

FLUID MECHANICAL OPTIMIZATION OF A DN25 VORTEX FLOW METER WITH NOVEL VORTEX DETECTION

E. von Lavante and S. Brinkhorst, University of Duisburg-Essen, Germany
A. Gedikli, Krohne Innovation GmbH, Duisburg, Germany
and H. Krisch, Krohne Messtechnik GmbH, Duisburg, Germany

Abstract

In the present investigation, a new design vortex flow meter with novel pressure detection chamber has been optimized and investigated numerically as well as experimentally. Instead of implementing the standard configuration with paddle for vortex detection, a pressure chamber of optimized size and position has been investigated, allowing much higher temperatures of the metered fluid. Whereas the standard design is limited to 240° C, the new design allows temperature in excess of 500° C. The present paper describes the results of numerical simulation of the corresponding high temperature flow field.

Introduction

In a typical vortex flow meter, 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, requiring linear dependency of the volumetric flow on the shedding frequency over a wide range of Reynolds numbers.

Downstream of the bluff body of width D (diameter of the test section), von Karman vortex street develops; the vortex shedding frequency f and the distance T between the vortices depend on the bluff body's shape, the bulk velocity, and the fluid properties. It can be easily shown by dimensional analysis that the Strouhal number Sr :

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

has to depend uniquely on the pipe flow Reynolds number, assuming incompressible flow with maximum Mach number below 0.3. In the above equation, u_m is the mean velocity

determining the volumetric flow rate. Many times, however, the frequency is expressed as the dimensional k-factor:

$$k = f / Q$$

with Q being the volumetric flow. The corresponding flow fields have been studied by, among others, von Lavante et al. [1] using a combination of numerical simulations and global experiments for validation. The signal detection and processing have been discussed by Hans et. al. [3] and [4]. 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 [5] and [7] 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 diffuser has been published by von Lavante et al. in [2]. More recently, von Lavante et al. [6, 9] studied the effect of upstream disturbances on the accuracy of various VFMs, to be followed by Gedikli [8] who extended the investigations in [9] to different installations of bluff bodies for several bluff body shapes.

In the classical design of the KROHNE vortex flow meter (Optiswirl 4700), a paddle is used as a sensor, containing piezoelectric elements. When flow passes about the bluff body a von Karman vortex street develops and the paddle surface underlies a periodic pressure change. The piezoelectric elements transform the mechanical movement of the paddle in electrical signal which can be evaluated in a signal processing unit. Such a sensor construction is restricted to medium temperatures under 240°-C. In order to achieve an accurate measurement at

temperatures as high as 500°C, a new design vortex flow meter has been developed. Here, instead of using a paddle which is positioned behind the bluff body and exposed to the high temperature fluid, the periodic change of pressure is detected by employing two circular holes that are positioned in the side wall at an appropriate location close to the bluff body and serve as a conduit transmitting pressure variations to a pressure chamber. The periodically changing pressure acts on two membranes in this chamber, deflecting them. The movement of the membrane is finally detected by a contact free system. The entire setup can be seen in Fig. 1. and Fig. 2.

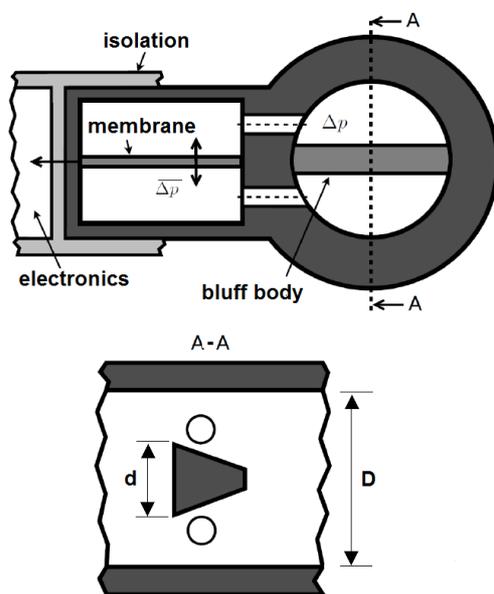


Figure 1: Principle of vortex flow meter with pressure chamber

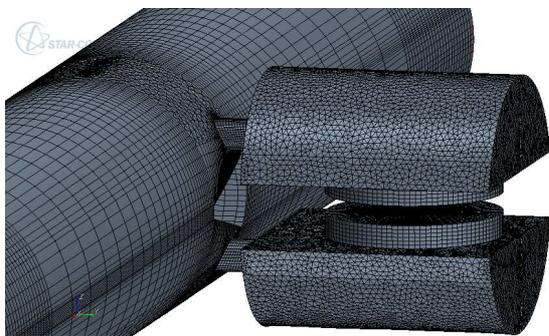


Figure 2: Detail of the computational grid with bluff body and pressure chamber

As in the original detection system, the main goal was the determination of the so called K-factor. The K-factor depends to large extend on the shape of the bluff body. Therefore, the

proven bluff body shape, used already in the original meter, has been kept unchanged.

The size and the location of the fluid mechanical system consisting of the bluff body, the channels conducting the pressure fluctuations, and the pressure chamber, were subject to a rather complex optimization. The goal was to achieve as high pressure difference across the membrane as possible without modifying the time-wise linearity of the frequency of the pressure waves.

In the present work, the modified DN25 VFM has been investigated. The optimization of the conduit position was first carried out and will be discussed below. Subsequently, the configuration in Figure 2 has been subjected to numerical flow simulation using air as the metered fluid for different Reynolds numbers by changing velocity (20 m/s, 40 m/s and 70 m/s) and pressure (1 bar and 350 bar) at an elevated temperature of 500°C (773 K).

Numerical Flow Simulation

The complex computational grid was generated using the Gridgen commercial software using the hybrid approach. As can be seen in Fig. 2, parts of the grid were structured for good resolution of viscous layers, and parts consisted of unstructured grids for easy meshing. The grid consisted of 660,000 cells; a small number considering the complexity of the geometry.

The flow simulation was accomplished using adapco Star CCM+, a commercial program. As the Reynolds numbers ranged between 25,000 and 6 million, the realizable k-epsilon turbulence model was used. At the inflow and outflow, undisturbed conditions were assumed. Interesting is the choice of the basic solver. At room temperature and mean velocity at the inflow of 70 m/s, the local Mach number exceeded 0.5, thus necessitating a solver of compressible flow with the close coupling between the energy equation and the momentum and continuity equations. In the present case, however, the highest Mach number in the flow field was approximately 0.3 due to the higher speed of sound, so that incompressible flow could be assumed.

Position of the pressure openings

Before the flow simulation of the entire modified meter could be started, the optimum

location of the openings for the conduits (tubes) leading from the measuring section to the pressure chamber had to be found. For this purpose, the air flow in the basic vortex flow meter configuration, consisting of the measuring section and the bluff body, was numerically simulated. After achieving periodic vortex shedding, the time dependent static pressure on the inner wall has been monitored. In order to find pressure fluctuation of the largest amplitude, the variance of pressure on the wall has been displayed as contours of constant value. The expression for variance is:

$$s^2(x) = \frac{1}{N-1} \left[\sum_{i=1}^N x_i^2 - \frac{1}{N} \left(\sum_{i=1}^N x_i \right)^2 \right]$$

where x_i is the field variable value, in our case the static pressure, and N is the number of time steps in the time-wise iteration. As the variance is a measure of the departure of the pressure values from the mean value, it is a good indication of the location of maximum amplitude of the fluctuation. A plot of a typical variance distribution for an inflow pressure of 1 bar and mean velocity of 20 m/s is shown in Figure 3.



Figure 3: Variance of the static pressure

The best location of the pressure ports would be close to the rearward tip of the bluff body (in Figure 3, the air is flowing from right to left), but this location is unpractical. The ports have a diameter of approximately 5 mm, being of the same order of magnitude as the size of the bluff body itself. Therefore, the next best possibility was selected above and below the sloped sides of the body, as close to the surface of the bluff body as possible. In subsequent experiments, this selection of the pressure ports location was confirmed as advantageous, giving clean pressure signals on the membrane in the chamber.

Results

The numerical flow simulations were carried out in order to answer following questions: a)

what is the amplitude and frequency of the pressure fluctuations at the membrane, b) how high is the temperature inside the chamber c) how does the K-factor or the Strouhal number, respectively, behave as a function of the Reynolds number d) what is the general distribution of the velocity in absence of the paddle.

The above questions will be addressed by considering the results for the case of 40 m/s at 1 bar and 773 K temperature.

STAR-CCM+

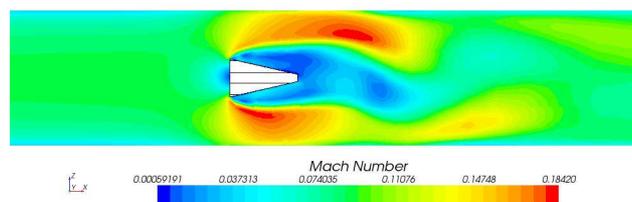


Figure 4: Mach number distribution

The Mach number distribution in the axial plane in Figure 4 shows the typical vortex street, with the highest Mach number of 0.18. The temperature distribution in Figure 5 shows relatively small differences in the flow field.

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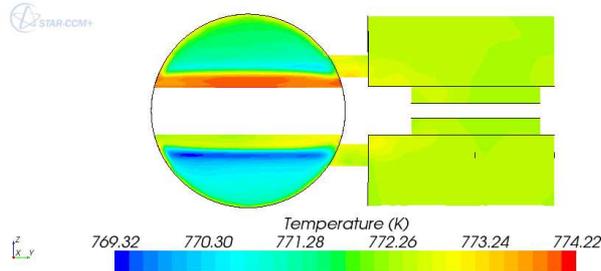


Figure 5: Temperature distribution

The velocity distribution in the cross-sectional area that includes the pressure chamber indicates the relatively low velocity levels in the chamber, and the high velocity below the bluff body due the local acceleration in the vortex.

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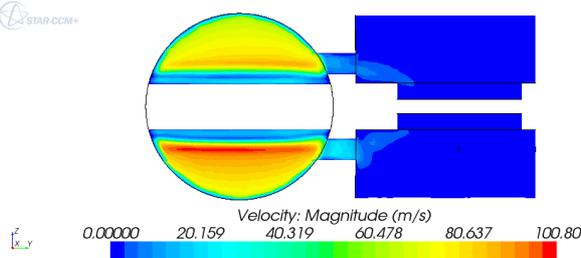


Figure 6: Distribution of velocity magnitude

The velocity magnitude in the pressure chamber is very low, leading to the conclusion that the pressure changes in the main measuring section of the meter (main pipe) are propagating into the chamber as pressure waves at approximately the speed of sound. The resulting frequencies and, therefore, also the K-factor are approximately 15% lower than in the low temperature case due to the higher viscosity of the metered gas. In liquids, the opposite behaviour is expected.

Finally, the resulting Strouhal number as a function of the Reynolds number can be seen in Figure 7.

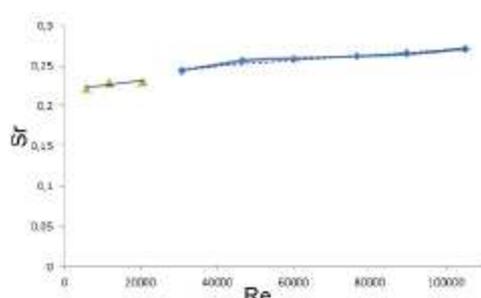


Figure 7: Strouhal number as a function of the Reynolds number for standard conditions ($T=300\text{ K}$) and the high temperature ($T=773\text{ K}$)

The Strouhal number is a weak function of the Reynolds number, increasing with increasing Reynolds number.

Conclusions

In the present paper, the results of investigation of a novel type of sensor arrangement in a DN25 vortex shedding flow meter have been presented. The flow field has been studied at gas temperature of 773 K at three different velocities and two pressures. The Mach number levels were significantly lower than in the low temperature cases, leading to incompressible flow behaviour. The K-factor for the higher temperature was lower due to the change of viscosity of the gas. The signal quality, obtained by integrating the pressures on the membrane, was very good, making the new configuration suitable for high temperature measurements.

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