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Control of tip vortices for a hydrofoil through grooved tip treatment

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ABSTRACT

Blade tip vortices can lead to cavitation for tidal turbines and generate cavitation noise when bubbles collapse. Thus, the blade tip vortices, along with the associated cavitation and its noise, remain a major challenge when further increasing turbines' tip speed ratio to achieve a higher total power output (Wimshurst *et al.*, 2018). Liu *et al.* (2024) numerically demonstrated that for a model-scale tidal turbine, a porous zone with a constant permeability at the blade tip with a spanwise extent of 0.1% of the turbine diameter can reduce the pressure drop in the tip vortices by 63%, while the turbine efficiency was barely affected. Liu and Tan (2018) presented a single-groove design to alleviate the Tip Leakage Vortex (TLV). They incorporated a C-shaped, shrinking groove at the blade tip, connecting the pressure and suction sides so that a jet flow is induced to impinge the TLV and thus mitigate the vortex. However, it also triggers new cavitation, as a new pressure minimum occurs within the groove because of the local flow acceleration. Building upon the above work, we develop a multi-groove design, with grooves distributed along the entire foil tip-chord, to mitigate the cavitation risk in the grooves and achieve the equivalent permeability. Streamwise and cross-flow Particle Image Velocimetry (PIV) measurements were employed to visualise flow around the foil tip and the wake structures. The PIV results show that the velocity magnitude inside the tip vortex is significantly reduced with the presence of grooves. We conjecture that this velocity reduction is associated with decreased suction within the tip vortex core, mitigating the risk of cavitation due to tip vortices. Cross-flow PIV measurements at downstream of the foil revealed that the vortex intensity (represented by non-dimensional vorticity and vortex swirling strength) is reduced by the grooves while the vortex size is enlarged. The introduction of grooves leads to a slight change in vortex circulation. Our results demonstrate that this method has the potential to mitigate tip vortex-induced cavitation, which would allow the operation of the turbines at a higher tip speed ratio, increasing energy yield. The proposed design is also manufacturable through conventional machining techniques. Future experiments will employ particle tracking velocimetry to compute the pressure from the flow field to directly quantify the suction within the tip vortex around a foil and a model-scale turbine.

References

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