Mirosław KABACIŃSKI [1], Roland PAWLICZEK [2]
[1] OPOLE UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF THERMAL ENGINEERING AND INDUSTRIAL FACILITIES,
Mikołajczyka 5, 45-271 Opole, Poland,
[2] OPOLE UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF MECHANICS AND MACHINE DESIGN,
Mikołajczyka 5, 45-271 Opole, Poland

Investigations of the vibration effect in a measurement system for air flow phenomena in large pipelines

Abstract

A measuring system for investigation of the air flow phenomena in large tubes is presented in this paper. The main goal is to measure and analyze the vibration effect of a sensing element used for air velocity and air stream measurement. It was observed that some vibrations occurred and involved damage effect in the flow sensor. The measuring system is based on the strain gauge technology with the use of a virtual instrument in the laboratory equipment. The presented system allows measuring, identifying and analyzing vibrations of the sensor in time and frequency domains. It was created as a virtual instrument, very easy to implement into the entire control system of the stand. It was found that the load of the sensing element was asymmetric and the mean load value, compared to variable loads, arose from disturbances of the air flow around the sensor. It was observed for the examined velocities of the air stream in the range up to 35 m/s.

Keywords: air flow, vibration, strain gauge, virtual instrument.

1. Introduction

It is well known that environmental parameters can influence the quality and accuracy of measurements. In the case of flow testing for slim sensing elements, the effect of vibrations usually occurs. It is induced by air flow around the sensor. Dynamical loadings, caused by the influence of vortices, are followed by periodically changing displacements of the flowmeter [1, 2]. These, under specific flow conditions, take form of enforced vibrations [3].

Parameters of turbulences of the air stream surrounding the sensor are difficult for measurement – mathematical modeling and simulations allow performing investigations in this case. The paper [4] presents a study on flowmeter oscillatory motion when subjected to periodical, enforced vibrations induced by vortex-shedding. The mathematical model of velocity distribution in the vicinity of a probe was investigated with the ANSYS/FLUENT Software [5] for different shapes of the cross-section of the flowmeter. Additionally, the authors present modal analysis to obtain modes and frequencies of vibration of the flowmeter. A method for calculating the dangerous modal frequencies with corresponding flow velocities was introduced and presented with some exemplary data.

The aim of this paper are studies concerning vibration identification of the flowmeter for the calculated local pressure on the sides of the sensor and the measurement of strains induced by air flow turbulences.

2. Calculation of the loading of the sensor

Numerical calculations were used to identify the loading affecting the sensor. A static pressure on the sensor walls was calculated using ANSYS/FLUENT software. The shape of the analyzed flowmeter was chosen when taking into account typical solution for such elements for flow systems with large tubes using standard profile rods. Fig. 1 shows a cross section through the flowmeter with the description of walls and vertices of the sensor, for which calculations were made.

Flow Averaging Tubes locally caused overpressure at the inflow side and underpressure at the outflow part. The static pressure after time averaging at every point around a diamond-shaped body is presented in Fig. 2a. As it was presented above, this process is strongly transient in time and the fluid streams change periodically (Fig. 2b).

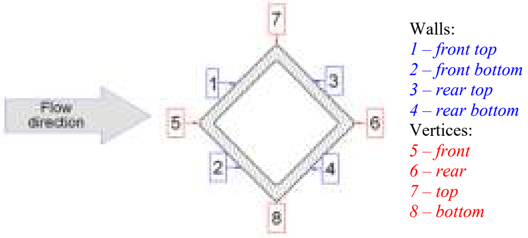


Fig. 1. Description of the cross-section of the sensor

Fig. 2. Influence of the probe cross-section on the streams of fluid assigned numerically [9]: a) averaged in time, b) variable in time for the selected time value

Fig. 3 shows the distributions of static pressures and magnitude velocities during the flow around the analyzed diamond profile for selected time instances at different values of mean velocities (5 m/s and 35 m/s).

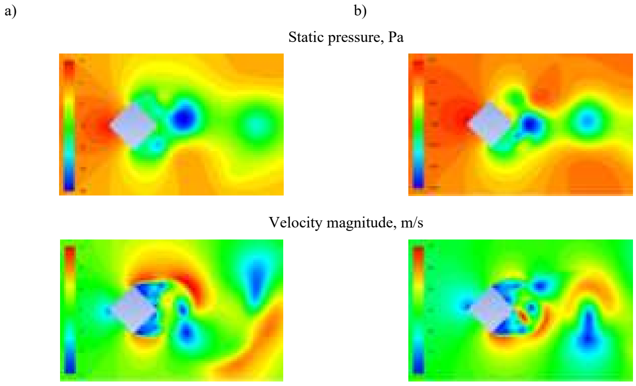


Fig. 3. Pressure and velocity magnitude distribution around the diamond–shaped sensor for: a) w=5 m/s, b) w=35 m/s

The vortex path is clearly discernible as it is generated by the geometric profile. This path is generated before the points of tapping underpressure, which leads to strongly changed pressure difference Δp in time. The largest differences of pressure and velocity with time are encountered behind the outflow surface of the non-streamlined cross-section.

The generated vortex path results in the periodical influence of the fluid on the probe. The range of frequency which is not concordant with the frequency of the vibrations of the installed flowmeter results in a hazard both of a probe failure and deterioration of the metrological properties. The manufacturers of flowmeters of the mentioned cross-section offer the ranges of the flow velocity for the particular flowmeters and suitable dimensions (diagonal equals to 25 mm or 42 mm). Otherwise, the conditions regarding the flowmeter fitting (one-sided and two-sided) can be taken into account.

Exemplary results of pressure calculations are presented in Fig. 4 for the cases of the lowest and the highest value of the average stream velocity (15 m/s and 35 m/s, respectively).

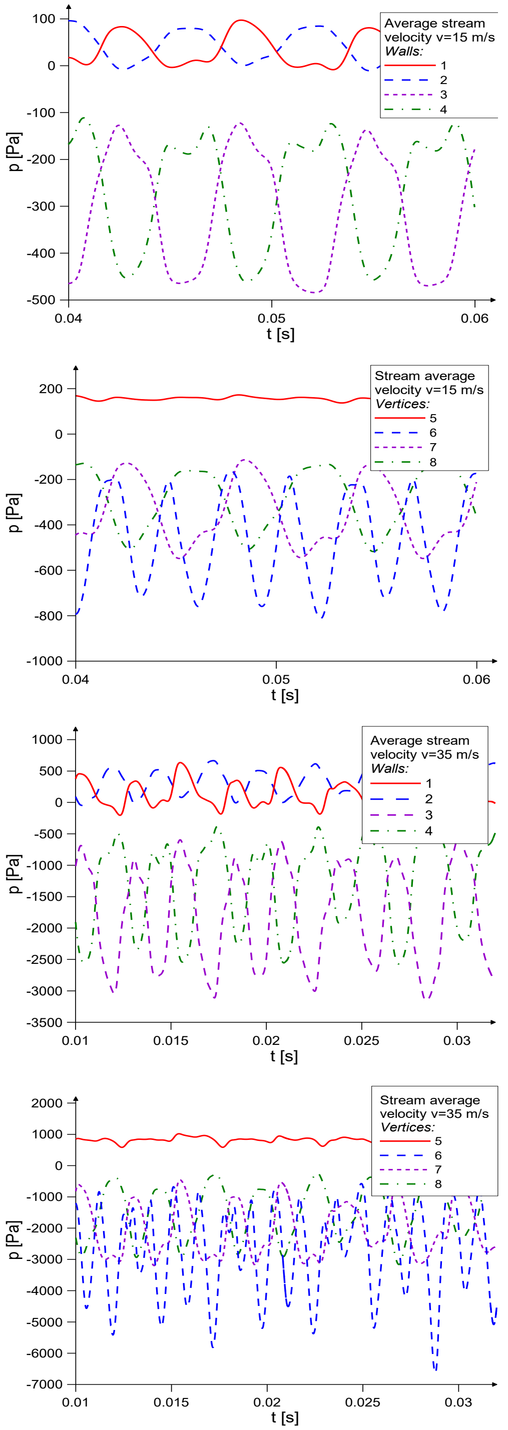


Fig. 4. Changes of the calculated pressure around the sensor

A negative value of pressure means underpressure. Comparing the diagrams we observe periodic time histories of the calculated pressure for both 15 m/s and 35 m/s average stream velocity. Additionally, it can be seen that a higher air stream velocity induces disturbances and the value of the pressure is much greater than in the other case. Also the mean value is presented in the diagrams. The pressures on the front top (line 1 in Fig.4.) and the rear top (line 3 in Fig.4.) are in phase as it is for the bottom walls: front and rear (line 2 and 4 in Fig.4, respectively). For the front top-bottom and rear top-bottom pairs the opposite signs can be seen. According to these observations, the sensor moves perpendicularly to the flow of the air stream. The relation between the amplitude of the pressure p_a and its mean value p_m due to the average stream velocity is shown in Fig. 5.

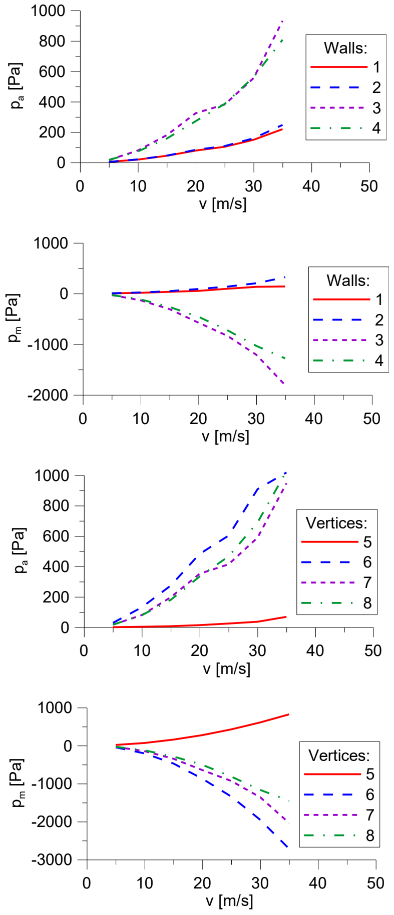


Fig. 5. Amplitude p_a and mean value p_m of the pressure vs. the average stream velocity

It can be seen that both amplitude and mean value of the pressure change significantly for the rear walls where the amplitudes are almost five times greater compared to the front walls and the mean value of the pressure is higher up to two orders. As far as vertices are concerned, only the front vertex has lower values of both pressure amplitude and mean value. In other cases, a significant increase is observed for higher average stream velocity.

3. The laboratory stand for air flow measurement

The presented test stand is usually used to examine different flowmeters and determine their characteristics. The view of the entire system is presented in Fig .6a [6, 7, 8]. The system consists of a wind tunnel and a set of pipes (from DN110 to DN400). The wind tunnel is used for flow measurements under stable and free air stream. It is possible to reach a stream velocity up to 36 m/s. This part of the stand is equipped with an absolute pressure sensor, a velocity control sensor and a thermometer. The pipe system allows calibrating the flowmeter and to define its characteristics. It is possible to arm the measurement area with a specific sensor to measure all necessary environmental parameters (e.g. turbine flowmeter, thermometer, absolute pressure sensor). The control system of the stand was designed according to the virtual instrument idea and consists of the NI CompactDAQ 9172 system

(Fig. 6a) equipped with specialised, universal transducers according to the type of signals existed in the presented stand.

3.1. Vibration measurement

The data acquisition system was extended with the NI USB 9237 – a 4-channel analogue input device designed for sensors such as strain gauges, pressure transducers, load cells, and other bridge-based measurements. It was assumed that measurement of vibrations would be made using strain gauges located on the active part of the air flow velocity sensor and the base signal would be presented as a time history of the strains of the sensor.

3.2. The sensor

A standard, square, thin wall profile rod 15×15×1.5 made of aluminum EN AW 6060 (Al MgSi), Young modulus E=70000 MPa, yield stress σ_y= 60 MPa, ultimate stress σ_U= 120 MPa) was used as a sensing component (Fig. 6b). A single-sided restraint was applied. Strain gauges were placed in the middle of the wall with a distance of 20 mm from the restraint. Measurements were taken with the use of the quarter bridge configuration of the gauges, where strains for each wall were measured separately.

Fig. 6. `a) The view of the stand. b) The flow sensor with strain gauges

3.3. Measurements results

The strains on the walls only were observed and recorded. It was impossible to use the strain gauges for vertices. The strain histories for selected air stream velocities (15 m/s and 35 m/s respectively) are shown in Fig. 7. A similar relation for the corresponding walls (front and rear) as well as for simulations and measurements is observed; however, for both cases strong disturbances are present. There is no such stable amplitude compared to the simulation results (see Fig. 4) and also so clear opposite phase effect is not visible. It means that the direction of real vibrations of the sensor is rather a random process and the recorded strain history is of variable amplitude type.

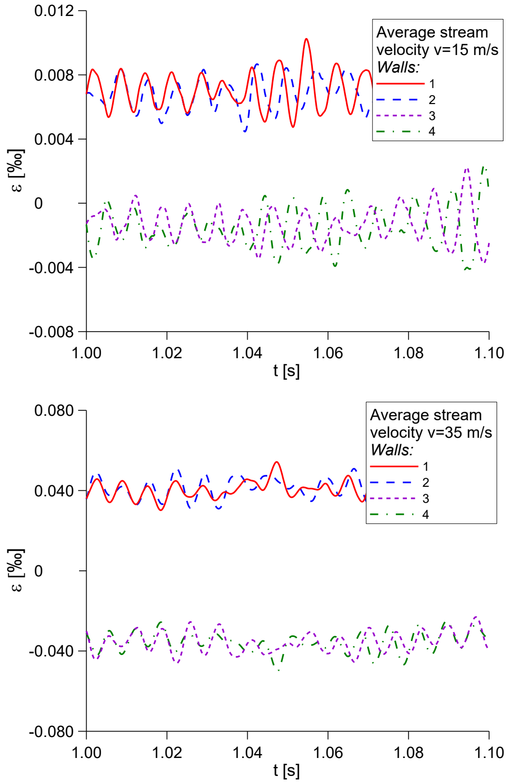


Fig. 7. Changes of the measured strains on the walls of the sensor

A trend of the increased amplitude with rising the average stream velocity can be also noted (Fig. 8).

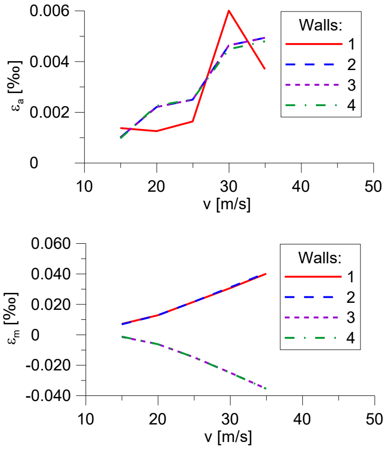


Fig. 8. Amplitude ε_a and mean value ε_m of the strains vs. the average stream velocity

Taking into account the changes of the mean strain value, the results correspond to the pressures on the walls: bigger underpressure on the rear walls induces the mean value of displacement in that direction, so there is the increasing mean strain for higher average stream velocities and this process is symmetrical.

4. Summary

Vibrations of the flow sensor have been presented in this paper. Simulation and measurement tests were described. The pressure on the walls of the sensors was considered as the results of two-dimensional simulations, while the laboratory tests gave information about the strains induced by the air stream flow around the sensor.

Taking into account the results and observations, the following conclusions have been drawn:

- simulations showed stable, periodic changes of the pressure on the walls of the sensors for smaller average air stream velocities while for the increased value of the velocity some disturbances of the amplitudes were observed,
- analysis of the phase shifts for simulations allowed defining the direction of the vibration as perpendicular to the vector of the air stream velocity,
- results of the measurements showed strong disturbances of the amplitude for all the cases of the applied average stream velocities, for which the phase shift between the recorded strains was rather a random process; this indicated random vibrations of the sensor,
- a two-dimensional based simulation must be extended to take into account interaction along the sensor axis,
- it was noted that the mean strain is an important parameter for the analyzed phenomena: in the critical case, the mean strain value is almost one order higher than the recorded amplitude.

This research was carried out with the support of the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM) University of Warsaw under grant no G53-22.

5. References

[1] Błazik-Borowa E., Flaga A.: Interference galloping of two Identical Circular Cylinders at Unsteady Air Onflow, In: 2EACWE, Genua 22-26 June 1997, 1997, pp. 1815-1822.

[2] Mittal S., Kumar V.: Flow-induced vibrations of light circular cylinder at Reynolds number 103 to 105, Journal of Sound and Vibration 245(5), 2001, pp. 923-946.

[3] Lewandowski R.: An application of Hartlen-Curie model and the finite element method to transient and steady state analysis of vortex-induced vibration of beam. In: Proceedings of the Second East European Conference on Wind Engineering, Prague 7-11 September, Vol. 1, 1998, pp. 121-126.

[4] Kabacinski M., Lachowicz C. T., Pospolita J.: Numerical Analysis of Flow Averaging Tubes in the Vortex-Shedding Regime. Archive of Mechanical Engineering. Vol.60, No. 2, Pages 283–297.

[5] ANSYS/Fluent, Fluid Dynamics Analysis Package. Fluid Dynamics International Inc., 2010.

[6] Kabacinski M., Kabza Z., Pospolita J.: Laboratory stand for flowmeters tests. Pomiary Automatyka Robotyka, Vol. 10/2010, p. 54 (in Polish).

[7] Kabacinski M., Pawliczek R.: Fully automated system for air velocity profile measurement. The Archive of Mechanical Engineering, vol. LIX, no.4, 2012, pp. 435 451.

[8] Kabacinski M., Pawliczek R.: Mechatronic concept for airflow test laboratory equipment. Solid State Phenomena Vols. 220-221 (2015), pp 445-450, Trans Tech Publications, Switzerland.

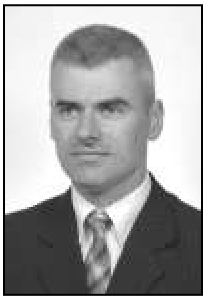
[9] Ansys Fluent 16.1, User's guide, 2015.

Received: 11.12.2015 Paper reviewed Accepted: 03.02.2016

Mirosław KABACIŃSKI, PhD, eng

Since 2004 employed at the Department of Thermal Engineering and Industrial Facilities of the Faculty of Mechanical Engineering of Opole University of Technology. His research work and scientific interests are focused on measurements of the flow of liquids in industrial systems by means of flowmeters with averaging dynamic pressure tubes – experimental investigations and numerical simulations with Ansys Fluent. Co-author of many publications related thematically with flowmeters with Pitot probes.

e-mail: m.kabacinski@po.opole.pl



Roland PAWLICZEK, PhD, eng

He works from 1993 year in the Department of Mechanics and Machine Design in Opole University of Technology. He is a member of European Structural Integrity Society (ESIS) and Polish Association of Theoretical and Applied Mechanics (PTMTS). His research interests concern applied mechanics and mechatronics. He published scientific papers in journals included in the WoS base as well as in different professional journals. He is an author of monographs and conference contributions, presented in digests of Polish and international circulation.

e-mail: r.pawliczek@po.opole.pl