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VORTEX FLOW FIELD INVESTIGATIONS WITH APPLICATION OF HOT-WIRE ANEMOMETER

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Abstract: Laboratory investigations of the fluid velocity field in the vortex meter are reported in the paper. The 2D hot-wire anemometer system has been applied for determination the velocity vector components and turbulence values distribution. Also, the spectral analysis of the fluid motion has been applied.
Keywords: vortex meter, hot-wire anemometer

1 INTRODUCTION

Vortex meter based on the Karman vortex street application belongs to the modern, future group of measuring devices. Besides of the high accuracy, it has a very good reliability, what is the most important feature in industrial applications.

The complexity of the phenomena in the vortex meter requires application of various research methods. Mathematical modelling, flow visualization, velocity profile investigations on measuring stand can be mentioned as examples of such methods. Due to the hot-wire anemometer application, a lot of information concerned the vortex growth and then its decay can be received. Hence, the better understanding of the phenomena occurring in the vortex meter is feasible.

2 METHOD DESCRIPTION

The phenomenon of the hot-wire cooled by the flowing fluid is applied in the method. Various modes of operation are in use. Due to the constant-temperature mode application (the current is controlled for providing the constant temperature of the probe) the best dynamic properties are secured.

In the case of the vortex meter, the specific fluid velocity distribution is found. Prevailing velocity component is consistent with the flow direction in the pipe. The bluff body location in the fluid (perpendicularly to the pipe axis) causes the swelling effect. Hence the local disturbances of the fluid velocity in the form of vortices flowing downstream the bluff body. The vortices development in the neighbourhood of the bluff body, and then their decay can be observed.

The most essential area, where the vortices originate, is just behind the bluff body, where the fluid flow is reduced. It is called the stagnation region.

As it results from the numerical modelling of the phenomena [1,2], the power and regularity of generated vortices are determined by dimensions of the region as well as by its movability. Hence the significance of identification of the region.

3 HOT-WIRE ANEMOMETER PRINCIPLES

The method based on the hot-wire anemometer application enables to determine the local flow velocity perpendicular to the wire.

Because the flow in the vortex meter is not steady state phenomenon, only the averaged values of the velocity represent the fluid displacement and oscillations. The integration time interval $\langle t_1;\ t_2\rangle$ have to be many times greater than oscillation period. The average velocity v_{av} of the fluid may be calculated as follows:

$$v_{av} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} v(t)\,dt \qquad (1)$$

and the flow turbulence τ:

$$\tau = \sqrt{\frac{1}{2 \cdot \Delta t} \int_{t-\Delta t}^{t+\Delta t} [v_\tau(t)]^2 dt} \quad (2)$$

where:

$$\vec{v}_\tau(t) = \vec{v}(t) - \vec{v}_{av} \quad (3)$$

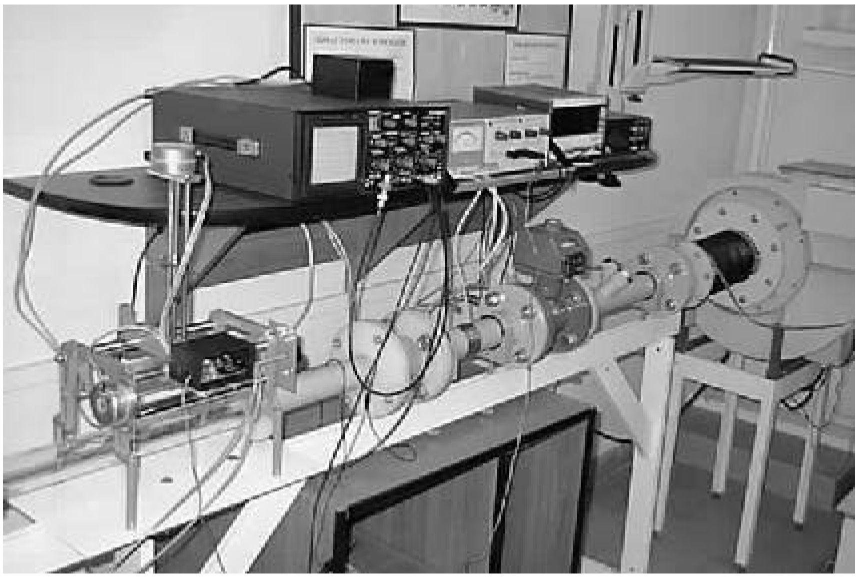
and:

$$\Delta t = t_2 - t_1 \quad (4)$$

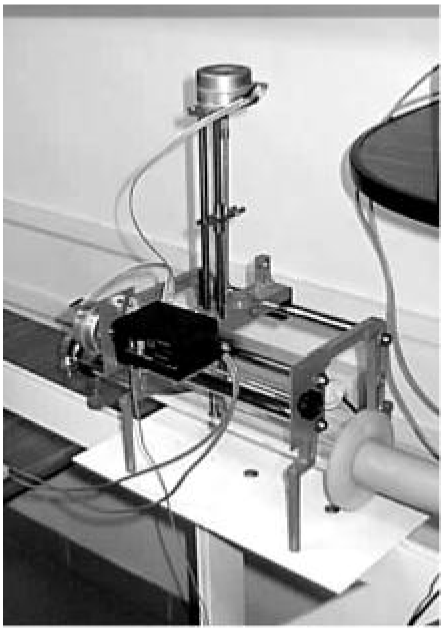
In the vortex meter it may occur the situation when in certain point of tested region there exists mostly the alternating velocity component. Hence the periodical alternation of velocity vector influences the hot-wire probe. As it is known, the sense of velocity vector is not distinguishable by the hot-wire probe. Hence the "full bridge rectifier" effect. It results in the fact, that the average velocity calculated by the measuring system is, in fact, the average value of absolute velocity. Also the turbulence calculated accordingly to the eq.(2) cannot be interpreted as rms. value of alternating velocity component.

4 MEASURING STAND

The laboratory tests have been carried out on the measuring stand for gas flowmeters calibration (Fot.1.). Specially designed module for the hot-wire probe displacement has been applied (Fot.2.). Due to possibility of step-by-step probe movement in two directions, the scanning of the flow field plane was feasible. The data acquisition and signal processing have been executed by computer control system as well as probe stepped movement.



Fot.1. General view on measuring stand



Fot.2. Module for hot-wire probe movement

5 LABORATORY TESTS

The laboratory tests were carried out on the measuring stand for gas flowmeters calibration. The circular cylinders diameter with the slit and without it were used as the bluff body. The hot-wire probe was moved in the pipe downstream the bluff body. The probe stepped movement with 1-mm grid in the plane perpendicular to the bluff body axis allowed the velocity distribution measurements (transverse and lengthways).

In Fig.1. the basic test arrangement with 2D hot-wire probe has been presented. The planes A and B perpendicular to the probe wires are the sensitive planes for velocity vectors respectively. The 2D probe is not selective enough in B plane to distinguish the two essential velocity vectors: perpendicular or parallel to the bluff body axis.

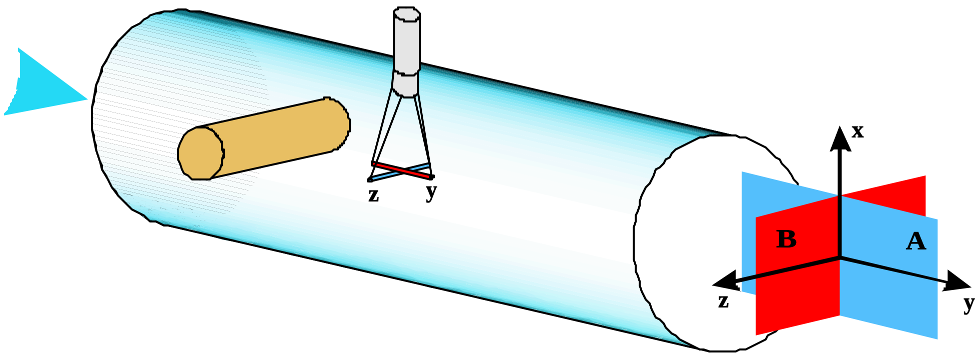


Figure 1. Basic test arrangement with 2D hot-wire probe

Due to the hot-wire probe movement in the plane perpendicular to the bluff body axis, the distribution of two components of the average velocity as well as turbulence have been calculated. In Fig.2. distributions of two components of flow velocity obtained for 13 mm circular cylinder with the slit and without it are shown. The corresponded turbulence distributions for both components are presented in Fig.3.

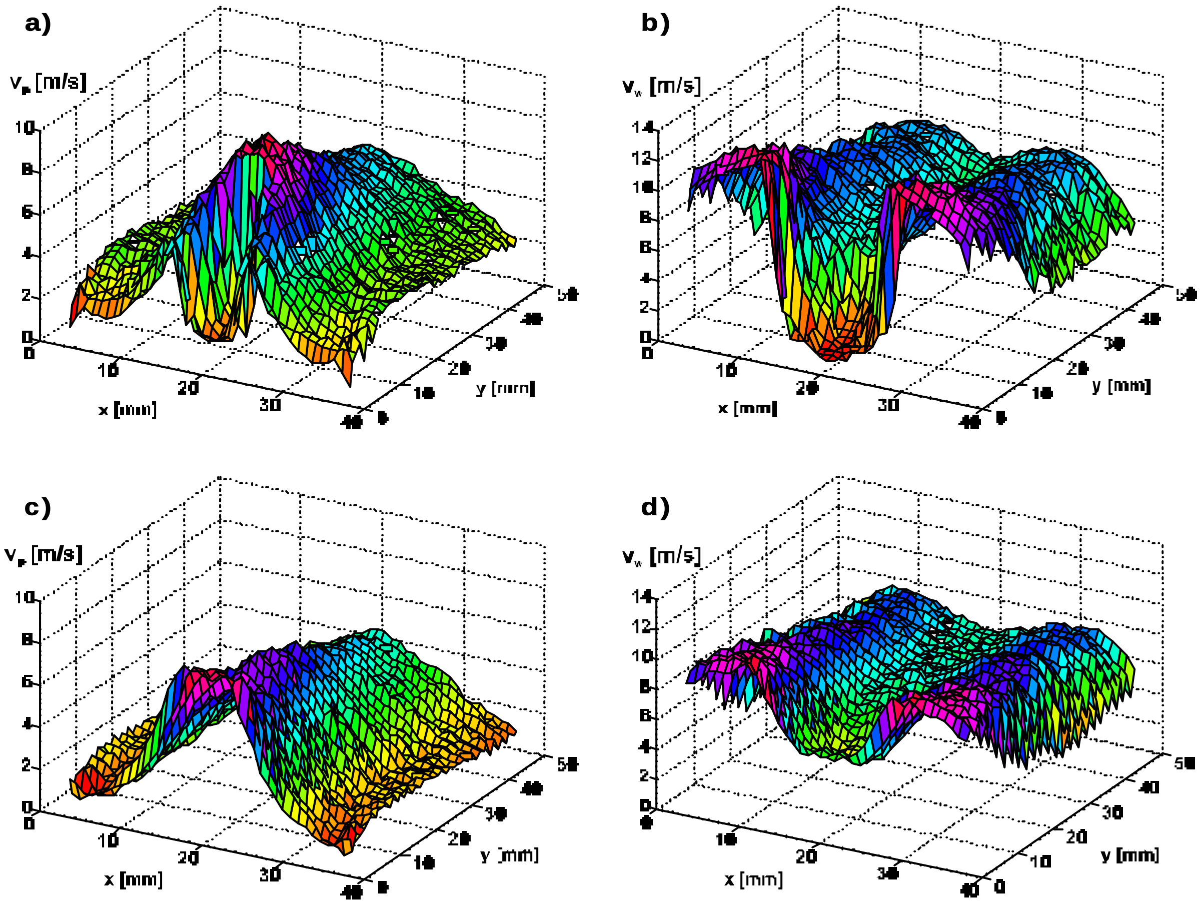


Figure 2. Mean velocity distributions - transverse (v_p) and lengthways (v_w) - in axial plane perpendicular to the 13-mm circular cylinder - without slit (a&b) and with slit (c&d)

On the basis of presented results, it is easy to conclude that 3D plots obtained for bluff bodies with the slit and without it differ each other in considerable manner. The most essential are the differences in close neighborhood of the bluff body. In the case of circular cylinder without the slit the characteristic region of reduced values of both velocity components is distinguished. On the contrary - in the case of circular cylinder with the slit we notice only the slightly reduced value of transverse velocity component in the shadow of the bluff body. The lengthways component, however, reveals considerable velocity values even in close nearness of the bluff body. This result is contradictory to boundary conditions where velocity component transversal to the wall have to come to zero value. Referring the values of velocity components with Fig.1., the sensitivity planes of hot-wires cause such malfunction, when v_x component is dominant. It can confirm the existence of perpendicular, to the bluff body, fluid motion in this region.

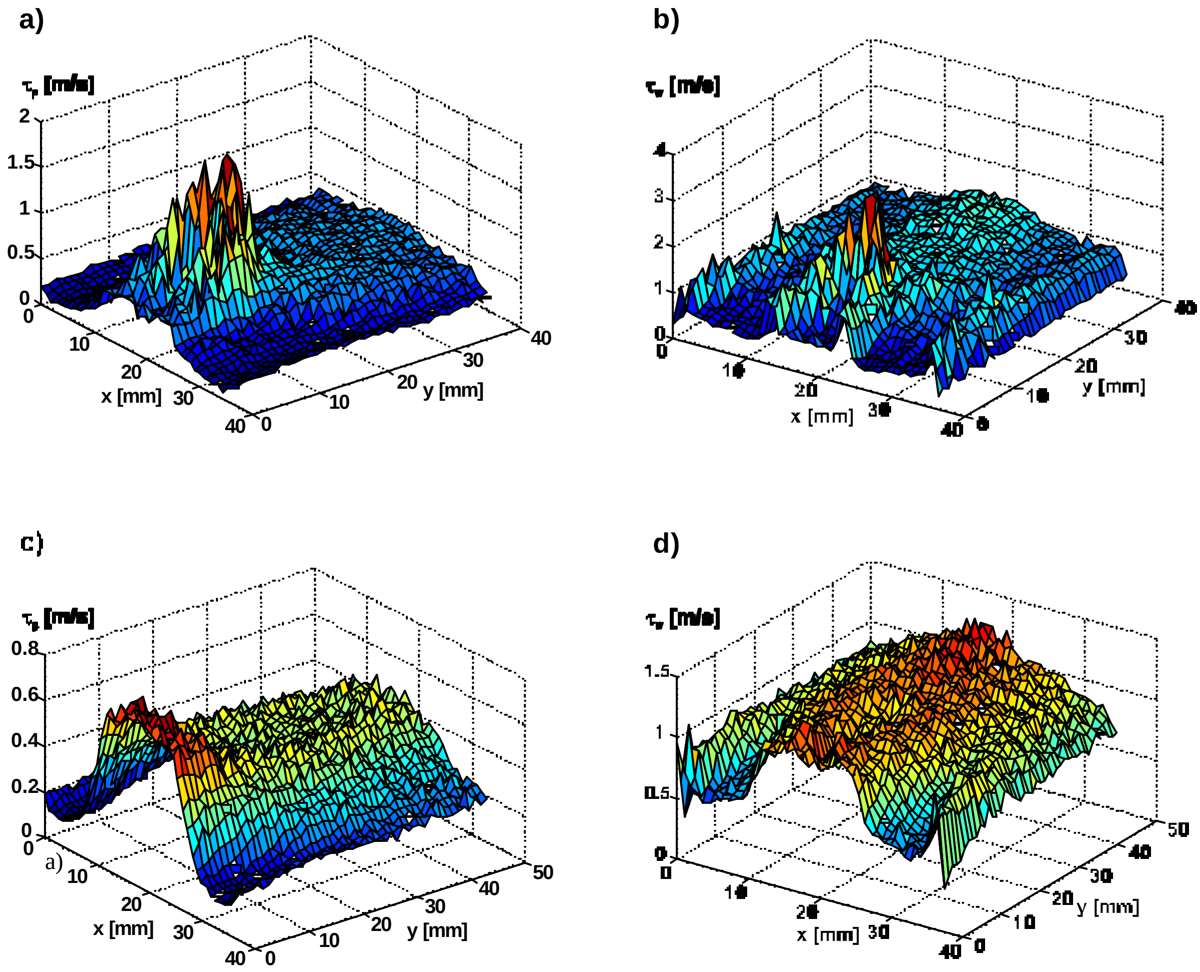


Figure 3. Turbulence distributions - transverse (τ_p) and lengthways (τ_w) - in axial plane perpendicular to the 13-mm circular cylinder - without slit (a&b) and with slit (c&d)

The differences noticed in velocity component distributions for both bluff bodies are confirmed on turbulence distributions plots (Fig.3.). Especially the 3D plots of v_p (Fig.2c) and τ_p (Fig.3c) are very similar, because of zero value averaged in time v_p component (boundary conditions). Thus, from eq.(2) turbulence definition, the calculated τ_p values correspond with v_p values. In all turbulence distribution 3D plots (except of Fig.3c) high values areas correspond to high gradient of velocity distribution. Comparing the local velocity and turbulence values with respecting the probe properties (Fig.1.) the rough interpretation of the flow circulation is feasible.

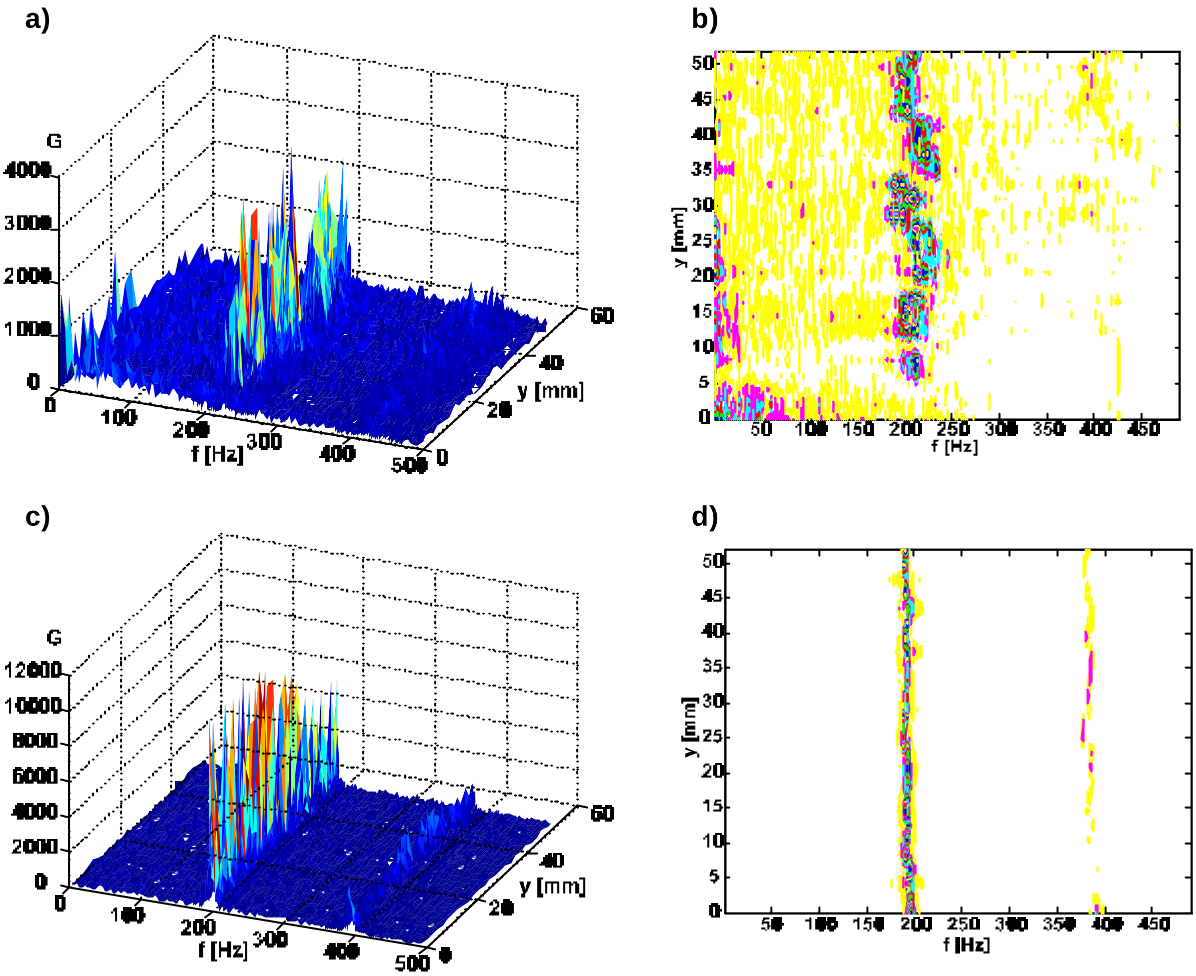


Figure 4. Power spectral density distribution of the transverse velocity component for circular cylinder of 13mm without slit (a&b) ant with slit (c&d).
Signal obtained along the line 6 mm distance aside pipe axis.

Spectral analysis of signals obtained from hot-wire probe was aimed at determination of their spectral properties. The value of the turbulence represents the intensity of ripple component of the fluid motion. Due to the spectral analysis, however, the determination of spectral properties of the signal is feasible. Particularly, in the vortex meter is very significant how much of the signal power belongs to the vortex frequency. The double frequency spectral line indicates the region with alternating velocity vector.

From the point of view of the signal processing, it is very important to maximize S/N ratio in the measuring signal. This value is very dependent to the bluff body design.

Presented in Fig.4. results of spectral analysis of transverse velocity component show the considerable differences in signal properties obtained from both types of tested bluff bodies. The power spectral density distribution for bluff body with the slit have much better S/N ratio and the power density line for the Strouhal frequency is better distinguished. In the case of the bluff body without the slit, however, the spectrum is rather broadened and in the close nearness of the bluff body disappears.

6 CONCLUSIONS

The hot-wire anemometer is a very useful tool for investigations of the phenomena in the vortex meter. Due to the method application, obtaining of additional information concerned the vortex shedding and especially the vortices development is feasible. On the basis of the results, the considerable differences in the vortex Karman street for tested bluff bodies without the slit and with the slit are found. The velocity distribution as well as the turbulence confirm, that the slit in the circular cylinder considerably improves generated vortices. It is strictly consistent with results of calibration carried out by the authors on the measuring stand. The spectral analysis of the measuring signals is found as very helpful approach in results presentation. Due to the spectral analysis application, the evaluation of generated vortices quality - from the point of view of signal processing easiness - is feasible.

Comparing turbulence distribution (Fig.3.) with referred spectra (Fig.4.) for bluff body without slit is noticeable, that intensive turbulence exists only up to 20 mm distance downstream the bluff body, only for 14mm<x<26mm because of gradient of v_p there. However, visible spectral line with Strouhal frequency exists over 50 mm distance along the axis (for x=20mm). Also the transverse velocity is distinguishable in similar distance (Fig.2a) with considerable decrease just behind the bluff body. Aside y axis for x=26mm the v_p values are rather low, thus the sharpness of the spectral line (Fig.4b) is unacceptable.

Finally, all mentioned above observations allows conclusions:

a) the slope of velocity distribution cause the peak of turbulence (similar to the boundary layer effect),
b) S/N ratio for the bluff body without the slit is much worse than the one with slit,
c) comparing the velocity components values, the circulation of the fluid can be roughly estimated in the investigated area.

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