Experimental investigation of the interaction of two cylinders in the flow pattern

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Abstract. This article discusses the behaviour and interaction of two circular cylinders in the flow pattern when one of the cylinders affects wake of the second cylinder. The wake behind the cylinder was investigated experimentally by using a time resolved PIV and CTA method. Velocity fields were obtained for several regimes of Reynolds numbers and several positions of the second cylinder. A frequency of vortex shedding was gained from the acquired images.

1 Introduction

Although the investigation of the mutual influence of the two cylinders in the flow field is given a lot of studies, it is still an open problem. Phenomena associated with the transition from a steady flow in the flow instability is still not fully explored, as well as the formation and behaviour of turbulent structures and especially the possibility of these structures and the stability of the flow of influence and later control. A knowledge of wake behaviour can have a major influence on the design and functionality of machines, systems engineering, technical applications, engineering structures and buildings, as well as finds application in other branches of natural sciences such as meteorology, astronomy and more.

To prevent undesired phenomena associated with the flow of the bluff body or, conversely, to promote desirable effects, it is necessary to characterize and identify the structure of the bluff body flow. Roshko in his work [1] describes a detailed research of a wake development behind a circular cylinder. The author divides the development of wake on several modes depending on the Reynolds number. More detailed research in this area allows for the development of measuring and computing methods in recent decades. M. M. Zdravkovich in his review [2] introduces the studies that solve the drag and lift in the tandem and side-by-side arrangement of two cylinders and influence of two identical cylinders on the frequency of vortex shedding. Strykowski and Sreenivasan in [3] deal experimentally and numerically the influence of the very small cylinder to the main cylinder and the formation of the vortex street behind the cylinder at low Reynolds numbers. In their work indicate that there are positions of secondary small cylinder in which it can control the vortex street. At

$Re = 80$ is reduced vortex shedding an average of 30%. Hwang and Choi classify in [4] methods of flow control for the bluff body and present results of comparing regions of attenuating instabilities using a small secondary cylinder. Mittal and Raghuvanshi solve in [5] the influence of a small secondary cylinder on the primary cylinder using numerical simulations at low Reynolds numbers. The authors compare their results with the experimental results of the work of other authors and focus on the causes of the influence of the control cylinders on the primary cylinder

This study focuses on acquiring knowledge about the influence of the size and position of the secondary cylinder to wake the primary cylinder. Experimental data are obtained using the time resolved PIV and CTA.

2 Experimental stands and measuring methods

2.1 Experimental stands

The experiments were carried out in two stands. First stand is a wind tunnel enabling a measurement with time resolved PIV, second stand is wind tunnel adapted for CTA method with hot - wire probe.

The first wind tunnel for measurement with PIV is closed circuit with open test section. The scheme is shown in Figure 1. The outlet nozzle has an octagonal shape. The maximum width of the outlet nozzle is 360 mm and maximum height is 200 mm. The test section is 395 mm long.

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Figure 1. Scheme of the wind tunnel

Measured cylinders were placed in a special construction in the test section. The first cylinder was fixed in the construction between two panels made from a plexiglass. The second cylinder was held between the two movable panels also made of plexiglass to allow a fluently move with the cylinder in vertical and horizontal direction in the first cylinder wake.

A measuring system of time resolved PIV consist of a laser diode, a high speed camera Olympus i-SPEED 3 and a Nikkor lens with 85 mm focal length and with extension. The laser diode has 1W output and wavelength of 532 nm. It was placed on the top of the construction, above the cylinders. The high speed camera has a resolution 1280 x 1024 active pixels and maximum frame rate 150000 fps, but for full resolution has maximum frame rate 2000 fps. For an experiment was used no more than 1500 fps, because the used laser diode doesn't have enough power for the higher frame rate. A fog generator Safex produced seeding particles for the PIV method. The Figure 2 shows an arrangement of the experiment.

Figure 2. Arrangement of experiment: 1 - camera, 2 – placement of laser, 3 – constructions in test section

The second tunnel for measurement with CTA is an Eiffel type wind tunnel (or open-circuit wind tunnel) with a closed test section. The length of the test section is 750 mm and its cross section has a size of 300 mm x 200 mm. Velocity range of this tunnel is 0-20 m/s and the turbulence intensity of the free stream in the inlet of the test section area is 1.1 %. The tunnel has an automatically

driven moving and measuring system for hot wire anemometry MiniCTA 54T30 (Dantec Dynamics) with 55P16 HW-probes and pressure velocity measuring technique include controlling and measuring software and real time FFT signal analysis, written in LabView (National Instruments).

3 Experimental results and discussions

The ratios of the cylinder diameters D/d (D – the diameter of first the cylinder, d – the diameter of the second cylinder) were 2.5, 2, 1.67 and 1. On the Figure 3 is an experimental set-up and coordinate system. The second cylinder was placed always behind the first cylinder.

Figure 3. Experimental set-up of the cylinders and a coordinate system. Origin of the coordinate system is at the centre of the primary cylinder.

Adjusting of a place of the cylinders based on review [4]. Authors of this review compare results of studies [3] and [6], where regions of influence (an attenuated instability) of secondary circular cylinder were observed. The coordinates of the second cylinder are shown in the Table 1. The R is position vector from the zero to the centre of secondary cylinder. The R can be calculated from the triangle, where coordinates x and y are hypotenuses. The second cylinder was placed behind the first cylinder in most cases, because the laser diode lighted the test section from above.

Table 1. Measured positions of secondary cylinder

Position No.	x/D	y/D	R
1	4.3	-1.25	44.8
2	3.2	-0.8	33
3	2.4	-0.8	25.3
4	1.95	-0.8	21.1
5	2	-0.6	20.9
6	1.5	-0.35	0.18
7	1.5	0	0

The regimes of the Reynolds numbers moved about in the range of 300 – 1300 for the TR PIV measurement (the regimes is related to the first cylinder).

3.1 Visualization

Visualisations of the flow field were obtained from PIV frames. Figures 4 and 5 show flow pattern for the cylinders ratio 2 and positions 2 and 3 for $Re = 1394$ (a flow direction is from left to right). The pictures are created from inverting of one frame from the camera. This visualizations show cylinders arrangement and basic characteristic of flow pattern. The first cylinder was overshadowed, because reflections from laser on its surface could destroy the camera.

Figure 4. Visualization of flow field for $Re = 1394$, $D/d = 2$, position 2

Figure 4. Visualization of flow field for $Re = 1394$, $D/d = 2$, position 3

3.2 Time resolved PIV

From the images obtained using time resolved PIV were evaluated velocity field, streamlines, vorticity and calculated vortex shedding frequency. For most of the measured positions and Re regimes was taken around 2500 images.

Figures from 5 to 11 shows streamlines for different cylinders arrangements, different D/d and several Re regimes (a flow direction is from right to left). This flow fields were obtain from vector statistic of 2500 velocity vector maps.

Figure 5. Streamlines for $Re = 549$, $D/d = 2.5$, position 7

Figure 6. Streamlines for $Re = 549$, $D/d = 2.5$, position 6

Figure 7. Streamlines for Re 549, D/d = 2.5, position 5

Figure 10. Streamlines for Re 549, D/d = 2.5, position 2

Figure 8. Streamlines for Re 549, D/d = 2.5, position 4

Figure 11. Streamlines for Re 549, D/d = 2.5, position 1

Figure 9. Streamlines for Re 549, D/d = 2.5, position 3

From these figures is obvious, that the smallest wake behind primary cylinder form, when the secondary cylinder is in position 1. This information about flow field confirms for other Re regimes and every D/d ratios. The velocity vector maps was obtained by adaptive correlation from each acquired images. The vorticity of flow field was calculated from definition

$$\omega = \left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z} \right) \vec{i} + \left(\frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x} \right) \vec{j} + \left(\frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y} \right) \vec{k} \quad (1),$$

where $\mathbf{v}$ is the vector of velocity and $\mathbf{i}$, $\mathbf{j}$ and $\mathbf{k}$ are the unit vectors in x, y and z direction.

On the Figures 12 and 13 is shown difference of flow field vorticity between position 1 and 4. The vorticity value for position 1 is little bit higher than for position 4, but it seems, that flow field for position 4 show higher vorticity for all flow field.

Figure 12. Vorticity of flow field for $D/d = 2.5$, $Re = 549$ and position 1

Figure 13. Vorticity of flow field for $D/d = 2.5$, $Re = 549$ and position 4

A power spectral density (PSD) was calculated from the measured velocity, which defines the distribution of signal power versus frequency. The formula for calculating the power spectral density S_{xx} is

$$S_{xx}(f) = \lim_{T_M \rightarrow \infty} \frac{1}{T_M} |X_{TM}(f)|^2 \quad (2) [8],$$

where TM is a measuring time, XTM is frequency spectrum, f is frequency. The PSD and the dominant frequencies were obtained using pwelch function in a MATLAB programming interface then, a graph of PSD for position 1 is shown on Figure 14. There is clearly evident the dominant frequency 19.04 Hz.

Figure 14. Graph of power spectral density

The Strouhal numbers were calculated from this dominant frequencies. On the Figure 15 is dependence of Strouhal number on R ratio for $D/d = 2.5$.

Figure 15. Dependence of Strouhal number on R ratio for $D/d=2.5$

The difference in value R for position 4 and 5 is very small, but it means for every regimes of Re a step change in value of Strouhal number. The position 3 ($R = 25.3$) has the lowest values of Strouhal number for three regimes of Re , but for $Re = 547$ this position mean a step change and St increases on value 0.25. The smallest fluctuations of St has the regime $Re = 311$.

3.3 CTA

Measuring with CTA was obtained for a compare with PIV results. On Figure 16 is this comparison. Identical values are only for three positions of measuring cylinders. Different results between this methods can be caused by incorrect measurement of the velocity in the CTA tunnel.

Figure 16. Comparison of Strouhal number between PIV and CTA

4 Conclusions

The investigation of flow pattern behind two circular cylinders was carried out. The influence of the secondary cylinder is different for different Reynolds numbers regimes. The obtained figures with evaluated streamlines for each position of cylinders show the size of wake behind the primary cylinder. It is obvious from the streamlines that there exist areas of the positions of the secondary cylinder, which considerably increase the size of the wake. From the evaluated velocity fields were obtained vorticity field, which correspond with the findings from the evaluation of streamlines.

For each position of the secondary cylinder was detected frequency of vortex shedding. From these frequencies it can generally say that there was no significant trend for the particular position of the secondary cylinder.

It was realized comparison between two different experimental methods: PIV and CTA. These two methods were not measured in the same wind tunnel, and even this may be the reason why the results of St do not match exactly.

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