23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

THE EFFECT OF VELOCITY PROFILE DEFORMATION OF AN AVERAGING PITOT TUBE

S. Pochwała[*], J. Wydrych[**], G. Borsuk[***]

Abstract: *Many industrial facilities, such as modern boiler equipment, demonstrate a high level of complexity. The management of the space around them forms the reason why it is impossible to install a flow meter in an appropriate location in accordance with the manufacturer's recommendations. An adequate location of a flowmeter forms a key aspect in securing correct measurements. Usually, a sufficiently long run of straight section of a pipeline upstream and downstream of the flowmeter is a part of such recommendations. The failure to meet such a condition can lead to the increase of the measurement uncertainty above the value that recommended by the flowmeter producer. The rationale for a study into applicability of averaging Pitot tubes in the area of flow disturbance is associated with operating problems with such equipment.*

Keywords: Averaging Pitot tubes, Flowmeter, Measurement uncertainty.

1. Introduction

A number of methods are currently used to determine fluid velocity, mass and volume flow. Such studies play an important role in the development of control and measuring systems. The measurement of these quantities is important in the context of apparatus and systems operation (Spitzer, 1996; Miller, 1983). The classification of the methods and equipment applied for measurements of mass or volume flow rate was based on multiple criteria (Chmielniak, 2008). The measured value forms the most important criterion of the classification applied with regard to the existing flowmeters (Turkowski, 2013; Vinod, 2012). As a principle, the criterion adopted for this distribution is based on the physical principle of their operation.

On the basis of the above criteria, the following classification of flowmeters was developed (Pospolita, 2004):

- an averaging flowmeter (orifice, averaging Pitot tubes),
- rotameter,
- turbine flowmeter, electromagnetic flowmeter, ultrasonic flowmeter,
- positive displacement flowmeters,
- Coriolis flowmeter,
- thermal flowmeter,
- vortex flowmeter,
- other (optical flowmeter, correlation flowmeter).

The range of the application of flowmeters applied in the metering and billing is very extensive. This area primarily includes various types of liquid and gas fuels, as well as heat and water supply to municipal and industrial customers, as well as the metering and billing based on the amount of wastewater discharge. Repeatedly the flow rates are counted in the hundreds of thousands m^3 of a medium per hour and pipe diameters are in the range of one or two and even more meters. This leads to considerable problems

---

[*] Adjunct prof. Sławomir Pochwała, PhD.: Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, 76 Prószkowska str.; 45-758, Opole; Poland, s.pochwala@po.opole.pl

[**] Adjunct prof. Jacek Wydrych, PhD.: Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, 76 Prószkowska str.; 45-758, Opole; Poland, j.wydrych@po.opole.pl

[***] Adjunct prof. Grzegorz Borsuk, PhD.: Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, 76 Prószkowska str.; 45-758, Opole; Poland, g.borsuk@po.opole.pl

associated with the selection of flowmeters and their installation. In spite of a wide range of flow conditioners available, all of them generate an additional value of local pressure drop. This, in turn, exclude their use in certain applications (Frattolillo et al., 2002). An incorrect selection can have a significant impact on the results of the measurement.

2. Methods

The metering and billing based on actual measurements are associated with a need to maintain the smallest possible measurement uncertainty. This condition often limits the selection of an appropriate flowmeter. For this reason, there is a need to develop and apply a variety of normative documents in the industrial installation. (Dobrowolski et al., 1992). Flowmeters with averaging Pitot tubes are being increasingly used because of significantly smaller pressure drops resulting from their installation, which is additionally coupled with simple system design and low operating cost. Pitot tubes are often used for fluid velocity and velocity profile measurements, along with Pitot tubes and other types of micro-orifices (molders). A pipe with an adequate design of the pressure tapping points for the reception of pressure forms the most important part of this type of a flowmeter. A molder is located in the measurement section of a pipeline. During the flow around the pressure sensor, the pressure in the front part of the sensor is higher than the static pressure in the pipeline because of the dynamic effect of the fluid flow. On the sides and the rear side of the sensor, the pressure is lower from the static pressure in the pipeline. Sensor shapes applied in the industry and the location of impulse tapping points can lead to a relatively constant value of flow coefficient K in a relatively wide range of flow parameters. This value is usually in the range from 0.6 to 0.8. The velocity determined for the averaging Pitot tubes was obtained on the basis of the formula:

$$w = K\sqrt{\frac{2\Delta p}{\rho}} \tag{1}$$

where: K – flow coefficient,
Δp – pressure drop,
P – fluid density.

3. Results

The research was carried out on a measuring system built with the purpose of experimental determination of the impact of flow obstacles on the results registered by a sensor during the measurement of averaging dynamic pressure. In the study, a centrifugal fan with a maximum flow rate of 12000 m^3/h was responsible for driving flow in the pipe, and it was powered by 37 kW three-phase motor (Kabaciński et al., 2010; Kabaciński et al., 2011 and Pochwała et al., 2016).

Fig. 1: General view of the measuring system.

Fig. 1 shows a general view of the measuring system. The research reported in this paper was carried out in a 3 x 30 ° segmented elbow. In the analyzed design of the averaging tube, six pressure tapping points were used upstream of the flowmeter, and they were arranged according to the principle of circle division into concentric rings with an equal area. Pressure tapping points applied for the measurements of the negative pressure were located downstream of the tube. The operating principle of a averaging tube is based on an adequate location of pressure tapping points. The research was carried out within the frequency range of the electric motor of 8.0 – 29.0 Hz with a step of 0.5 Hz, corresponding to the measured velocity with a reference flowmeter in the range 8.0 – 30 m/s.

Reference measurements were carried out in a straight tube section at a distance of 35 diameters from the flowmeter. Measurements were carried out by setting the averaging tube in two characteristic positions with respect to the obstacle in the horizontal and vertical axes with a vertical air inflow to the fully open throttle valve. As a result of the calculations, it was possible to make a comparison between the flow rates and values of the flow coefficient in the sections where the measured velocity profile was fully developed. For fully open throttle valve the distance was 35 diameters – as it is shown in the diagrams K/K_{35}. Figs. 2 and 3 show the results of the experimental research for the Introbar flowmeter.

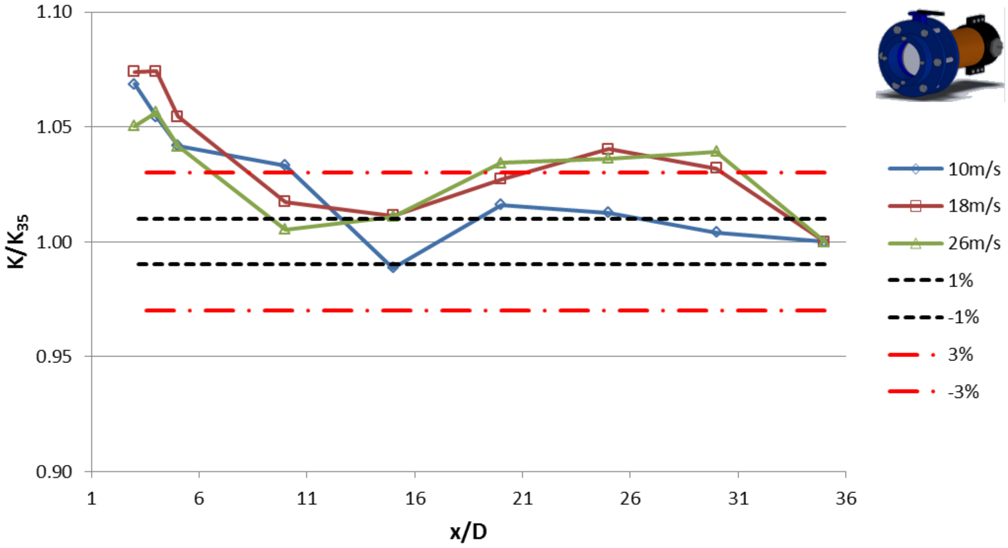

Fig. 2: Flow coefficient K/K_{35} Introbar flowmeter related to the distance from the obstacle for vertical tube orientation.

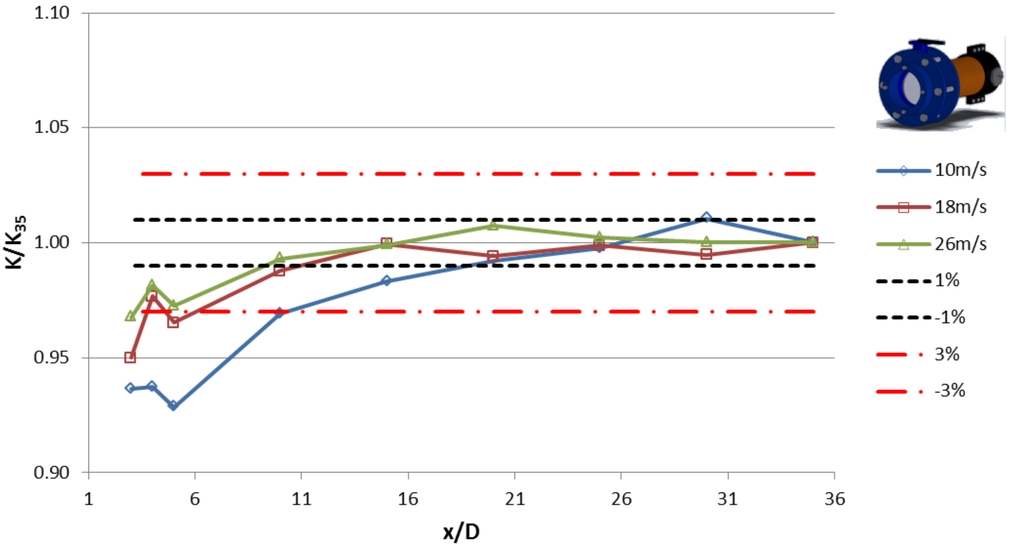

Fig. 3: Flow coefficient K/K_{35} Introbar flowmeter related to the distance from the obstacle for horizontal tube orientation.

Tab. 1 shows the variations of flow coefficient K_{av}/D with respect to K_{av35} of the tested flowmeter. The values of K_{av}/D were averaged for the entire range of the analyzed velocity (10 ÷ 30 m/s at 93 measuring points) and subsequently compared with the value of the flow coefficient determined for the position where the velocity profile is fully developed. The summary of deviations K_{av}/D with respect to K_{av20} was based on the formula:

$$\delta K_{lok} = \frac{K_{av/D} - K_{av35}}{K_{av35}} * 100\% \tag{2}$$

The disadvantageous places from the metrological point of view, i.e. ones for which the additional uncertainty associated with the location of the sensor is greater than ± 3 % in the table are marked in red.

Tab. 1: List of additional uncertainty depending on the location of the sensor δK_{lok}.

INTROBAR									
δK_{lok}	3D	4D	5D	10D	15D	20D	25D	30D	35D
Vertical	6.4 %	6.2 %	4.9 %	1.2 %	0.7 %	3.0 %	3.1 %	3.0 %	0.0 %
Horizontal	4.9 %	3.1 %	4.3 %	1.8 %	0.8 %	0.3 %	0.2 %	0.0 %	0.0 %

4. Conclusions

The research reported in this paper focused on the influence of the installation comprising a fully open throttle valve on the results registered by the averaging Pitot tubes. The research was carried out for three gas velocities equal to 10, 18, and 26 m/s. The reference velocity was determined using a turbine flow meter with a total uncertainty of ± 0.5 % over the entire range of the analyzed velocities. The research was conducted in several tube sections located at various distances from a flow obstacle. The research and analysis led to the formulation of a few statements for application in metrology. For the distance equal to 3, 4, 5 and 25 equivalent diameters, a significant increase in additional uncertainty was noted for all analyzed velocities for the vertical tube orientation. This is attributable to the formation of a vortex downstream from the fully open throttle valve. The analysis of the results demonstrated that it is possible to use averaging Pitot tubes at much smaller distances than the ones recommended by the manufacturers. A total uncertainty of ± 4 % can offer the applicability of the analyzed flowmeters in a series of control systems in technological processes, e.g. for the control of the combustion process.

References

Chmielniak, T., Kotowicz, J. and Węcel, D. (2008) Experimental and numerical investigations of the averaging Pitot tube and analysis of installation effects on the flow coefficient. Flow Measurement and Instrumentation, No. 19, pp. 301-306.

Dobrowolski, B. and Kabza, Z. (1992) Theoretical analysis of the influence of axisymmetric deformation of the velocity profile and steram swirling on metrological characteristics of pressure differential devices. Opole University of Technology, Opole (in Polish).

Frattolillo, A and Massarotti, N. (2002) Flow conditioners efficiency a comparison based on numerical approach. Flow Measurement and Instrumentation, No. 13, pp. 1-11.

Kabaciński, M. and Pospolita, J. (2011) Experimental research into a new design of flow-averaging tube. Flow Measurement and Instrumentation. Vol. 22, Iss. 5, pp. 421-427.

Kabaciński, M., Kabza, Z. and Pospolita, J. (2010) Laboratory set for flowmeters testing, Measurements Automation Robotics, No. 10, pp. 53-57.

Miller, R.W. (1983) Flow measurement engineering handbook, Mc Graw Hill Book Company.

Pochwała, S. and Pospolita, J. (2016) Analysis of applicability of flow averaging pitot tubes in the areas of flow disturbance. Metrology and Measurements Systems, Vol. XXIII, No. 1, pp. 71-84.

Pospolita, J. (2004) Measurements of fluid streams. Opole University of Technology, Opole (in Polish).

Spitzer, D.W. (1996) Flow Measurement. Practical Guides for Measurement and Control, Instrument Society of America, United States of America.

Turkowski, M. and Szufleński, P. (2013) New criteria for the experimental validation of CFD simulations. Flow Measurement and Instrumentation, No. 34, pp. 1-10.

Vinod, V., Chandran, T., Padmakumar, G. and Rajan, K.K. (2012) Calibration of an averaging Pitot tube by numerical simulations. . Flow Measurement and Instrumentation, No. 24, pp. 26-28.