Experimental study of the wake turbulence of three-bladed horizontal axis tidal turbine

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1. Introduction

As well as characterising the power extraction for a tidal stream turbine it is also important to characterise the wake development of a turbine. Experimental studies into the characters of wakes have been conducted using the mesh disk rotors [1] and model horizontal axis turbines [2-4]. However, the investigations undertaken into the wakes behind tidal stream turbines are still limited, especially for the turbulent flow field development. This research is conducted to investigate the 3-dimensional structures of Reynolds normal and shear stress within the turbine's wake, and further analysis the Reynolds-stress anisotropy and the effect factors of wake turbulence development.

2. Experiments description

Testing was undertaken in a flume with a hyperbolic-type inlet. The working section is 14.4 m long by 0.8 m wide, the conditions under which the experiments were completed were 0.54 m water depth with mean velocity U_0=0.59 m/s. A 3-bladed horizontal axis tidal turbine is employed, the rotor centre axis is located at a depth of 0.25 m below water surface, midway along the working section, and the a blockage ratio is approximately 16.4%.Time varying velocities were measured using ADV with velocity range ±1 m/s. Velocity measurements were taken upstream of the turbine at distances of 0.6 Rotor Diameter (RD) and 1RD, and downstream from 1RD behind the turbine to 20RD. The spacing is 25 mm between two measurement locations in the spanwise direction and 30 mm in the vertical direction.

3. Wake turbulence

3.1 Velocity deficit

Wake velocity deficit is induced by turbine rotation and support structure, and it recovers with distance increasing downstream, shown in Fig.1.

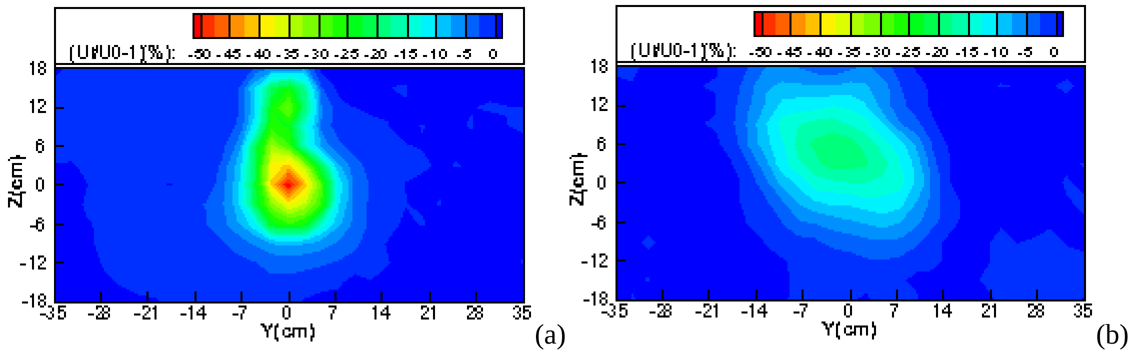
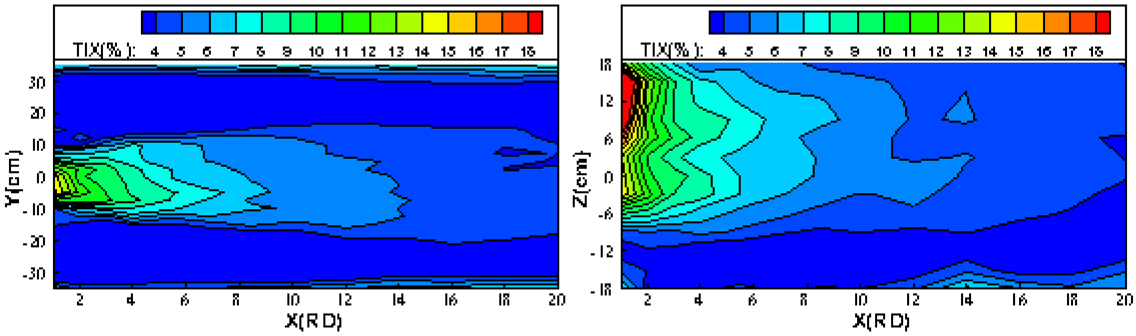


Fig. 1. Velocity deficit of wake at (a) 1RD and (b) 7RD downstream

3.2 Reynolds normal stress

Fig.2. presents the 3D structure development of streamwise Reynolds normal stress behind tidal turbine. For transverse and vertical Reynolds normal stress, the change patterns are similar to the streamwise Reynolds normal stress in both directions, but the effects of vertical Reynolds normal stress is less significant than the other two. Analysing the 3-dimensional Reynolds normal stress, it reveals that the wake turbulence is strongly anisotropic.

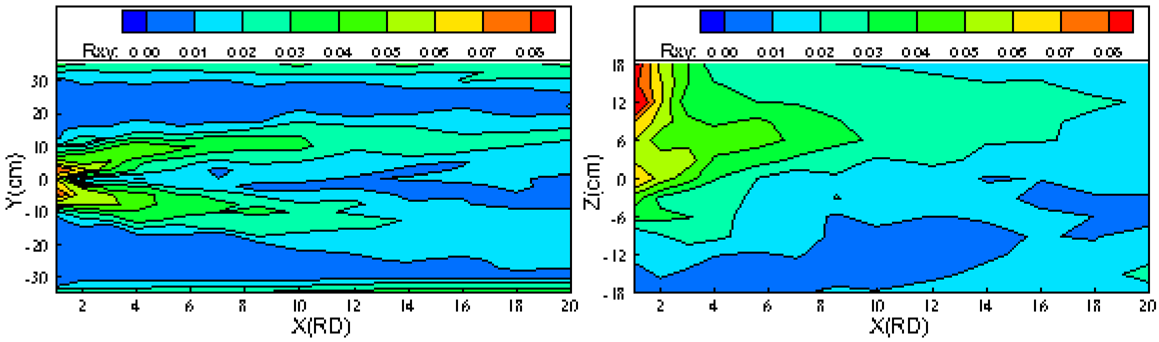


(a) Z=0cm (b) Y=0cm

Fig. 2. The development of streamwise Reynolds normal stress within the wakes downstream.

3.3 Reynolds shear stress

As shown in Fig.3., two zones on both besides of rotor centre can easily be distinguished in Z=0 cm. In the vertical direction, the shear layers have completely merged from X>3RD, and the zone moves towards free surface.



(a) Z=0 cm (b) Y=3.5 cm

Fig. 3. The 3-dimensional development of Reynolds shear stress within the wakes downstream.

4. Discussion

In order to better understand the turbulent flow field, this study further analyses the effect factors of wake turbulence development by comparing other horizontal axis turbine experiments. The preliminary conclusion is that the distribution shape of wake turbulence just behind the turbine is mainly dependent on the TSR. The delay rate of wake turbulence is influenced by both the blockage ratio and turbulent intensity of the ambient flow.

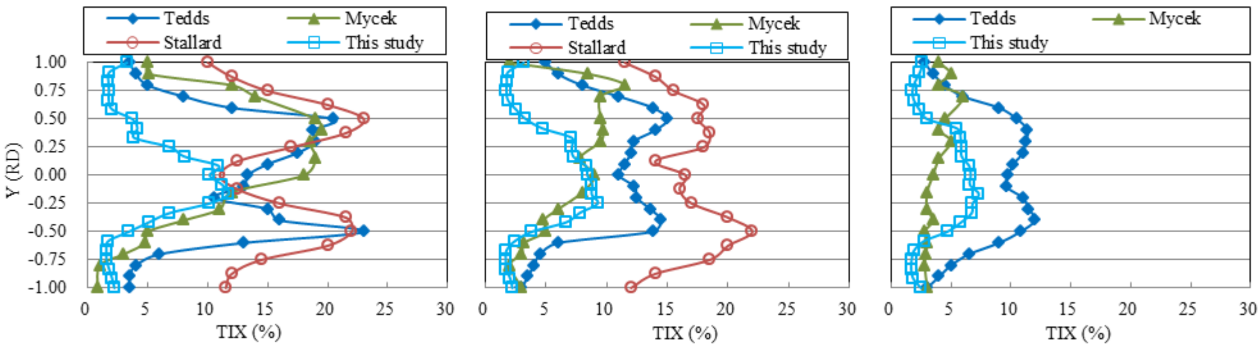


Fig.4. Transvers profiles of turbulence intensity at X=2RD, 4RD and 7RD

5. Conclusions

The wake turbulence of a three-bladed horizontal axis tidal turbine has been investigated using detailed 3-dimensional velocity measurements. The results indicate that the 3-dimensional structure of turbulent flow field induced by the presence of tidal turbine is complex, the Reynolds stress is strongly anisotropy due to the blade rotation. The support structure has a significant effect on the near wake. The distribution zone of Reynolds stress moves towards free surface as the development of wake further downstream. The distribution pattern of wake turbulence intensity just behind turbine is significantly dependent on the turbine TRS, the recovery rate is impacted by both blockage ratio and turbulence intensity of ambient flow, but the 3-dimensional change patterns is influenced by the velocity profiles in the vertical direction during the wake turbulence development process.

References

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