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INFLUENCE OF VORTEX STRUCTURES ON PRESSURE AND ULTRASOUND IN VORTEX FLOW-METERS

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Abstract: Designing bluff-bodies for the ultrasonic vortex frequency measurement almost leads to very different geometries as they are used for the vortex detection method by pressure sensors. In some cases they have the same form but they are facing their backside to the inflow. The developing process is not only restricted by the demand for a constant Strouhal number and a strong linear dependency of the vortex frequency to the mean flow velocity but also by the vortex detection method.
Keywords: ultrasound, flow measurement, bluff-body geometry

1 INTRODUCTION

Many flowtechnical problems need for their quantitative solution a volume or a mass flow determination. For this purpose different procedures of flow measurement were developed. The actual research deals with vortex frequency flowmeters, which determine the vortex frequency on the basis of modulated ultrasonic signals. For the demodulation of the ultrasonic signals digital procedures are developed, which enable a simultaneous demodulation of amplitude and phaseshift of the carrier signal. In commercial vortex shedding flowmeter different forms of bluff bodies are used whose shape is determined by the application of pressure sensors. With the up-to-date used ultrasonic measuring procedure the bluff body shape is more freely selectable, it is only limited by the request to stability and oscillation. Measurements with ultrasonic receivers at conventional bluff bodies generate only very unreliable signals, so that the investigation of further geometries was necessary. A reliable signal processing is only possible with optimised bluff body geometry [1]. Different bluff body forms were examined with regard to a simple digital signal processing. In this work the different influence of the bluff body's shape on the detection method, ultrasound and pressure sensor is presented. The research is assisted by numerical simulations which are also presented.

2 VORTEX SHEDDING FLOWMETER

If a body is flowed round by a fluid with sufficiently large flow rate the fluid separates from the surface at the backside. A well-known phenomenon is the Kármán vortex street, which develops downstream the body. As a function of the Reynolds number periodically vortices with a certain frequency separate alternating from both sides of the body. The dependence of the vortex frequency f on the mean flow rate v_m and the width of the bluff body d is represented by the dimensionless Strouhal number:

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

The Strouhal number is also a function of the Reynolds number. If the Strouhal number can be kept constant over the interesting velocity range by special shaping of the bluff body, the flow rate can be determined only by the vortex frequency.

2.1 Measurement with Pressure Sensors

The measurement of the vortex frequency can be done by different physical procedures [2]. Into most commercial vortex flowmeter for the determination of the vortex frequency pressure sensors are inserted. The sensors are fixed to the tube wall or to the bluff body. For a simple signal processing bluff bodies are developed, which generate a strong pressure signal with only one dominant frequency. Due to the small sensitivity of the pressure sensors in vortex frequency measuring instruments bluff bodies with large dimensions are used. To generate reliable signals with a sufficient amplitude usually bluff bodies with width of 24 percent of the pipe diameter are required [3]. These large dimensions lead to a very high pressure loss in the pipe flow.

2.2 Measurement with Ultrasound

Just as the measurement of the vortex frequency with pressure sensors inside the pipe wall also the detection of the vortex structures is possible by an ultrasonic barrier. Common systems use the transit time principle or the phase modulation of an ultrasonic barrier [2], which is located in a short distance behind the bluff body perpendicularly to the direction of flow and to the bluff body (Figure 1).

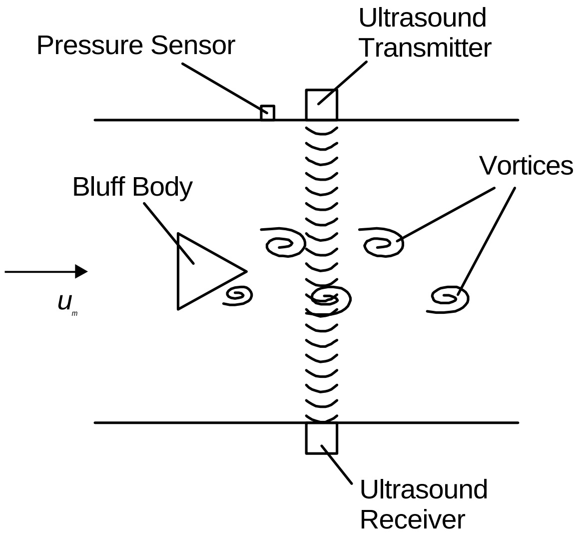

Figure 1: Principle of vortex shedding flowmeter.

3 SIMULATION

The numerical algorithm employed uses the three-dimensional, time-dependent full Navier-Stokes equations describing the conservation of mass, momentum and energy of the flow.

The program is based on the finite-volume formulation, using a cell-centered organisation of the control-volumes. The spatial discretisation is carried out with the help of Roe's Flux Difference Scheme, a Godunov-type method providing an approximate solution of the Riemann problem on the cell interfaces.

The method has been proved to be very accurate and effective in the simulation of low Mach number viscous flows.

Upwind-biased differences are used for the convective terms, central differences for the viscous fluxes.

Starting with a constant initialisation of the scalar variables and body-fitted velocity components, the integration in time is carried out by a modified explicit Runge-Kutta time stepping as well as, optionally, an implicit Approximate-Factorisation method (AF) or Symmetric-Gauss-Seidel (SGS) scheme.

The simulations were carried out on structured grids. The mesh points were arranged according to an algebraic distribution and clustered at the solid walls to ensure enough gridpoints in the boundary layers. The domain was divided into several blocks to make the formulation of the boundary conditions and handling a complex geometry easier. Furthermore, the Multiblock-structure was necessary to compute the flow on parallel computers. For the inlet and outlet planes, the subsonic one-dimensional non-reflecting boundary conditions were implemented. They were based on the Riemann invariants normal to the pipe cross-section. These conditions made the pressure waves and other disturbances run out of the domain without reflection. The interzonal boundary conditions provided the data exchange among the blocks; at the walls, the no-slip solid viscous wall boundary conditions were used.

4 MEASUREMENT RESULTS

Various shapes have been tested with regard to their linear behaviour in pressure and ultrasonic signal. In this paper the results of a triangular bluff body with a width of 24 mm and a length of 48 mm (Figure 2 and 4) and a T-shaped bluff body with a width and length of 10 mm (Figure 6 and 8) are presented. Both bluff bodies were investigated for an orientation in both directions in the common way as it is used in commercial flowmeters facing the flat, wide side to the inflow and the other way round.

For this paper all measurements were done in a test arrangement with a pipe diameter of 100 mm. A turbine gasmeter is used as a reference with a deviation within 0.5 %. The flow is velocity controlled from 1 up to 30 m/s. The used test fluid was air at 1 bar static pressure. The used ultrasonic measurement system is based on the inphase and quadrature modulation sampling for the demodulation of phase shift and amplitude of the ultrasonic carrier frequency. The signal processing was done with a personal computer. The simulated timesignal was calculated by the velocity component perpendicular to the pipe axis along a straight line at a position behind the bluff body that corresponds with the ultrasonic beam in the measurement system.

4.1 Triangular Bluff Body

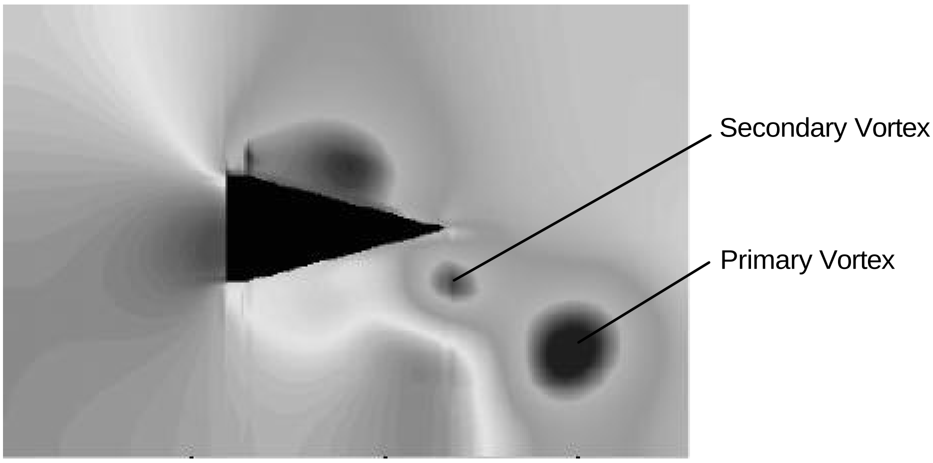

Figure 2: Pressure field of a simulated vortex street of a triangular bluff body with a width of 24 mm used in the common way

In Figure 2 the simulated pressure plot of a vortex street behind a triangular bluff body is shown. The pressure plot was selected for the presentation of the simulation results because of the best visualisation. The velocity field circulates clockwise and anticlockwise around the pressure structures. The vortex at the lower side has fully separated but at the same side a secondary smaller vortex is developed. This secondary vortex leads to a secondary maximum in the simulated time signal (Figure3). The same secondary effect can be noticed at the measured phase shift of the ultrasonic signal. The pressure signal measured in the tube wall is not effected by the secondary vortex.

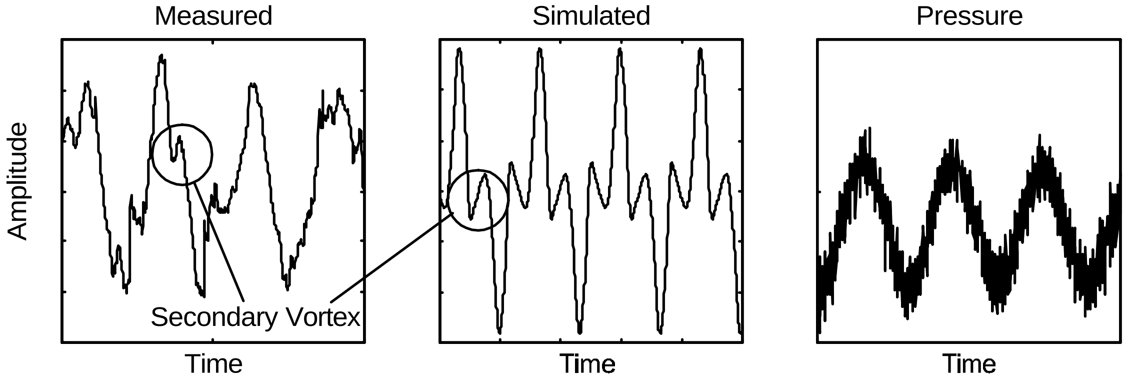

Figure 3: Measured ultrasonic phaseshift and simulated timesignal of a triangular bluff body used in the common way.

The triangular bluff body facing the flat side to the inflow is an optimised shape for many commercial vortex shedding flowmeters using pressure sensors for the detection of the vortex frequency. The same shape used for the measurement system combined with ultrasound leads to less good signals. The secondary effect on the ultrasonic signal prevents a simple digital signal processing.

Using the same shape turned around for vortex generation the measurement and the simulation leads as expected to very different results with large benefit for the ultrasound measurement method.

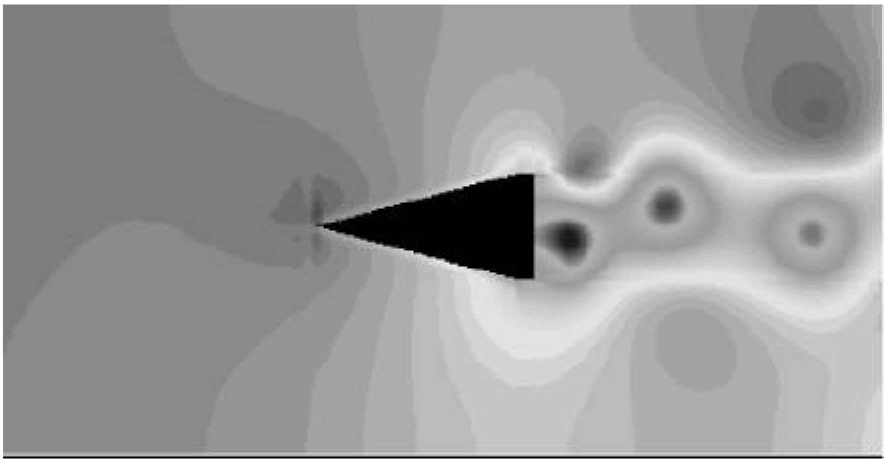

Figure 4: Pressure field of a simulated vortex street of a triangular bluff body with a width of 24 mm facing the edge to the inflow

In Figure 4 the pressure plot of the triangular bluff body facing the edge to the inflow is shown. The vortices separate at the backside without the development of any secondary vortices. The vortex street is fully developed in the middle of the pipe. The pressure fluctuations at the wall are very small so that a detection of the vortex frequency by pressure sensors becomes impossible. In the simulated timesignal there is no secondary effect visible. The measured timesignal of the ultrasonic phaseshift shows also a very sinusoidal behaviour without the influence of secondary effects but the amplitude variates strongly. The use of the triangular bluff body in the two different directions shows the influence on both detection methods ultrasound and pressure sensors. The pressure sensor requires a strong pressure signal, secondary effects have no influence on the signal. An ultrasonic barrier is much more sensitive to secondary vortices it requires well defined structures without any secondary effects.

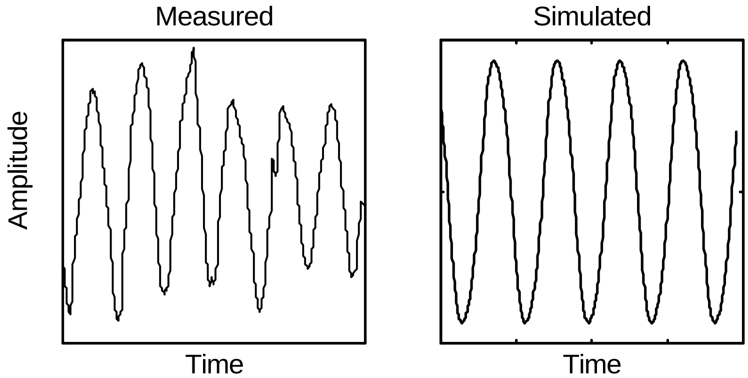

Figure 5: Measured and simulated timesignal of the ultrasonic phaseshift of a triangular bluff body facing the edge to the inflow.

4.2 T-Shaped Bluff Body

Another type of bluff bodies used in commercial vortex shedding flowmeters combined with pressure sensors is the T-shaped form. For ultrasonic measurement the width can be decreased to only 10 mm while maintaining the signals quality.

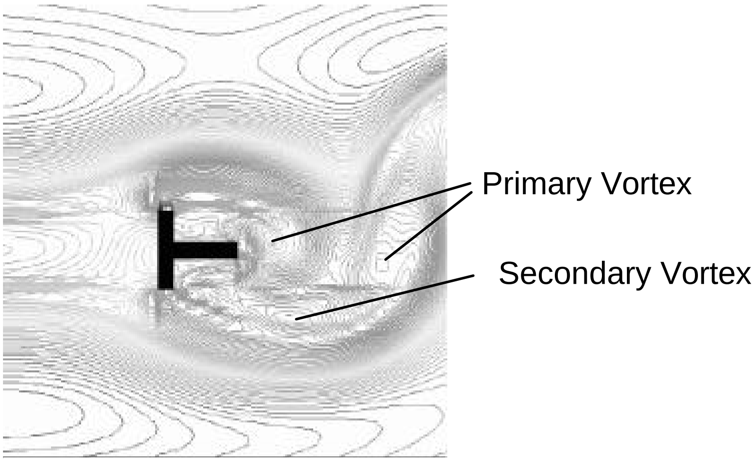

Figure 6: Density plot of a simulated vortex street of a T-shaped bluff body with a width of 10 mm used in the common way. It is only displayed the center part of the pipe.

In Figure 6 the density plot of a T-shaped bluff body used in the common way facing the flat side to the inflow is shown. The picture is zoomed into the center part of the pipe for a better visualisation. The simulation is done for the whole diameter but the flow near the wall is hardly affected by the vortices. Also parallel to the primary vortex a secondary vortex of very low amplitude is separating. The measured timesignal of the phaseshift of the ultrasonic signal shows the influence of the secondary vortex similar to the signal of the triangular bluff body. The simulated timesignal is not affected by the secondary vortex. The low influence can be explained by the simplification of the ultrasonic transmission.

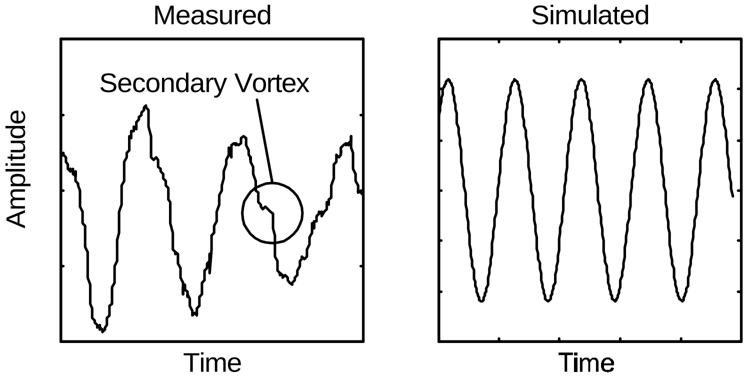

Figure 7: Measured and simulated timesignal of the ultrasonic phaseshift of a T-shaped bluff body used in the common way.

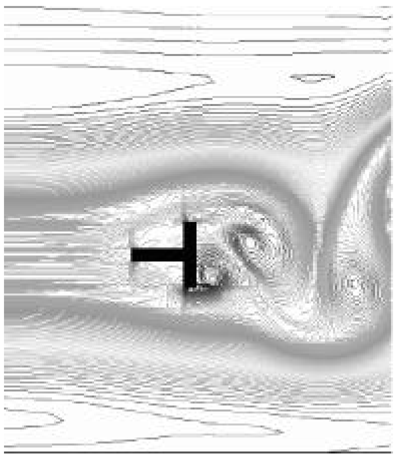

Figure 8: Density plot of a simulated vortex street of a T-shaped bluff body with a width of 10 mm facing the bar to the inflow. It is only displayed the center part of the pipe.

As shown for the triangular bluff body the T-shaped form generates well defined signals for the ultrasonic detection method, too, if it is used the other way round. The density plot (Figure 8) shows only primary vortices with a strong restriction to each other. The simulated and the measured time signals (Figure 9) show a very well defined sinusoidal behaviour that is not disturbed by any secondary vortex. The amplitude modulation of the phaseshift is much smaller as shown for the triangular bluff body. A pressure signal at the pipe wall could not be measured because of the very small dimensions of the body.

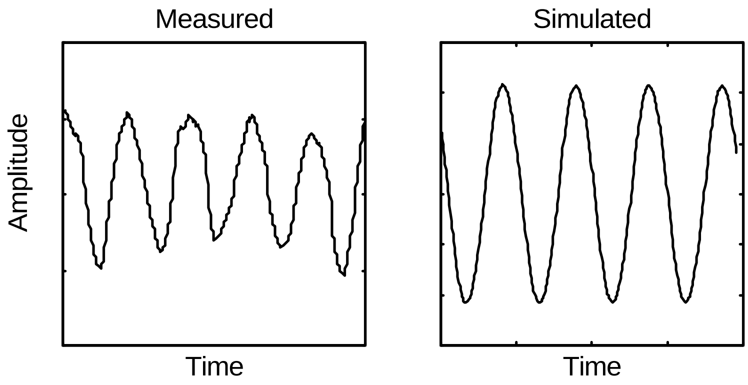

Figure 9: Measured and simulated timesignal of the ultrasonic phaseshift of a T-shaped bluff body facing the bar to the inflow.

5 CONCLUSION

The different detection methods ultrasound and pressure sensors for the vortex frequency require often contrary shaping of the bluff bodies. Shapes optimised for the pressure detection method are not automatically applicable for ultrasound.

The major advantage of ultrasound in vortex flowmeters in comparison to pressure sensors is the much higher sensitivity. The ultrasonic signal is disturbed much more by secondary effects than the pressure signal but a special shaping of the bluff bodies leads also for ultrasound to a very strong signal without secondary effects for a simple and cost saving signal processing.

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