MŰEGYETEM 1782

GÉPÉSZET 2010

PROCEEDINGS OF THE SEVENTH CONFERENCE ON MECHANICAL ENGINEERING

May 25-26, 2010
Budapest, Hungary

COMPACT disc
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ISBN 978-963-313-007-0

Budapest University of Technology and Economics
Faculty of Mechanical Engineering

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PROCEEDINGS OF THE 7th CONFERENCE ON MECHANICAL ENGINEERING

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May 25-26, 2010, Budapest, Hungary

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Gépészet 2010. Proceedings of the 7th Conference on Mechanical Engineering. Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Budapest, 2010

ISBN 978-963-313-007-0

Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Budapest, 2010

FOREWORD

It was 12 years ago when the Faculty of Mechanical Engineering at the Budapest University of Technology and Economics started the conference series 'Mechanical Engineering'. Each conference of the series had defined a special topic in mechanical engineering, in this year our focus is the 'Advanced Technologies'. According to the goal and the desire of the organizer this conference provides a forum for presenting new scientific results in different fields of mechanical engineering and possibility for young scientists to introduce their work. In this year the organizers tried to open the conference inviting prominent members in the IPC and more foreign authors and participants. Keeping this track the actual conference the 7th 'GÉPÉSZET 2010' is a new starting point which retains the original goals and moves to the direction of the recognized international conferences.

Parallel this conference the Industrial Design Education celebrates its 15th anniversary. A special workshop was organized in the frame of GÉPÉSZET 2010 as a simultaneous program of the conference. Other activity in the frame of this conference the 'Precision Glass Manufacturing' training program organized by the Production4micro network of the EU supported Integrated Project.

Professor Gábor Stépán
Dean, Faculty of Mechanical Engineering

GÉPÉSZET 2010

7th Conference on Mechanical Engineering

Budapest University of Technology and Economics, May 25-26, 2010

Organised by Faculty of Mechanical Engineering

APPLICATION OF SCHLIEREN MEASUREMENT TECHNIQUE FOR FORCED CONVECTION FROM A HEATED CIRCULAR CYLINDER

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Abstract: *Flow around cylinders has been investigated experimentally for a long time and has a very broad literature. The main objective of the present experimental investigation is to determine the temperature field around a heated cylinder for the case of low Reynolds number and forced convection. The present experiments were also carried out in a wind tunnel using Schlieren systems. Z-type Schlieren and BOS (Background Oriented Schlieren) systems were built up for our measurements. Detailed information about measurement systems and first results are presented in this study. Based on the results the future goals are determined.*

Keywords: *Schlieren, BOS, experiment, temperature field*

1. INTRODUCTION

Prismatic bodies placed in a flow often have different temperature compared to that of the surrounding such as electrical transmission lines, cartridge heaters, pipes of heat exchangers, factory chimneys and so on. The structure of the flow, developing around prismatic bodies has been already examined for a long time. The evolving Kármán vortex street was and is examined by numerous researchers both experimentally and numerically. Schlieren measurement technique has also been investigated by many researchers [1-3]. For example, such a Schlieren system can be used for the visualization of shockwaves in a supersonic tunnel [4-6]. The system is basically adapted for 2D measurement (first part of this project); there are many problems with 3D measurements [1]. The method has also been used for general visualization of heat transport processes [1]. Our experimental tests were carried out at low Reynolds numbers (Re<200), thus the flow field was approximately two dimensional (same flow in every normal plans of the heated circular cylinder). In this work the adaptability of a Schlieren system is investigated, which should be ultimately applicable in a wind-tunnel in order to investigate forced convection flows. An electrically heated circular cylinder was placed perpendicular to the flow in a wind-tunnel. The first objective of this work is to compare the different type of Schlieren system such as: z-type Schlieren system and BOS (Background Oriented Schlieren) system.

The main objective of this research is to determine the structure of the instantaneous temperature field. The results show, that both systems will be good for quantitative measurements, but the BOS system results will be better for quantitative image processing. Image processing will be the next important part of this project.

2. PRINCIPLE OF SCHLIEREN MEASUREMENT TECHNIQUE

The basic optical Schlieren system uses light from a single collimated source shining on, or from behind, a target object. Variations in refractive index caused by density gradients in the fluid distort the collimated light beam. The collimated light is focused with a lens, and a knife-edge is placed at the focal point, positioned to block about half the light. In flows of uniform density this will simply make the photograph half as bright. However in flows with density variations the beam is deviated and focussed in an area covered by the knife-edge and thus is blocked. The result is a set of lighter and darker patches corresponding to positive and negative fluid density gradients in the direction normal to the knife-edge. When a knife-edge is used, the system is generally referred to as a Schlieren system, which measures the first derivative of density in the direction of the knife-edge. Temperature is determined from density (refractive index) [1]. The principle of that is shown in Figure 1.

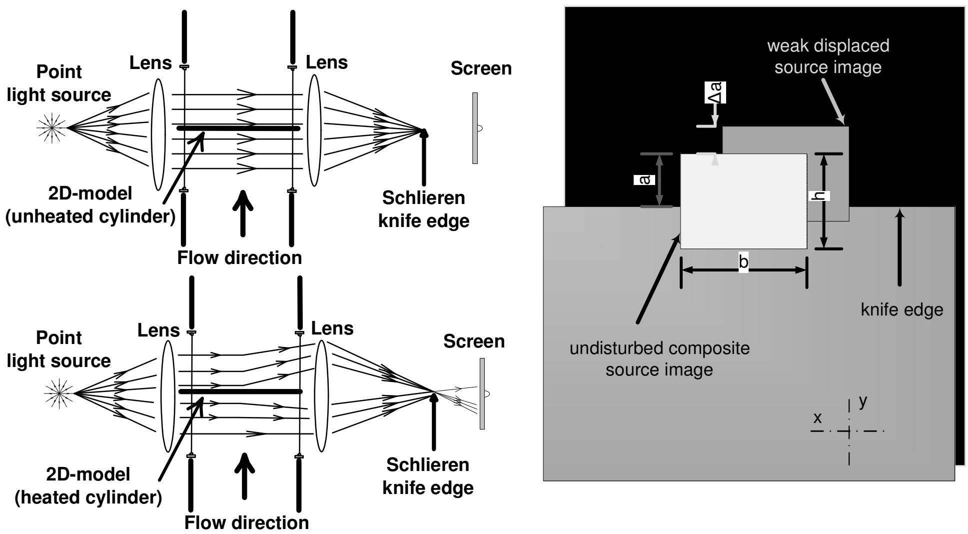

Figure 1. Measurement setup of Schlieren system

The sensitivity of a measuring instrument is one of its basic characteristics, relating the output of the instrument to the input received. In the case of Schlieren optics at least those considered here – the output is a 2-D image in x and y-coordinates. More specifically, it is an array of picture elements characterized by amplitude or greyscale contrast variations.

Now consider the case of a Schlieren object in the test area that refracts a certain light ray through angle ε having y-component ε_y (see in Figure 1). This causes a weak elemental source image to shift upward in the knife-edge plane by a distance $\Delta a = \varepsilon_y \cdot f_2$. Substituting Δa for a, one obtains:

$$\Delta E = \frac{B \cdot b \cdot \varepsilon_y}{m^2 \cdot f_1} \quad (1)$$

which, describe the incremental gain of illuminance at the corresponding image point due to the refraction ε_y in the test area. Where B is the illuminance of the light source and f_1 is the focal length of the first mirror and m is the magnification factor (ratio between image size and test area).

Contrast in the Schlieren image refers to the ratio of differential illuminance ΔE at an image point to the general background level E.

$$C = \frac{\Delta E}{E} = \frac{f_2 \cdot \varepsilon_y}{a} \tag{2}$$

This image contrast is the output of the Schlieren instrument [1]. The input is a pattern of irregular ray deflections ε, resulting from refractive-index gradients in the test area, in an otherwise regular beam. Since the sensitivity of any instrument is basically an influence coefficient, i.e. d(output)/d(input). Schlieren sensitivity is the rate of change of image contrast with respect to refraction angle:

$$S = \frac{dC}{d\varepsilon} = \frac{f_2}{a} \tag{3}$$

Temperature field can be calculated from the contrast changes (refractive-index changing).

3. PRINCIPLE OF BACKGROUND ORIENTED SCHLIEREN SYSTEM

The set up for BOS measurements requires only a single camera focused on a background, which normally consists of a paper with randomly distributed dot pattern [6]. The size of the pattern should be optimised according to the magnification of the set up such as one dot is imaged by 2-3 pixels of the CCD chip. At least two pictures have to be stored: a reference image without the density effect and a measurement image, with the investigated density effect. The principle set up is shown in Figure 1.

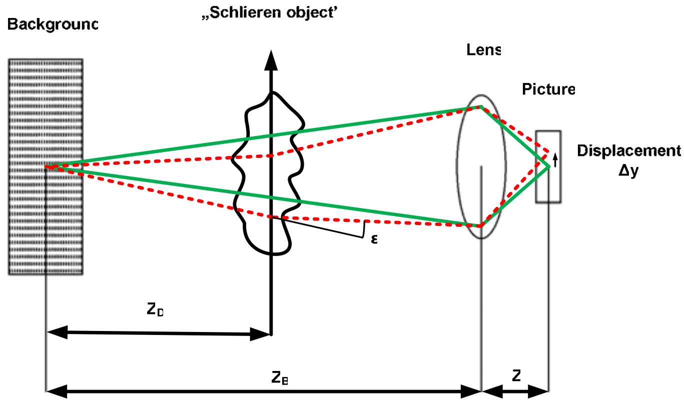

Figure 2. Principle of BOS system

Without the density effect, one point of the background is imaged on the image plane as shown by the green line. With the density effect, the light rays will be deviated by the angle ε and will be imaged on another location on the background, as shown by the dashed red line. The distance between the two images of the background pattern is named: Δx. Due to the density gradients, the background pattern will be imaged on another place on the measurement image. The displacement of this pattern can be detected by using standard cross correlation algorithms. The cross correlation algorithms developed for particle image Velocimetry (PIV) are very much suitable for this task.

The displacement vectors resulting from PIV analysis must be translated into density gradient vectors in order to move the BOS analysis towards completion. By assuming the flow is strictly two-dimensional, the density gradient along any given light ray passing through the Schlieren object can then be assumed constant [5]. Given these assumptions, the relation between image displacement and density gradient can be simply written using two algebraic equations. Equation 4. defines the relationship between angular deflection of a light ray (ε) and image displacement (d) as

$$\varepsilon = -dh / z_D \quad (4)$$

where h is the physical dimension of a pixel in the background plane (i.e. a conversion between displacement in pixel units to a length unit) and z_D is the distance between background plane and Schlieren object. Equation 5. defines the relation between density gradient $(\nabla\rho)$ and angular deflection (ε) as

$$\varepsilon = K \cdot W \cdot \nabla\rho \quad (5)$$

where W is the width of the Schlieren object. The variable K is the Gladstone-Dale constant which is found using the relation between density (ρ) and the index of refraction (n) as shown in Equation 6.

$$n = 1 + K \cdot \rho \quad (6)$$

It is interesting to note that there is no calibration required for this 2D background oriented Schlieren analysis; simply a few careful measurements are all that is needed to convert displacement to density gradients.

4. APPLICATION OF THE SCHLIEREN SYSTEM IN THE WIND TUNNEL

BOS measurements have been carried out in the Laboratory of Fluid Dynamics, University of Magdeburg in Germany (see in Figure 3.).

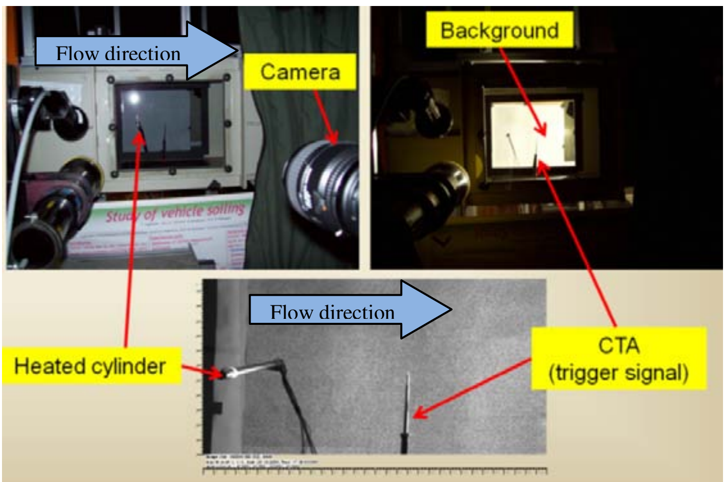

Figure 3. Set up of BOS system

A random dot field was applied to the background and camera type was Dantec® FlowSense Mk2 (maximum frame rate: 30.1 Hz in single frame mode).

The Schlieren system is applied to qualitatively describe the temperature distribution in a flow around a heated cylinder [4]. The z-type Schlieren measurement system has been adapted according to the available place around the test section of the wind tunnel. Properties of z-type system are the following: mirror thickness 25% of the diameter, optical quality of the mirror $\lambda/8$, offset angle (θ) 3.81°, f-number $f/10$ and distance between the mirrors 4500 mm (see in Figure 4.).

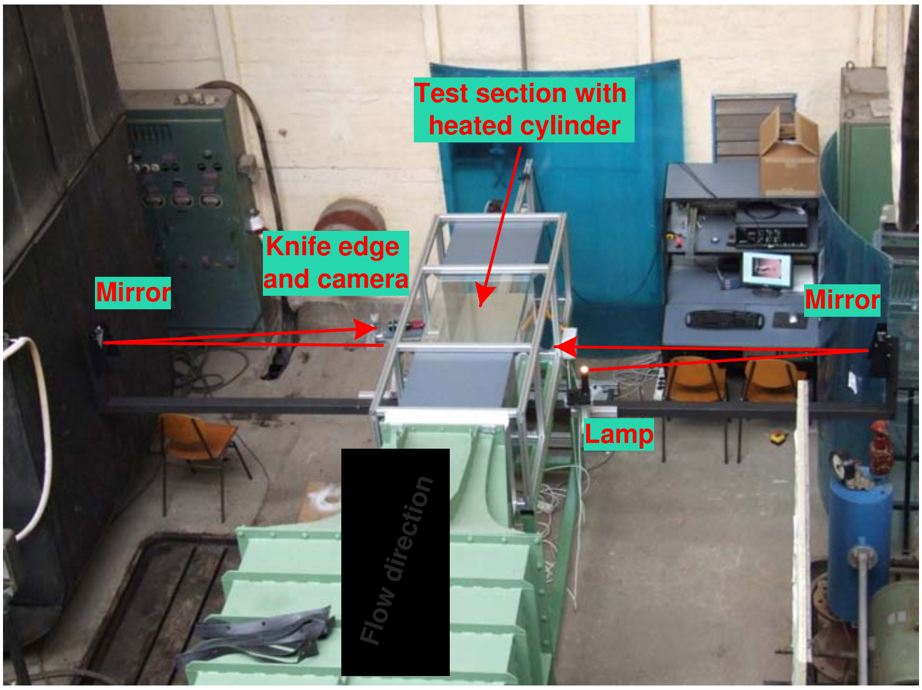

Figure 4. Set up of z-type Schlieren system

5. VISUALIZATION OF THE TEMPERATURE FIELD

First optical tests helped to determine the proper background pattern for BOS in the present configuration. The recorded BOS images were processed by a commercial PIV-software. The temperature field can finally be quantified by means of this software based on post-processing. First BOS tests can be seen in Figure 5.

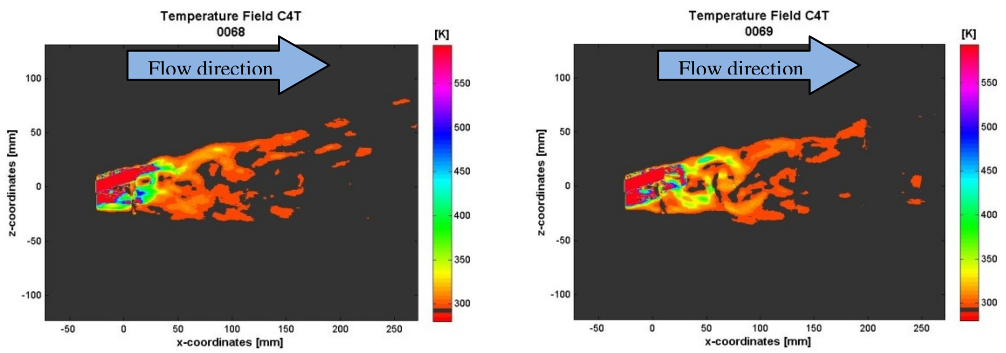

Figure 5. Temperature field around heated cylinder by BOS (573 K and 0.3 m/s)

The temperature field also was determined by z-type Schlieren system. First result for different velocities is shown by the Schlieren images in Figure 6.

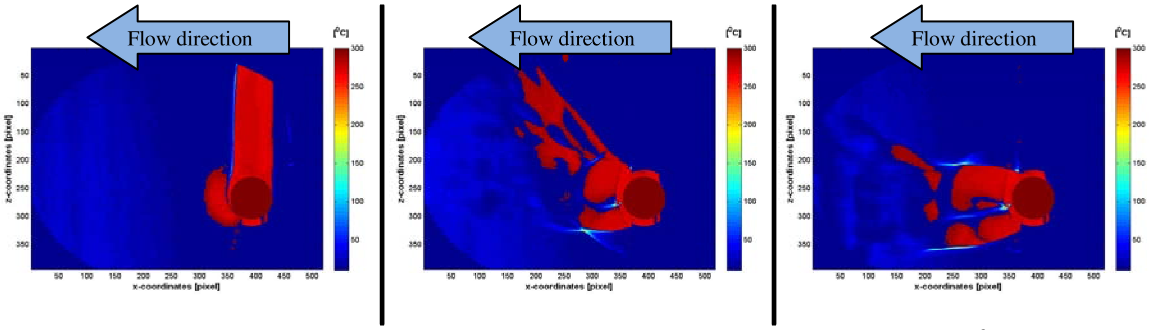

Figure 6. Temperature field around heated cylinder by z-type Schlieren (300 ^oC and velocity range 0-0.3 m/s)

The principle usability of our z-type Schlieren system was confirmed by these results, as with increasing velocities, the temperature distribution was changing as well. Free and forced convection can be recognized Figure 6.

6. CONCLUSION

The measurement results presented in this work confirm that the BOS and z-type Schlieren system are in principle suitable to visualize and quantitative analyze the temperature field in a wind tunnel. However, considerable improvements (such as precision knife edge and special optical system to solve the distortion problem) are still required in the existing system to make more precise and really accurate measurements. In order to analyze the images in a further step, the recording quality must be increased to get more meaningful images.

ACKNOWLEDGEMENTS

The authors are grateful to NKTH-OTKA (68207) and to the Hungarian-German Intergovernmental S&T co-operation programs P-MÖB/836, for the financial support of this research.

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