

Influence of the variation of the angle of incidence in vortex-shedding metering

Oliver Ricken, Volker Hans

(Institute of Measurement and Control, University Duisburg-Essen, Schuetzenbahn 70, 45117 Essen, Germany)

Abstract In vortex-shedding metering not only the shape of a bluff body is important but also the angle of incidence of the bluff body plays a major role in connection with production tolerances and unsymmetrical inflow. In the present investigation the influence of different angles of incidence of bluff bodies on the measured vortex frequency and the flow around the bluff body was studied by using ultrasonic barriers and rectangular and triangular shapes with 1:1 ratio of width to length for the bluff body. It became apparent that the vortices separate at different edges by inclination of the bluff body. The results were ensured by numerical simulations.

Keywords: vortex-shedding flow metering, ultrasonic, bluff body, angle of incidence

1. Introduction

Vortex meters detect flow velocity by measuring the frequency of the vortices, separating from a bluff body [1]. The frequency of these "Karman" vortices is directly proportional to the mean velocity of the moving fluid, independent of gas or liquid. In commercial vortex shedding meters the angle of incidence varies because of production tolerances. This raises the question of the influence of different angles of incidence of the bluff body on the measured frequency and on the flow around the bluff body. In addition it can be a hint of the behaviour of the bluff body under unsymmetrical flow. The frequency of the vortices usually is measured with pressure sensors which are fitted in the side of the pipe or the side of the bluff body. This kind of measuring only covers one or two points of the flow and there is no virtue in doing that for basic investigation of the whole flow. The measurement by using the influence of the flow on an ultrasonic beam covers the range of one diameter of the flow and makes it possible to take the whole width of flow into account. Because of this the investigations were carried out by using an ultrasonic transmitter and an ultrasonic receiver placed on the opposite side of the pipe perpendicular to the inflow and the bluff body. The ultrasonic beam is modulated by the normal turbulence of the turbulent flow and superposing Karman vortices in phase and amplitude [2]. To eliminate the carrier frequency of the ultrasonic beam an electronic undersampling technique [3] is used. To extract the phase and amplitude signal an electronic Hilbert transformation is carried out before the data are evaluated on a personal computer.

2. Measurement set up

For the investigation of the influence of different angles of incidence, a triangle bluff body with the width / height ratio of 1:1 was applied, Fig. 2-1. The

bluff body is variable in its angle of incidence. In the first arrangement the flat side of the bluff body is facing to inflow, Fig. 2-2 upper graphic. This is called the conventional set up because it is the mostly used set up for commercial vortex flow meters. A so-called unconventional set up is shown in the lower graphic in Fig. 2-2. and it is known for its better resolution in frequency than the conventional set up. For the conventional as well as for the unconventional set up the angle of incidence has been varied from 0° to 26.5° . The maximum angle equals to the angle if the long side is parallel to the flow. The diameter of the pipe is 100 mm. The arrangement of the bluff body and the ultrasonic beam in the pipe is shown in Fig. 2-3.

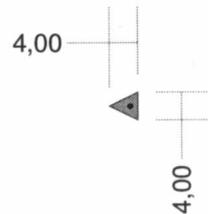


Fig. 2-1 Dimensions of the bluff body

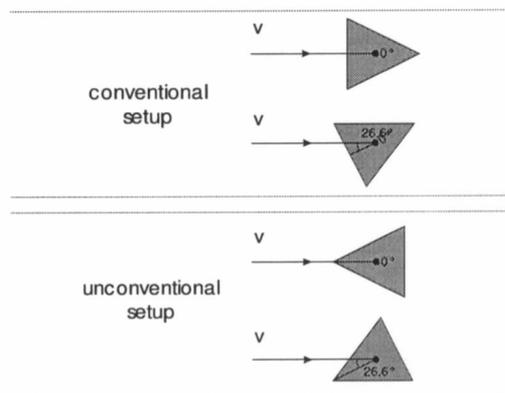


Fig. 2-2 Different set ups of the bluff body

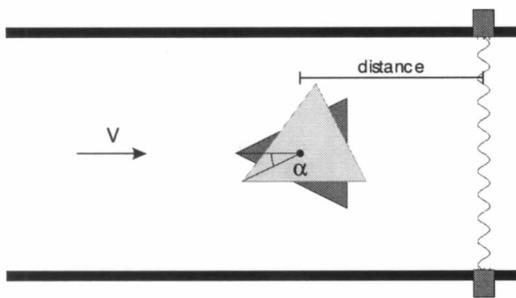


Fig. 2-3 Arrangement of the bluff body and the ultrasonic beam

The investigation of the vortices is made by three pairs of ultrasonic transmitters and receivers in different distances to the bluff body (75mm, 135mm, 165mm). Measurements were made for flow velocities from of 2 m/s to 25 m/s for each angle of incidence. For the measurements the amplitude modulation of an ultrasonic 220 kHz carrier caused by the vortices is evaluated [4]. The vortex frequency is detected by the maximum in the frequency domain of the amplitude signal.

3. Theoretical Approach and Experimental results

The Strouhal-Number is defined as

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

where v represents the mean velocity of the flow and d represents the characteristic diameter respectively the width of the vortex street or the projection area of the bluff body while f stands for the frequency of vortices.

For a geometrically similar body the Strouhal-Number is constant for different diameters. So the frequency only depends on the diameter while the velocity is constant. It doesn't matter if the velocity is increased or the diameter is decreased as long as the Reynolds-Number is in the range where the Strouhal-Number is constant. If the Strouhal-Number is considered to be constant while the projection area of the bluff body is changing and the velocity keeps constant the frequency only depends on the projection area, yielding to

$$f = \frac{Sr \cdot v}{d \cdot \cos(\alpha)} \quad (2)$$

First measurements were carried out with a rectangular bluff body because of its simple shape.

The size of the bluff body is 10 mm by 2 mm with the wide side to the inflow. In Fig. 3-1 the results of investigation of this bluff body is shown.

In Fig. 3-2 the frequencies under consideration of equation (2) calculated for the velocities of 2m/s and 25m/s in comparison to the experimental results are shown. It is obvious that the frequency not only depends on the projection area of the bluff body in flow direction. But for lower changes of the angle there is a good congruence with the experimental results. The reason of the deviations is the change of shape that is shown to the inflow so that the geometric similarity no longer is given. The reasons for the considerable increase of the curve on the right region of Fig. 3-1 became obvious. By looking at the shape of the rectangle it can be seen that the point of separation jumps from on edge to the other. For low angles there is no mentionable change but for high angles there is a big change of shape and the edges the vortices separate from have different distances to each other. This tends to result in non-uniform ratio between angle and frequency.

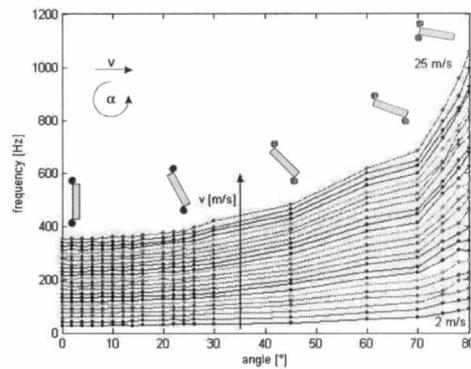


Fig. 3-1 Measured frequencies depending on angle of incidence and velocity for a rectangular bluff body

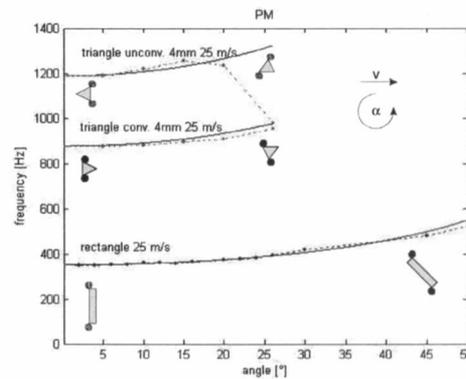


Fig. 3-2 Calculated frequencies under consideration of equation (2) in comparison to the experimental results (dotted).

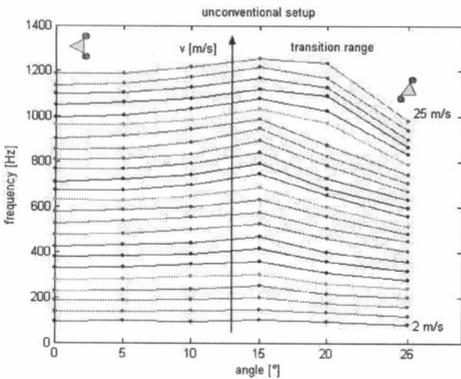
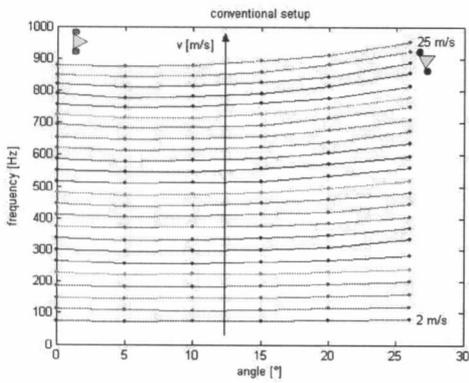


Fig. 3-3 Measured frequencies depending on angle of incidence and velocity for a triangular bluff body in conventional and unconventional set up

In Fig. 3-3 the equivalent to Fig. 3-1 for the triangular bluff body is shown. In the upper Figure the conventional set up shows no exceptional behaviour. The frequency increases like expected under consideration of equation (2). But in the lower Figure for the unconventional set up the jump of the separation point between 15° and 26° can be seen. There seems to be a transition range at about 20° where the separation point is not fixed and moves along the side of the triangle. For lower velocities the curve is bent upwards while it is bent downwards for higher velocities.

For the lower velocities the upward bent curve can be explained with the different shape that is shown to the inflow when the separation point jumps from one edge to the other. The diameter that is shown to the inflow changes from a bluff body of a width of 4mm to bluff body of the width of

$$d_{new} = \sqrt{2^2 + 4^2} \text{ mm} = 4.47 \text{ mm}, \quad (3)$$

as it is shown in Fig. 3-4, so that it can be considered:

$$f = \frac{Sr_{new} \cdot v}{d_{new} \cdot \cos(\arctan(\frac{4\text{mm}}{2\text{mm}}) - \alpha)} \quad (4)$$

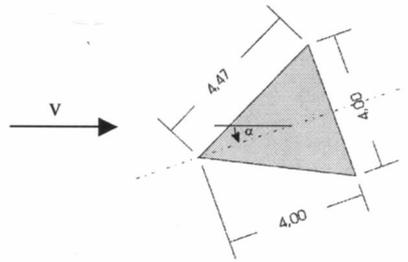


Fig. 3-4 New diameter that is shown to the inflow

here Sr_{new} is calculated by the frequency of the rightmost angle 26° because at this angle the shape mostly equals to the shape of a bluff body with the diameter of d_{new} . The result for a lower velocity of 5 m/s is shown in Fig. 3-5.

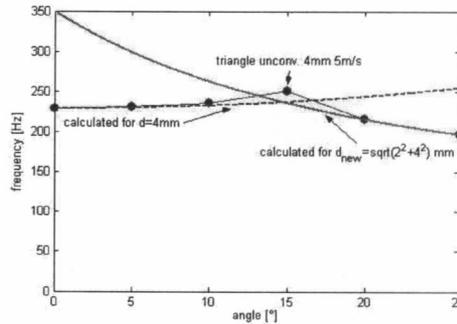


Fig. 3-5 Comparison of calculated and measured frequencies

As it is visible in the upper right of Fig. 3-3 equation (4) is no longer valid for higher velocities. The curve is bent downwards instead of upward and can be explained by the unsymmetrical flow around the bluff body that comes more important for higher velocities. The bluff body acts as an airfoil with a given angle of attack and a high unsymmetrical flow yields a pressure loss and a lift force on the upper side of the bluff body so that higher frequencies can be generated.

4. Conclusion

It is obvious that the influence of the variation of the angle of incidence depends extremely on the shape of the bluff body. The triangle in unconventional set up has the better resolution in frequency than the triangle in conventional set up, but also has the disadvantage of being very sensible to a higher angle of incidence.

It reacts with a abrupt decrease of the frequency at a certain angle. So the triangle in conventional set up is more useful, if a extremely unsymmetrical flow is expected. The reasons for the drastically change of

Frequency was found in the jumping of the separation point from one edge to the next. This results in a different Diameter that is shown to the inflow and yields to a different Strouhal Number.

References

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