Visualization of flow in nuclear reactor fuel cell model

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Abstract The injection of dye is long time a popular method of visualization in a water flow. In paper are described experimental works with model of nuclear reactor fuel cell. In water flow is injected acrylic dye by manual piston pump. Filament lines are illuminated with Xenon stroboscopic lamp. Video sequences are realized with high speed digital monochromatic video camera, frame rate up to 50 images per second. For frame acquiring and analysis is used software Motion studio pro.

1 Introduction

Flow visualization in water has played an important role in the understanding of fluid motions. It is clear that visual observations of flow phenomena were the first and, for a long time, the only experimental techniques available. One of the most important discoveries in the history of experimental fluid mechanics was a result of using aniline dye to produce coloured water. This was the Osborne Reynolds experiment (1883) with a small filament of coloured water in the center of a tube filled with clear water. As the velocity was increased through the tube, the transition from laminar to turbulent flow was observed by watching the formation of eddies and the subsequent diffusion of the coloured water. Excellent reviews of the many available techniques have been presented by Merzkirch [1]. A large variety of experimental equipment and procedures has been used in connection with the dye injection method of flow visualization. In this article are presented experimental works, which was realized on a model of fuel cell reactor.

2 Experimental model and test rig

Model of the VVER 440 nuclear power plant fuel cell is installed in the laboratory of The Institute of Thermal Power Engineering, Slovak University of Technology in Bratislava. For visualization experiments was developed model of mixing chamber. Material of the chamber is fully transparent, plexi-glass in this case. Geometrical characteristics: cuboid with hexagonal cross section. The model is created with the 1:1,125 scale. More information about the model and measurements are possible in the previous articles [2], [3]. Physical model of fuel assembly is designed for observation of water flow in fuel assembly output section. In the plane of fuel rod bundle ending are visualized a mixing processes: heated (primary) water that is flowing along fuel rods bundle with cool (secondary) water flowing from one of the tube triplet α, π, γ with outer diameter 8 mm and inner diameter 5,6 mm and/or central tube with outer and inner diameter 10 mm and 8,5 mm. A large number of dyes and dye solutions have been used for the marking of filament lines in water tunnels [1]. The most popular used dyes are food colouring, acrylic painting pigments and ink. Many other substances, including fluorescent materials, have also been used. Presented works was realized with acrylic painting pigment as a colour filament. Pigmented flow was illuminated by Xenon stroboscopic lamp 4. Used stroboscopic lamp is used as a back light configuration **Fig. 1**. This configuration of the illumination lamp provides a strongly diffuse light, because the light flash is goes trough the mixing chamber 1, which is filled with the water. Mixing flow is acquired by digital monochromatic camera 2.

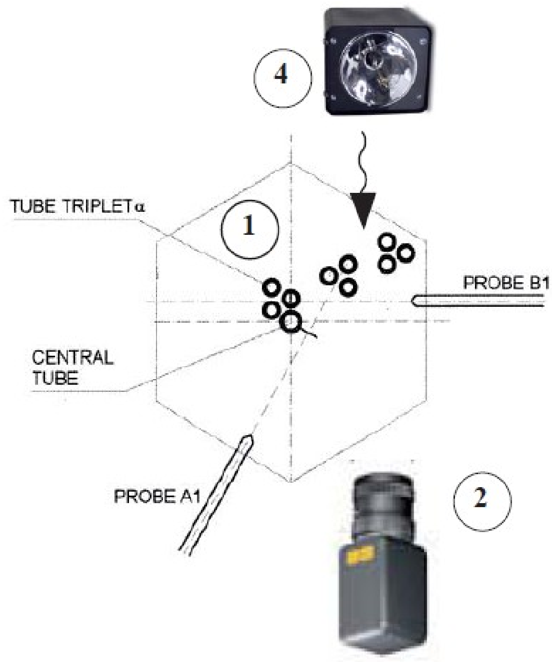

Fig. 1 Basic diagram of mixing flow visualization

The injection of dye without significantly altering the flow under study is a primary concern. It is important that the velocity of the injected dye must be equal to the velocity of the surrounding flow. This helps maintain a stable dye filament and reduces the disturbance to the surrounding flow. The problems of injecting dye from manually operated a volume displacement pump upstream of the model are the same as with the early smoke tunnels. The presence of the injection rake or tube in the flow disturbs the chamber flow, which in turn, disturbs the dye filaments. To circumvent this problem, the dye is usually injected from pipes in triplet configuration of the model. It is difficult to accurately pulse dye filaments for direct velocity measurements, and thus, continuous dye filaments are generally used.

3 Specification of experimental apparatus

Flow visualization is powerful method for observation a several aspects of the mixing flows into model of fuel cell chamber. The basic schema of the experimental set up for mixing flow visualization behind the fuel rods is presented in **Fig. 2**. Experimental configuration of visualization parts is integrated from following components and subsystems: 1. This part is a special hydraulic chamber. Construction of the chamber was described in a previously subsection, also you can see details in previously published articles. 2. The high speed digital video camera. This is a monochromatic digital camera RedLake Y3. This camera has integrated CMOS video chip with very low inter-frame time (less than 100 ns in double rate mode). Digital camera has embedded 4 GB video memory and digital communication links USB 2.0 and Giga Ethernet. For synchronization of Xenon lamp driver is used TTL output. 3. DAQ, vision and control system. System is integrated at Windows XP Workstation platform. DAQ and control I/O card is from National Instruments product range. DAQ I/O card is used for control of the experiment. For vision applications is used software Motion Studio (Motion Studio Pro for selected analyses). 4. The illumination tool. MVS Machine vision stroboscope is designed for fixed installation in any application requiring continuous stroboscopic visual inspection. The MVS has an extremely bright xenon light output with adjustable pulse width and focal distance for optimized target illumination. Connect a existing trigger signal or the optional Frequency Controller with LCD. Connect multiple units together in parallel for applications with wide illumination area requirements. 5. Driver for high voltage xenon stroboscopic lamp. Driver is synchronized from Y3 digital video camera by TTL synchronisation link.

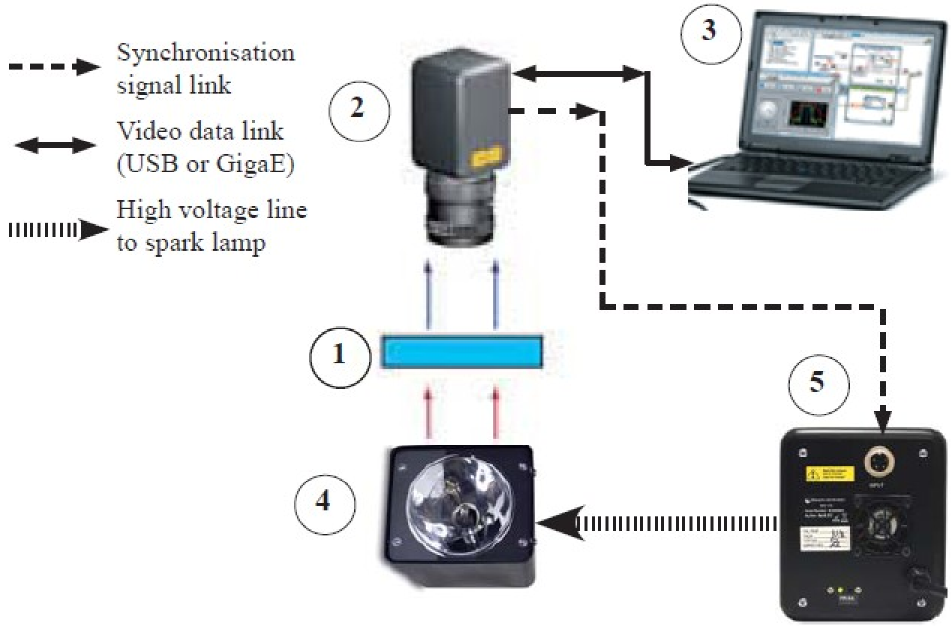

Fig. 2 Schema of the experimental set

In many applications was used a photographic techniques for image acquire. Because the velocities involved in experimental mixture chamber are quite low and there is great contrast between the coloured dyes and the surrounding water flow, no exotic photographic techniques are necessary. In presented works is used vision system monochromatic vision system.

4 Results of the experiments

Acquired data from experimental system described in preliminary chapter have two marginal characteristics: numeric data - acquired values of a analog physical signals (e.g. pressure, temperature, mass flow) and calculated values are stored as a data file [2]. Video experimental data are stored in digital camera video memory as first step, after the data are transmitted to Vision software via communication link (USB 2.0 as standard) and stored as a digital video file (HDD of DAQ and Vision system). Format of the video file is optional, but saving as *.RAW format is necessary for advanced post-analysis. Via decoding of stored *.RAW video file the set of the digital pictures is available for detail analyses and advanced measurements, **Fig. 4**.

Experiments were realised in a few steps. The first one: choice adequate apparatus configuration (optical conditions, time of exposition, number of acquired frames, video sequence durations, etc). The second one: focussing of the region of interest. This is a very difficult in the case, when calculation of the focussing distance is impossible. However, another focussing method is necessary. Focussing of ROI in mixing chamber was realised with air bubbles as a trace particles, **Fig. 3**.

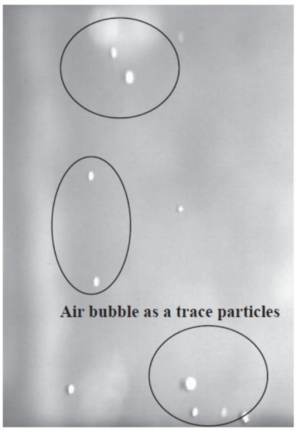

Fig. 3 Air bubble for ROI focussing

Fig. 4 Pictures isolated from video sequence

5 Conclusion

In the article is presented one method for visualization of flow in mixing chamber of model the fuel cell model. Visualization of two flows (cold and heated water) is realized by the injection of the acrylic pigment into mixing flows. Experimental results of the first experiment phase have qualitative character only, **Fig. 4**. For quantitative description of the mixing flows is necessary modification of the experimental test rig and analyses methods.

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