PIV Measurements in the Draft Tube of a Down-Scale Propeller Turbine: Phase-Averaged Analysis

N. Sotoudeh[1], S. Shirghaee[1], L. R. Andersson[1], J. Sunstrom[1], M. Raisee[2], M. J. Cervantes[1]

[1]*Department of Engineering Sciences and Mathematics, Division of Fluid and Experimental Mechanics, Luleå University of Technology, Luleå, Sweden*

[2]*School of Mechanical Engineering, University of Tehran, Tehran, Iran*

Hydraulic turbines act increasingly as a balancing tool of the electrical grid due to the intermittent participation of other renewable energy sources in power generation. As a result, they run more often in off-design conditions. Instabilities arise away from the best efficiency point (BEP) for single regulated hydraulic turbines such as propeller and Francis turbines. During part load (PL), the rotating vortex rope (RVR) generates synchronous and asynchronous pressure oscillations, which increases wear and tear and decreases hydraulic efficiency. Therefore, accurately evaluating and understanding the flow field away from BEP is necessary to widen the operation of single regulated hydraulic turbines.

Particle image velocimetry (PIV) is used in the present study to measure the velocity profiles in the draft tube of a down-scale propeller turbine. The turbine consists of a spiral casing, a distributor with eight stay vanes and ten adjustable guide vanes, a runner with a 100 mm diameter and six blades, and a draft tube with a plexiglass cone. The velocity is measured using 2Dimensional-2Components (2D-2C) and stereoscopic 2D-3C PIV during PL, with 85% of the turbine's BEP discharge. To track the phase of the RVR motion, two pressure sensors with a 180˚ circumferential separation were mounted on the draft tube wall. The pressure signal was subsequently used as a reference for phase averaging of the PIV data. To synchronize the pressure and PIV measurements, the triggering signal of one camera and the pressure were recorded on the same DAQ.

The PIV experiments were performed using a commercially available device from the Lavision. The flow was seeded with ten µm diameter particles and illuminated with an ND: YAG laser. The high-speed CCD cameras with 2048×2048 pixels captured the particle movements to measure the velocity. The measurements were performed in double-pulse mode with a 50 Hz frequency and pulse separation of 350 µs to ensure the particle's motion was less than 8 pixels. The images are analyzed using interrogation windows of 32×32 pixels with 75% overlap to obtain the velocity profiles.

Results

Figures 1 (a) to (d) show the phase averaged axial obtained from 2D-C and 2D-3D PIV, and figures 1 (e) and (f) show the tangential velocity from 2D-3C PIV. The phase averaged axial velocity profiles from both measurements show a quasi-stagnation zone around the central axis that expands downstream due to the diffusing shape of the draft tube's conical section. During PL operation of the turbine, RVR is the dominant phenomenon, and the RVR phase strongly influences the flow field. Figures 1 (a) and (b) illustrate that the high velocity on the wall rotates with RVR rotation during the turbine's PL operation. As a result, the flow field is also symmetric when RVR rotates 180˚ between figure 1 (a) and (b). Figures 1 (c) and (d) show a similar pattern in the phase-averaged axial velocity profiles of the 2D-3C measurements. The phase-averaged tangential velocity presented in figures 1 (e) and (f) also shows that the flow is rotating in the draft tube symmetrically.

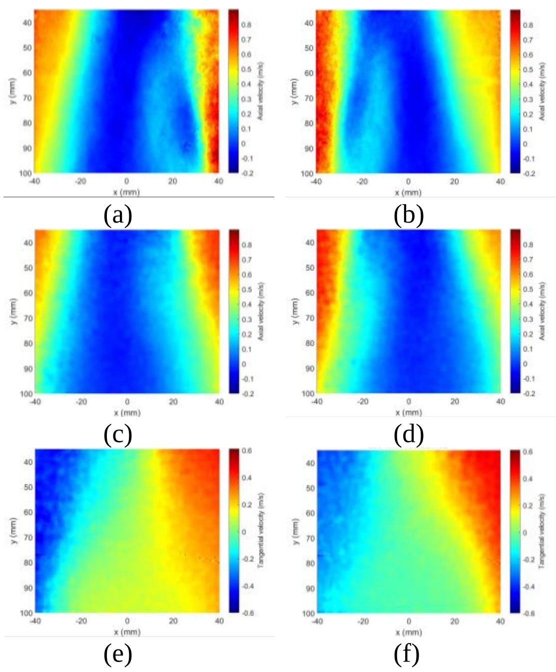

Figure 1: Phase averaged velocity contours in the conical section of the draft tube during PL operation. The figure on the left and right columns are separated by half of an RVR period: (a) and (b) axial velocity contours in 2D-2C PIV, (c) and (d) axial velocity contours in 2D-3C PIV, and (e) and (f) 180˚ apart tangential velocity contours in 2D-3C PIV.

Corresponding author email: nahale.sotoudeh@ltu.se