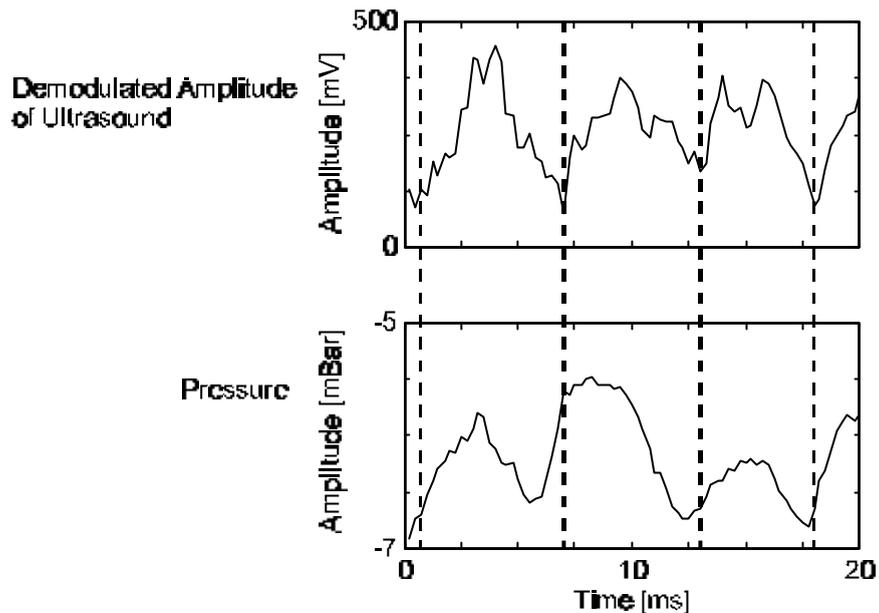
In the lower picture the pressure timesignal of one position of the sensor is plotted. The probe was placed at  $x=50$  mm and  $y=20$  mm. The coordinates refer to Figure 2. At this location the maximum of the upper vortices cross the ultrasonic beam. By comparison the amplitude of the ultrasonic signal shows more influences of secondary effects in the timesignal. The frequency of the ultrasonic signal is twice as high as the measured pressure signal. This is effected by the two different measurement principles. The pressure sensor detects only the pressure fluctuations passing the location of measurement. The signal is caused by the vortices in the upper half of the pipe. The calculated frequency equals the vortex frequency per definition. The ultrasonic signal integrates along the beam and detects both vortices at the upper and lower half of the pipe. The resulting frequency is twice as high. The minimum of the amplitude or the maximum of amplitude modulation of ultrasound is simultaneous to the rising and falling edge of the pressure signal marked by dotted lines. At that time the pressure gradient reaches it's maximum.



**Figure 4:** Top: Timesignal of the ultrasonic barrier at the position  $x=50$  mm. Bottom: Timesignal of a pressure sensor at the location  $x=50$ mm,  $y=-20$  mm.

In Figure 4 is shown the timesignal of the demodulated amplitude of the ultrasonic signal in the upper diagram again. In the lower picture is plotted in correlation to the ultrasonic signal the timesignal of the pressure at the position  $x=50$  mm and  $y= -20$  mm. This location is on the ultrasonic beam in a distance of 30 mm to the transmitter where the vortices of the lower half of the vortex street cross the ultrasonic beam. The phase angle of the pressure signal in relation to the first pressure signal in figure 3 has shifted for 180 degree. As shown in figure 3 the maximum of amplitude modulation of ultrasound is simultaneous to the highest pressure gradient.

The pressure plot in figure 5 in the lower picture shows the timesignal of pressure integrated along the ultrasonic beam in correlation to the amplitude modulated ultrasound. The timesignal shows a frequency which is twice as high as the vortex frequency detected by the pressure sensor at only one location but with much smaller amplitude. Based on the fact that the measuring chamber is symmetric to the pipe axis in the measurement layer the vortex street develops symmetrically, too, with a phaseshift of 180 degree of the vortices. In theory the result of the addition of two sinusoidal signals with a phase angle of 180 degree is zero. The remaining periodic part in the integrated signal shows the non-sinusoidal part of the vortex pressure signal. The smoother signal progression of the pressure signal at the discrete measurement locations and of the integrated pressure signal in relation to the ultrasound shows the higher sensitivity of ultrasound to secondary effects.



**Figure 5:** Top: Timesignal of the ultrasonic barrier at the position  $x=50$  mm. Bottom: Timesignal of pressure integrated along the ultrasonic beam

## 5 CONCLUSION

The pressure measurement inside the fully developed vortex street gives a first insight into the correlation between ultrasound and pressure in a vortex shedding flow-meter. The picture with a rather low resolution contains first information of the effects of the modulation process. In the timesignals the non-linear connection of pressure and sound was shown which is caused by the integrating measurement principle of the ultrasonic technique.

Further measurements with a higher signal resolution in amplitude, time and in range will improve the quality of the pressure plot and give more information of the correlation.

## 6 ACKNOWLEDGEMENTS

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## 7 REFERENCES

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