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EXPERIMENTAL STUDY OF THE FLOW FIELD IN T-JUNCTION MODEL USING PIV METHOD

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Abstract: *Reported here is the experimental study in the pipe line element T-junction. The velocity fields were measured by PIV method with 3-camera alignment. This alignment makes accessible T-junction areas covered by image distortions and refraction irregularities in drilled glass block. Four basic connection regimes are studied with flow ratios into inlet branches in turn. Flow field is described with a numerical vector maps and presented as scalar maps with streamlines. Velocity profiles in the inlet and outlet branches are generated. Visualizations of the flow with streamlines and vector fields provide the basic characteristic of flows mixing, separations, vorticities etc. Analyzed datasets are used for evaluation and verification of numerical models.*

Keywords: ***T-junction, PIV, measurement, calibration.***

1. Introduction

In these days every industrial application includes the complex system of conducting pipes. The pipe systems are used for water delivery in agriculture, combustion chambers, cooling and heating systems, and chemical reactors, as well as for household application. Every system is divided into many branches. The pipeline nets consist of pipes, shaped pieces: T-junctions, elbows, contracting and expanding elements, pumps, valves, taps, etc. Each splitting and T-junction brings unsteady structures to the flow field and generates disturbances and energy losses.

The aim of the research in this area is to design pipe system that enables to keep required parameters at the exit of the system with minimum consumed energy and without any systems destruction.

The suitable way for the system behavior prediction is a numerical simulation of the whole complex system or its most exposed parts. The mathematical models have to deal with the pressure variables as the system is unsteady, the energy balance and many boundary conditions.

The applicable mathematical model has to be confirmed by the dataset measured on the real model. The previous experimental studies approached the model with the square pipe profiles (Hirota et al., 2008; Louda et al., 2010). This simplification enables comfortable optical access, but brings incomparable dataset to the real situation.

This study was realized on the real glass model of the T-junction with circular profile, the numerical model of this geometry type was designed and described in (Stigler, 2006; 2006a, 2007). The PIV measurement of the circular profile meets many procedural problems such as image distortions, border refraction changes and the image shift in the tube intersection. The solving of these basic problems is described in this paper.

The 3-camera PIV system was applied for the experimental study of the unsteady turbulent flow. This paper is focused on designing the calibration sequence method. The functionality of this method is proved and demonstrated on the real model instance measurement.

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2. Experimental setup

The experimental study of the T-junction real model with circular profile meets many procedural problems such as image distortions, border refractive index changes and the image shift in the tube intersection. These problems emphasize during the image analyzing and flow velocity processing. The 3-camera alignment is used to avoid further complications. This new alignment brings enough information for the calibration sequence method application and image rectification.

The Fig. 1 shows the laser and the 3-camera alignment to the model position. The real glass model was connected to the open pipe system with the pump and the header tank. The T-junction is drilled and polished into the monolithic glass block. The inner diameter of the circular profiled branch is ∅ 50 mm and it is branched under 90°. The whole system was filled with test fluid - water at 20°C.

The investigated area was illuminated by Nd:YAG 532 nm green pulse laser horizontally set to the model. The first camera was fixed above the model to observe the T-junction area. The next two cameras were put together and fixed in angle 45° with laser plane.

The inflow rate was constantly kept on 5.5 l/s. The flow field was measured in several states: a) branch A opened, branch B closed, b) branch B opened, branch A closed, c) branch A and branch B opened with the flow dividing in the ratios 20% - 80%, 40% - 60%, 60% - 40%, 80% - 20%.

The test fluid was seeded with Rhodamine B coated 10 μm particles and the cameras were set with orange 570 nm filter to reduce the glass wall reflections.

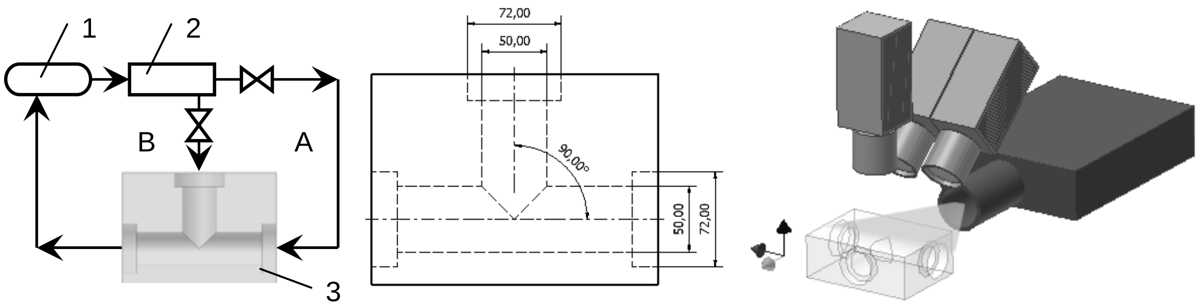

Fig. 1: Measurement circuit (1) header tank, (2) pump, (3) glass model, (A) and (B) inlet branches; T-junction model proportion; Experimental setup and measurement system alignment.

3. Calibration methods

Experimental data were recorded according to the setup mentioned in Chapter 2. Three cameras captured the laser lighted plane under different angle and with non-equal magnitude. Image analyzing algorithms were designed to assemble these camera's images. The calibration procedure was split into four steps:

1. calibration images recording and pre-processing,
2. camera image dewarping,
3. dewarped image rotation and the change of magnitude,
4. images assembling.

The special calibration target was manufactured for the purpose of calibration. The target filled whole area of the T-junction model. Plane of the target covered with dot matrix was aligned into the laser light sheet in the central line of T-junction. Calibration records of this target were used to calculate the image distortion model.

The distortion of the image was caused by the camera recording parallax (see the experimental setup in Fig. 1) and the curvature of drilled glass wall. Calibration images were preprocessed to identify the maximal amount of dots in the target matrix, original captured image was not well lighted and did not offer sufficient contrast between matrix dots and background. Partial tresholding algorithm and mathematical morphology functions solved this drawback. All camera images were calibrated and dewarped separately with appropriate calibration model.

The optical axes of cameras were not parallel, so the images should be rotated before assembling. Dot matrix was used again to define the rotation angle of each camera image. Distance between the laser sheet and the camera chip differs a little, so the magnitude of each camera image was adjusted. The methods of subpixel interpolation were used for the ratio recalculation to keep the maximal accuracy.

In the final step the rebuilt images from three cameras were put together. The area with the examined volume was selected, so the masking procedures were not necessary. The result of images rebuilding and assembling is seen in Fig. 2.

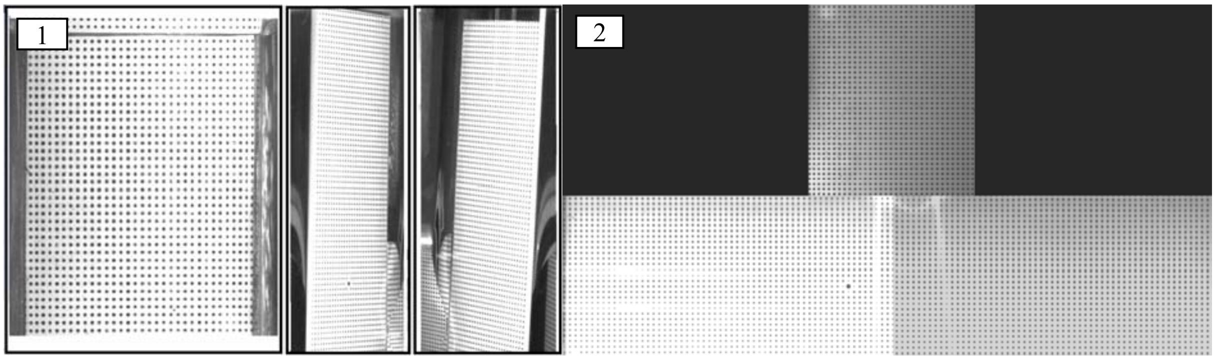

Fig. 2: Image distortion (1) before and (2) after calibration process and camera images assembling.

4. Results and discussion

In this chapter there are presented only some typical results of the flow field in one specific regime. Datasets of all regimes and all ratios will be used for the evaluation and verification of numerical model. The flow incomes to the straight branch A and the sideward branch B. On the vector map in Fig. 3 the flow field of ratio 40% - 60% is captured. Vectors in the area close to the outlet demonstrate 3-dimensional character of the flow.

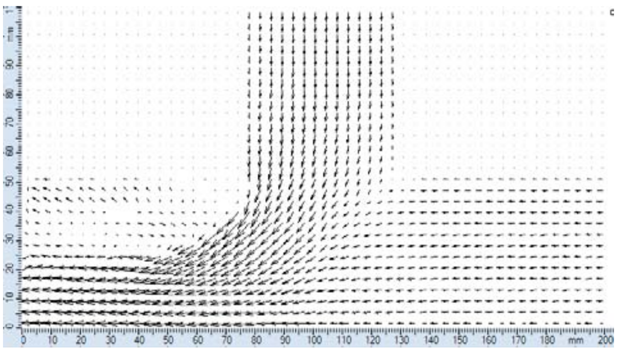

Fig. 3: Flow field of the ratio 40% - 60%.

Mixing of the flow, snap to zone and the flow separation changes are displayed and compared on the scalar maps with stream lines of the ratios 40% - 60% and 80% - 20%.

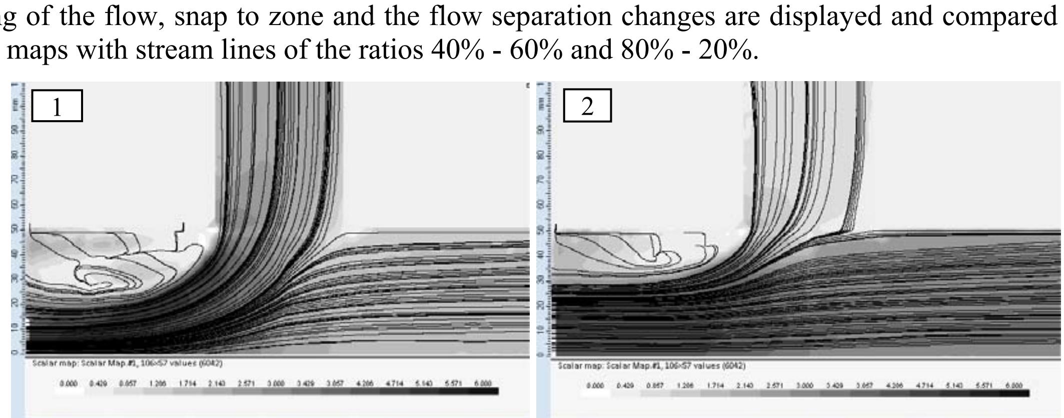

Fig. 4: Comparison of the flow in the ratios (1) 40% - 60% and (2) 80% - 20%.

Velocity profiles in all three branches are presented in the Fig. 5. Profiles are plotted in the distance of 1.5 diameters from the T-junction axes intersection. As it is seen in Fig. 5 the velocities are not calculated close to the wall. PIV results are influenced by laser light reflections on the glass surface and also by considerable velocity gradient in the interrogation area in witch velocity vector is determined. This effect is significant in the boundary layer of the flow. The dimensions of interrogation area correspond to 1.8 x 1.8 mm. Half of this area closer to the wall is masked and not exploited for velocity calculation to suppress these systematic errors.

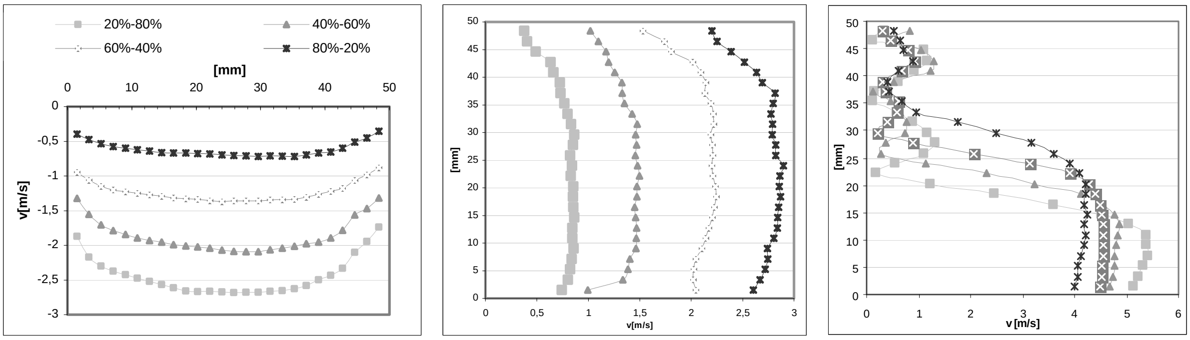

Fig. 5: Velocity profiles, 1.5 diameters from the axes intersection; left-branch B, center – branch A, right – outlet branch.

It is an obvious influence of the flow inlet in the sideward branch B. Velocities closer to the (right) wall are decreased by the flow blending (ratios 20% - 80%, 40% - 60%, 60% - 40%).

5. Conclusion

Experimental study of the flow in real T-junction model with circular profile has been made. Flow field was observed with a 3-camera PIV alignment. Unique image analyzing and calibration methods were designed. The T-junction flow characteristics were studied in four regimes of connection and various input flow ratios. Fluctuations, flow separations characteristics and 3-dimensional character of the flow were identified.

It confirmed the suitability of the designed 3-camera alignment and calibration methods on the experiment, where the image distortion occurs and direct optical access is unavailable.

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References

Hirota, M., Nakayama, H., Koide, S., Takeuchi, I. (2008) Experimental Study on Turbulent Flow and Mixing in Counter-Flow Type T-Junction, in: Journal of Thermal Science and Technology, 3, 1, pp. 147-158.

Louda, P., Kozel, K., Příhoda, J., Beneš, L., Kopáček T. (2010) Numerical solution of incompressible flow through branched channels, Comput. Fluids, doi:10.1016/j.compfluid.2010.12.003.

Stigler, J. (2006) Tee junction as a pipeline net element Part 1. A new mathematical model, in: Journal of Mechanical Engineering 57, 5, pp. 249-262.

Stigler, J. (2006) Tee junction as a pipeline net element Part 2. Coefficients determination, in: Journal of Mechanical Engineering 57, 5, pp. 263-270.

Stigler, J. (2007) Mathematical model of the unsteady fluid flow through tee-junction, in: 2nd IAHR Int. Meeting of the Workgroup on Cavitation and Dynamic Problems in Hydraulic Machinery and Systems, Timisoara, Romania, pp. 83-92.