PIV WAKE CHARACTERISTICS MEASUREMENT
ON OFFSHORE FLOARING WIND TURBINE WITH PICHING MOTION

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ABSTRACT

This study implemented a Particle Image Velocimetry (PIV) system to analyze the wake characteristics of a Floating Offshore Wind Turbine (FOWT) under pitching motion. Using a wind tunnel, the wake behavior was measured across different Strouhal numbers (St). Low St (<0.2) induced vertical oscillation, while high St (>0.4) resulted in wake pulsation.

KEY WORDS

Offshore floating wind turbine, Wake, Particle image velocimetry

1. INTRODUCTION

Floating offshore wind turbines (FOWTs) are a type of wind turbine that can be operated in deep sea area where bottom-fixed turbine cannot operate. However, FOWTs motion in complex ways[1] due to waves and wind make the more complicated wake behavior than fixed wind turbine. The wake of FOWTs is known to depend on the Strouhal number (St = fD/U, where f is the oscillation frequency, D is the rotor diameter, and U is the wind speed). Because of these motions, the wake shows unsteady behavior, such as meandering and pulsation. In previous experiments at the Research Institute for Applied Mechanics, Kyushu University, hot-wire anemometers (HWA) and ultrasonic anemometers (USA) were used to measure the wake of FOWTs. However, both methods only collect data from one point at a time, which limits their ability to measure the wake over a wide area at the same time. This study aims to solve this problem by implementing a Particle Image Velocimetry (PIV) system. Using this new system, we will measure the wake of a wind turbine model that simulates a FOWT. Our goal is to better understand the structure of the wake and its behavior.

2. PIV measurement of FOWT's wake

This study conducted PIV (Particle Image Velocimetry) measurements using the Temperature-Controlled Clean Wind Tunnel at the Research Institute for Applied Mechanics, Kyushu University. The wind tunnel has a cross-section of 1*1 m^2 in height and width, with a measurement section length of 13.5 m. Fig. 1 shows a schematic diagram of the PIV setup. The PIV measurement area covers approximately 1 m in height and 2 m in width. Two measurement areas, Area 1 and Area 2, were recorded separately using the same 3 W semiconductor laser sheet and high-speed CMOS camera (FASTCAM mini WX100, Photron) with a resolution of 2048px × 2048px and 32GB RAM. Measurements were performed at a wind speed U_0 =1 m/s, with an image capture rate of 125 fps. To optimize memory usage, the image resolution was reduced to 2048 px × 1024px to match the measurement area, allowing a maximum recording time of about 43.68 seconds. A smoke generator (Kanomax) was used to provide seeding particles. Since the wind tunnel operates with a single-pass suction flow system rather than a closed-loop design, the seeding particles had to be intentionally distributed within the laser sheet area. The captured data were processed using FlowExpertII (KATO KOKEN) software, which applied a window deformation iterative multigrid method. In this algorithm, the interrogation window size was gradually reduced from 64 px × 64 px from 16 px × 16 px and a 50% overlap.

The FOWT model used a MEL airfoil rotor with a diameter $D = 2R$ =0.442 m, mounted on a pitching oscillation device. The rotor's center was set at 550 mm height with a maximum pitch angle of ±5°. Wake measurements were conducted using PIV under various pitch oscillation periods, with a rotor speed ω =184 rpm and tip-speed ratio $\lambda = \omega R/U_0 \approx 4.3$.

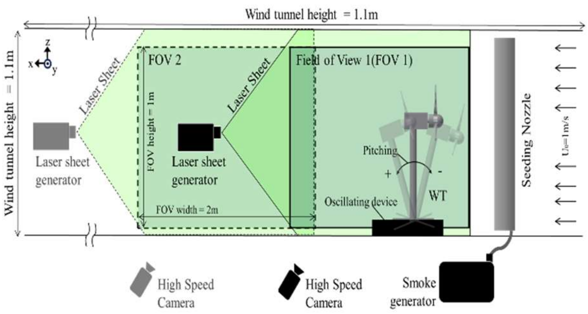

Fig. 2 Side view of PIV experimental

3. Result and discussion of wake measurement using phase average

Figure 4 shows the vertical profiles of wind speed U at $x = 3D$ over time for each pitch oscillation

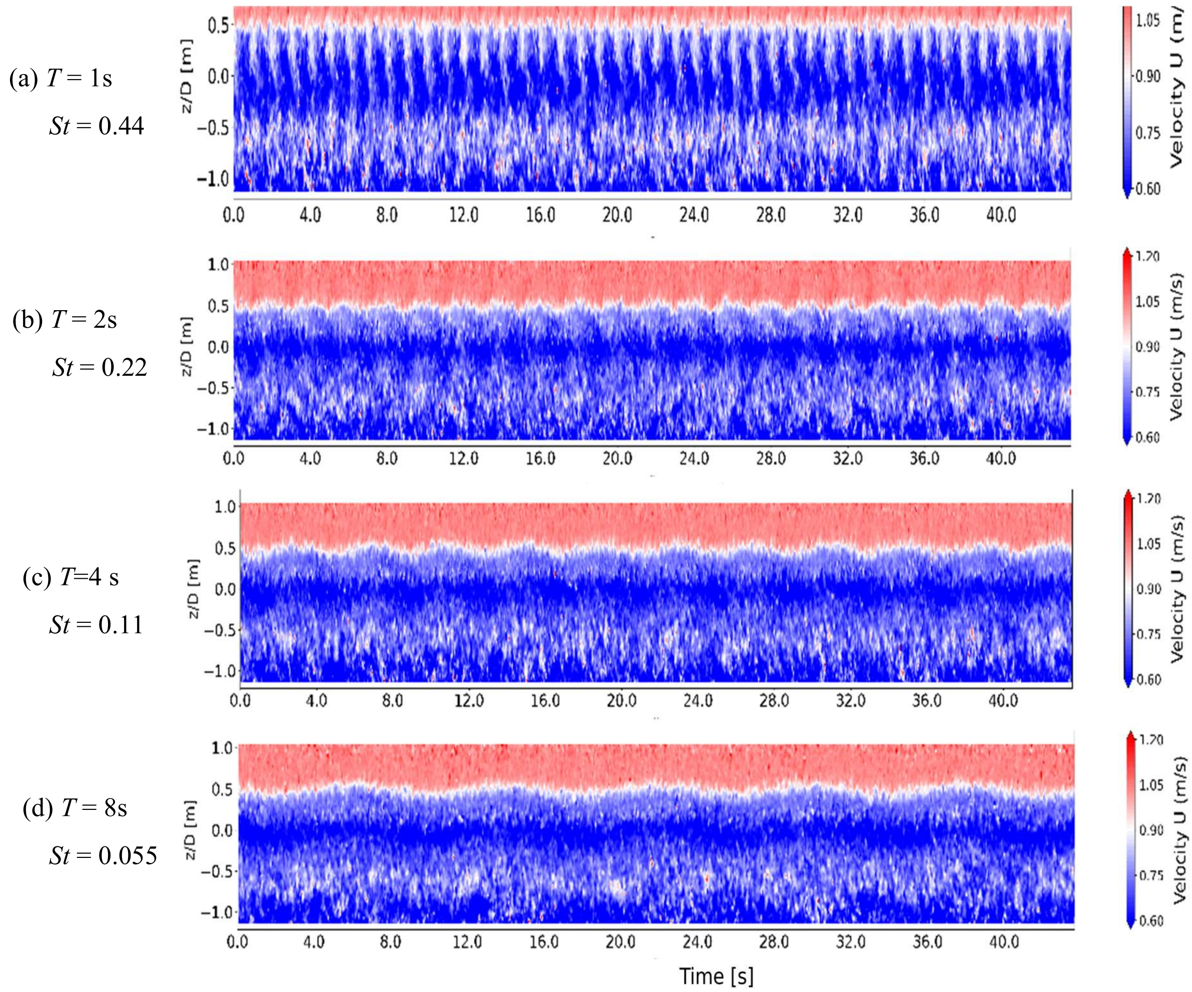

Fig. 2 Time series of vertical profiles of wind speed UU at $x/D = 3$

period. For the longest period, $T = 8\,\mathrm{s}$ ($St = 0.055$) (Fig. 2 (d)), the wake oscillates vertically in sync with the pitching cycle. The velocity deficit region created by the wind turbine maintains its distribution shape while its center moves up and down according to the oscillation period. Additionally, velocity deficits are observed near the floor at $z/D \in [-0.6, -1{,}0]$, likely caused by the oscillating mechanism rather than the turbine's wake. In contrast, for the shortest period studied, T =1 s ($St = 0.44$) (Fig. 2 (a)), the velocity deficit fluctuates in strength within a single oscillation cycle, indicating pulsation. Furthermore, examining the upper outer region of the velocity deficit at $z/D \in [0.5, 1.0]$ reveals that flow speed increases periodically. This phenomenon is believed to occur when the turbine tilts forward, as the increased relative wind speed due to the St enables the turbine to push against the wind more effectively. For T =2 s ($St = 0.22$) (Fig. 2 (b)), similar pulsating behavior is observed, but with higher temporal continuity and smaller amplitude, resulting in smoother variations. Additionally, for $T = 4\,\mathrm{s}$ ($St = 0.11$) (Fig. 4 (c)), slight pulsation in velocity deficit are seen near the center of the wake. However, the overall wake exhibits vertical oscillations similar to those at T =8 s.

4. Conclusion

This study demonstrates the complex dynamics of floating offshore wind turbine (FOWT) wakes under various pitch oscillation periods. The results show that low Strouhal numbers ($St < 0.2$) produce vertical oscillations in the wake, with the velocity deficit region maintaining its shape while shifting up and down. Conversely, high Strouhal numbers (St >0.4) lead to significant pulsation within each oscillation cycle, causing fluctuations in the velocity deficit. The mixed characteristics observed at intermediate Strouhal numbers ($0.2 < St < 0.4$) suggest a combination of both vertical oscillation and pulsation effects. These findings highlight the dynamic relationship between oscillation periods and wake behavior, emphasizing that both temporal continuity and oscillation frequency play essential roles in wake recovery and stability. Understanding these wake dynamics offers critical insights for designing and managing floating wind farms to enhance operational efficiency.

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