

# EFFECTS OF UPSTREAM BUTTERFLY VALVE ON THE ACCURACY OF A VORTEX FLOW METER

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**Abstract:** The problem of accurate determination of volumetric flows by means of vortex-shedding flowmeters in the case of upstream disturbances caused by an butterfly valve, installed 5 diameters upstream of the meter, has been studied. To this end, the flow about the bluff body used in the presently studied vortex-shedding flow meter, having DN25 (simulation) and DN50 (experiments) test sections, was investigated experimentally and numerically.

**Keywords:** Vortex Flow Meters, Flow Simulation, Experimental Flow Metering, Accuracy. Upstream Disturbance.

## 1. Introduction

Many chemical and environmental processes found in the corresponding industries require volume- or mass flow data for their completion. Number of promising new methods for flow rate measurement have been recently developed. One relatively simple flow measurement device is the so-called vortex-shedding flow meter, in which the volumetric flow is determined by observing the relationship between the vortex-shedding frequency from a bluff body attached inside a channel, and the corresponding mean velocity about it. The bluff body causes production of a system of periodic vortices (von Karman vortex street), whose frequency can be correlated with the mean flow velocity and, therefore, the volumetric flow. This procedure assumes a regular and well defined vortex structure as well as shedding mechanism, resulting mostly in linear dependency of the volumetric flow on the shedding frequency over a wide range of Reynolds numbers.

In principle, the vortex-shedding flow meters use the separation frequency of vortices behind a bluff body to measure the mean flow velocity of a fluid flow. Downstream of the bluff body, von Karman vortex street develops; its width  $D$  and distance  $T$  between the vortices depend on this frequency, and therefore on the bluff body's shape. Preferably, the vortex-shedding frequency should depend linearly on the mean flow velocity for a wide Reynolds number range. The dependency of the vortex frequency  $f$ , the mean flow (bulk) velocity  $u_m$  and the width of the bluff body  $D$  is expressed by the dimensionless Strouhal number  $Sr$ :

$$Sr = (D \cdot f) / u_m$$

or the dimensional k-factor:

$$k = f / Q$$

with  $Q$  being the volumetric flow.

By now, commercial vortex flow meters use a large variety of bluff body shapes, test sections (conical inflow and outflow, constrictors of various shapes) and signal detection systems (pick-up). The corresponding flow fields have been studied by, among others, Johnson [4], Fureby [1] and Madabhushi et. al. [5] using mostly numerical simulations. The signal detection and processing have been discussed by Hans et. al. [2] and [3]. The potential for improvement of

signal quality by modifying the shape of the bluff body was investigated by von Lavante et al. [6]), It has been also observed that a slight uncontrolled modification of the assumed geometry of a particular vortex-shedding flow meter, e.g. shape, location relative to the surrounding casing and change of shape due to wear caused by particles suspended in the metered fluid, could cause a shift of its characteristic frequencies, leading to unreliable volumetric flow data. The influence of the manufacturing tolerances on the accuracy of vortex-shedding flow meters and abrasion by particles suspended in the metered fluid has been investigated in [7] and [8] by von Lavante et al. A detailed study of the flow field in small size commercial vortex-shedding flow meters with inflow and outflow conditioned by a Venturi nozzle and a diffusor has been published by von Lavante et al. in [9].

In the present investigation, the effects of upstream disturbances caused by a butterfly valve, arrested in two different positions, on the k-factor of a vortex flow meter was investigated using numerical and experimental methods. Although the flow field downstream of the valve was unsteady, with a characteristic frequency of periodic disturbances close to the vortex shedding frequency, the effect on the k-factor and with that on the accuracy of the meter was minimal.

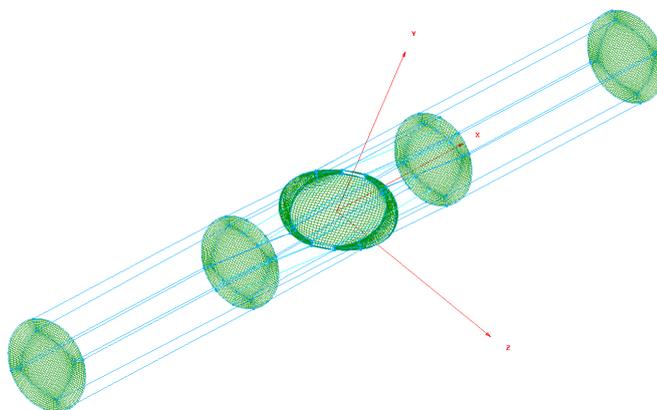
## 2. Methods of Investigation

### 2.1 General Remarks

Early in the present investigation, it was decided to use the Fluent commercial flow simulation program due to its robustness. The task of studying the influence of the butterfly valve on the vortex shedding frequency was carried out in two stages. First, the flow field at the butterfly valve in a DN 25 pipe was simulated; in this case, the valve as well as upstream pipe of 5 D length and downstream pipe of equally 5 D length were included. Two opening angles of the valve were employed, 30 degrees and 45 degrees (0 degrees = fully open). Secondly, the same butterfly valve was combined with the corresponding DN 25 vortex flow meter 8 D downstream of it.

### 2.2 Grid Generation

The computational grid was generated using the commercial program GRIDGEN using structured grid. A view of the grid for the 45 degrees opening angle can be seen in figure 1. The grid consisted of 757,000 cells for the 45 degrees opening angle and 432,000 cells for the 30 degrees case.



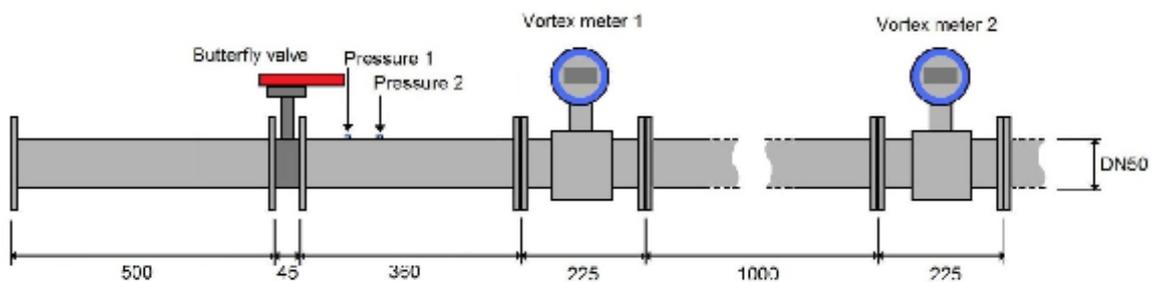
*Fig. 1 Several cuts through the structured grid for the valve only, 45° open.*

## 2.3 Numerical Simulation

In the present work, the commercial product Fluent, Ver. 6.3 was used. As the maximum Mach number reached up to 0.8, the segregated solver had to be used in its ideal gas mode, being suitable for weakly compressible flows. The working fluid was assumed to be air at atmospheric conditions. Due to the requirement of matching Reynolds numbers with the experimental work, being between  $Re=12,000$  and  $Re=48,000$ , the bulk velocities were between 7.27 m/s and 29 m/s. At the inflow, the Gersten turbulent profile was implemented for the corresponding Reynolds number. Throughout the simulation, the  $k-\epsilon$  realizable turbulence model was used, with turbulent intensity at the inlet being assumed to be 2%.

## 2.4 Experimental Setup

In the experimental part of the present work, air at atmospheric conditions was again the working fluid. Due to the given installation characteristics of the test rig, the size of the test section was DN 50. The opening angles of 0, 30 and 45 degrees were studied.

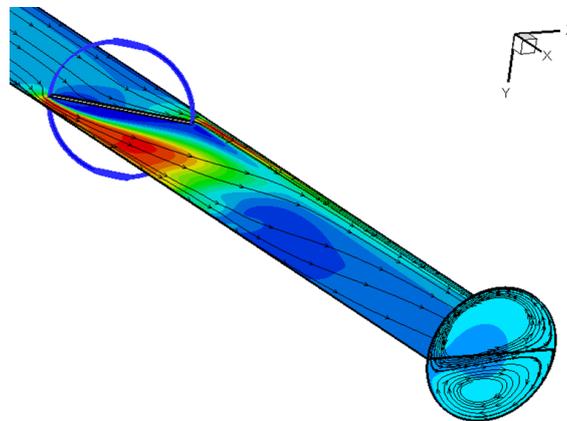


*Fig. Experimental setup.*

The tests were performed with air bulk velocity of 7, 17.5, 29, 45.5 and 60 m/s. The vortex meters were calibrated in advance on the water calibration bench using a MID reference flow meter.

## 3. Results

A three-dimensional view of the flow field at the valve is offered in figure 1. The flow is coming



*Fig. 2 Three-dimensional view of the flow field at the valve at 45 degrees opening angle.*

from left to right at a bulk velocity of 29 m/s. Clearly visible are the regions of high velocity (red) in the narrow passage between the valve and the pipe housing. At the outflow, a significant secondary flow is recognizable. The same type of flow is displayed in figure 3 using meridional and cross-sectional views. Again, the blockage effect of the valve can be seen in the right picture. On the lee side of the valve, the flow is massively separated. In the middle (1.5 D downstream) and the left (2.0 D downstream) pictures, the secondary vortices are visible. Due to their asymmetric character, unsteady flow behind the valve was expected.

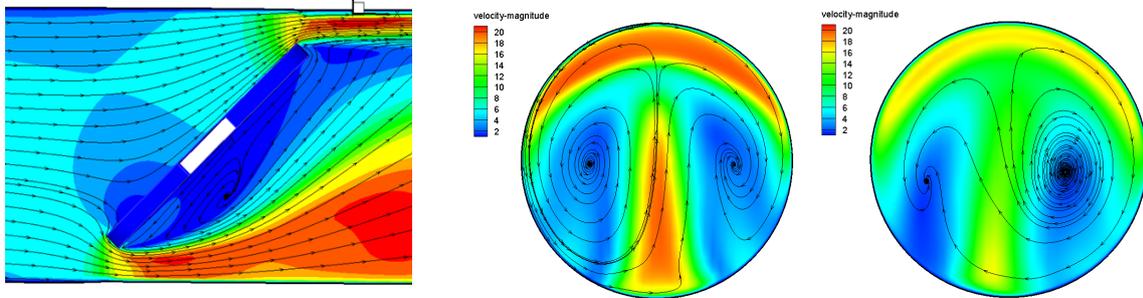


Fig. 3 Flow field at the valve at 45 degrees opening angle and 29 m/s bulk velocity.

A view of the wake behind the valve is offered in figure 4. The irregular form of the wake indicate an existence of the so called von Karman vortex street with a distinct frequency of vortex shedding.

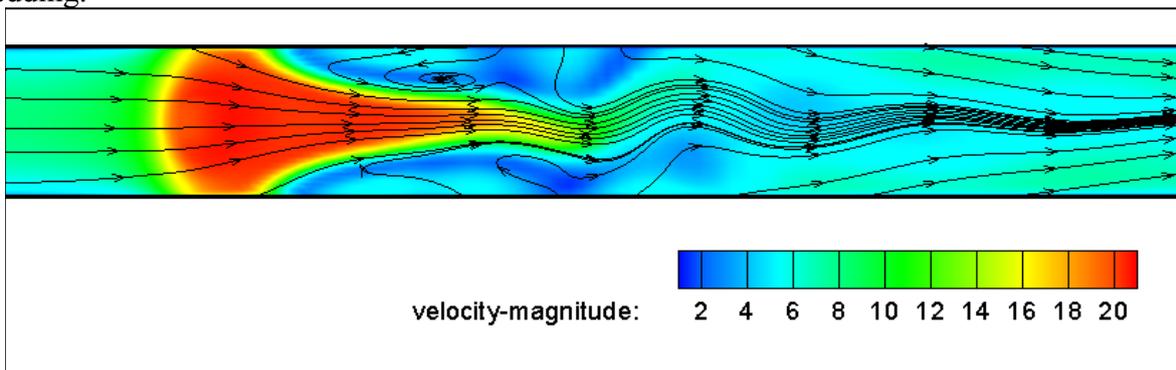


Fig. 4 Flow field in the wake of the valve at 45 degrees opening angle and 29 m/s bulk velocity.

In order to evaluate the unsteady character of the wake, the pressure fluctuations 2 D downstream of the valve location were recorded and analyzed using DFT. The result in the frequency domain can be seen in figure 5.

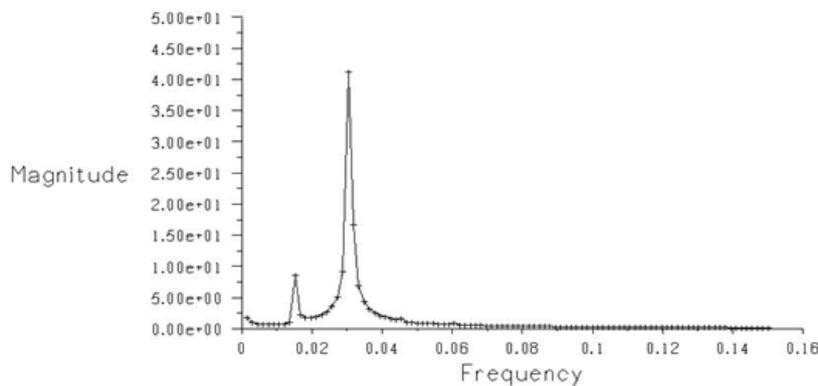


Fig. 5 Frequency of pressure fluctuation in the wake of flow field in Fig. 4.

The dominant frequency (see figure 6) possesses a subharmonic part at one half of its value. Unfortunately, the dominant frequency is very close to the frequency of primary vortex shedding in the flow meter. The frequencies of the valve at different opening angles and bulk velocities were compared to the vortex meter frequency in figure 6.

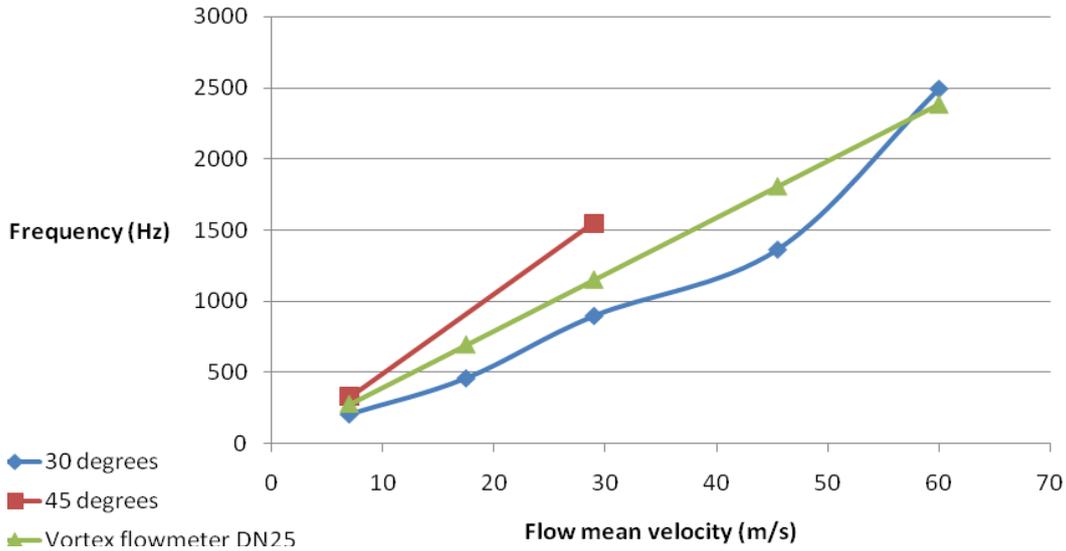


Fig. 5 Frequency of pressure fluctuations in the wake of flow field in Fig. 4.

Obviously, all three frequencies are of the same order of magnitude, making so called lock-up possible. In that case, the vortex shedding frequency changes to the frequency of the forcing disturbance. In the experimental work, however, this effect was not observed. The explanation can be deduced by considering figure 6. Here, the decay of the amplitude of the pressure disturbance due to the butterfly valve is plotted as a function of the distance downstream of the valve.

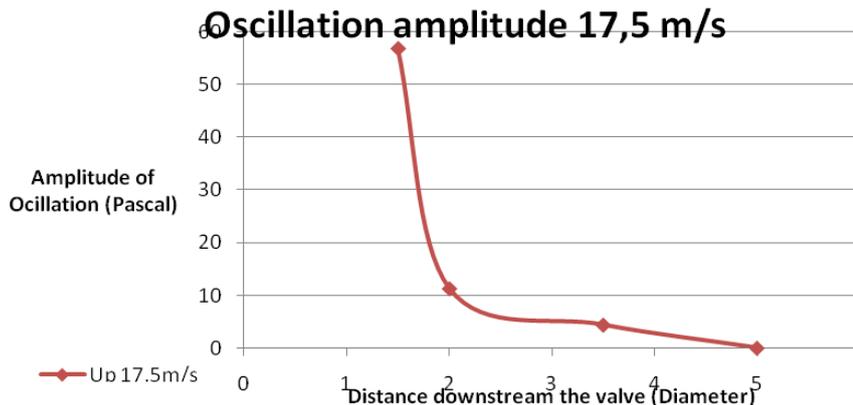


Fig. 6 Frequency of pressure fluctuations in the wake of the valve.

The amplitude quickly decreases with the downstream distance, reaching approximately zero after 5 D.

The deviation obtained from the numerical simulation as well as the experimental investigation is

summerized in Table 1 below for the bulk velocity of 7 m/s.

Case	Numerical	Experimental
30 degrees open	2.77 %	0.7 %
45 degrees open	1.16 %	0.5 %

*Table 1: Deviation due to butterfly valve.*

## 6. Conclusions

In the present work, the combination of butterfly valve and vortex flow meter has been investigated using numerical simulation and experimental verification. Initially, the flow field about the butterfly valve has been simulated separately from the vortex meter. The flow field was unsteady with a periodic vortex shedding at frequencies that were close to those in the flow meter. However, the amplitude of these disturbances decreased rapidly with downstream distance. A distance between the valve and the meter of 8 D was sufficient to minimize the influence of the valve on the k-factor of the meter. The experimental work verified that the meter was only marginally affected by the valve as long as the distance between them was in excess of 8 D. The measured deviation of the k-factor was, however, much smaller than the numerically determined value.

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