The Effect of Tidal Flow Directionality on Tidal Turbine Performance Characteristics

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Summary: As marine turbine technology verges on the realm of economic viability the question of how long will these devices last is an important one. This paper looks at the axial bending moments experienced from CFD modelling of Cardiff University's concept tidal turbine in a uniform profile for three different scenarios. The magnitude and direction in which the axial bending moment acts is an important feature in determining likely sources of wear in the drive train, such as bearings. By determining the source and magnitude of these bending moments, possibilities for reducing them and limiting their impact on devices can be made.

Introduction

As full scale prototypes are begin tested and meeting the challenges of the marine environment there are various design philosophies still being trialled with some sign of convergence on a generic design as has been seen in the wind sector. The primary focus of designers has been into HATTs. Many of these devices are supported by a cylindrical support tower or stanchion, however little work has been published on the direct effect of such a support structure on the axial bending moments of a HATT, especially when the stanchion is upstream of the blades, as could be the case for turbines operating in bi-directional tidal flow. The basis of this work comes from prior work by Mason-Jones et al [1] which found the presence of asymmetric loading on turbines and the compounded complexity with the presence of a stanchion. Using the same turbine and similar cylindrical stanchion the work in this paper focuses on the magnitude and direction of the resultant axial bending moments acting on the drive shaft from the turbine. Three scenarios are considered; a) with no stanchion, b) turbine in front of the stanchion and c) turbine behind the stanchion. Validation has been established through a comparison of the Power Coefficients between the no stanchion case with the previous study [1], though on going experimental work in progress.

Methods

ANSYS CFX is a Computational Fluid Dynamics (CFD) modelling package which offers well documented and validated success in its field. For the models being considered the Reynolds Averaged Navier Stokes (RANS) equations were used along with the Shear Stress Transport (SST) equation as the viscous model to close the equations. To determine the axial bending moments acting on the shaft during a single rotation a transient CFD model was used. During operation, axial thrust loads act at the centre of pressure on each of the turbine blades. These give rise to bending moments which can be measured about the vertical and horizontal axis (M_X and M_Y).From this, the magnitude of the resultant axial bending moment is obtained and the angle at which it is acting.
It is expected that the angle of bending moment will align itself toward the dominant bending moment either about the x or y axis. If the moment in the x-direction is greater than the moment in the y-direction the angle of bending moment is expected to be close to 90° or 270°. Likewise if the moment in the y-direction is greater than that in the x-direction the angle will be closer to 0° or 180°.

Results

a) No Stanchion

When there is no stanchion present the resultant bending moment from the turbine about the rotating axis is small but present as can be seen from Figure 1. There are three peaks/ troughs in the data which suggests a slight inherent bending moment, this may come from the geometry of the blades however its magnitude is such that it is negligible in comparison to when there is a stanchion present.

b) Turbine in Front of the Stanchion

Figure 2 shows non-symmetric axial loading is exerted on the drive shaft, resulting in an axial bending moment. There are 6 distinct peaks and troughs in the magnitude of the bending moment during one rotation. The peaks correspond with when one of the blades has just passed the stanchion at either Top Dead Centre (TDC) or Bottom Dead Centre (BDC). This suggests there is a delayed interaction between the blades and stanchion. As the flow diverges around the stanchion the passing blade will experience significantly lower axial thrust than the other two blades in the unsheltered flow, thus the axial bending moment increases. As the blade moves out from the sheltered area in front of the stanchion its axial thrust increases, evening the distribution and reducing the axial bending moment. The angle of the bending moment follows the rule stated in above section. The curve is a repeating pattern every 120°, considering this first cycle in Figure 2, the angle is continually decreasing showing the direction of the bending moment is moving in an anti-clockwise manner. However there are 2 distinct interruptions in the gradient of this slope and these correspond to the peaks of the axial bending moment when one blade has just passed though TDC or BDC.

c) Turbine Behind the Stanchion

Figure 3 shows significant non-symmetric loading being exerted on the drive shaft. This results in much greater axial bending moment. Again there are 6 distinct peaks and troughs in the magnitude of the bending moment during one

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rotation. The increased amplitude between peak and trough is due to the increased shelter the blade passing the stanchion receives. Being in the wake of the stanchion the axial thrust on the blade is significantly less, however the blades in unsheltered flow experience the same axial loads as before. The increased difference between the axial loads on the blades leads to the increased axial bending moment. Notice the magnitude of the troughs has not changed between the two stanchion cases. This is because when all blades are equally exposed in both scenarios (b & c) the axial thrusts on them have the same even distribution. The location of the peaks and troughs has shifted due to the flow having to pass the stanchion before interacting with the turbine. The angle or direction of bending moment has also been affected by this. In the previous case the angle showed an anticlockwise (decreasing) pattern. In this circumstance there is a clockwise (increasing) pattern. The rule relating to the dominant bending moment and direction remains true, and again there are two distinct interruptions in the gradient of the curve which correspond with the blades entering the shadow of the stanchion.

Conclusions

The presence of such significant axial bending moments, as seen in scenario c) is undesirable due to its inevitable impact on the wear of drive train parts. Bearings along the drive shaft of the turbine will suffer significant fatigue issues from such loading regimes, resulting in shorter maintenance periods and increasing the cost per kWh on the turbine.

It has been established that the source of the significant axial bending moments comes from the interaction with the stanchion. As is clear removing the stanchion would be the best solution; however that is not possible with many designs. Therefore the reduction of these axial bending moments must be made; the use of a yaw mechanism would maintain the turbine upstream of the stanchion, preventing the more severe scenario. In addition, reducing the stanchions diameter or replacing with a hydrodynamic profile would also reduce these moments.

This work is limited to the effect of the stanchion on these bending moments. Other issues must also be considered for a true system such as velocity profiles [1] and waves [2].

Acknowledgements:

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References:

[1] Mason-Jones A, O'Doherty DM, Morris CE, O'Doherty T. (2013) *Influence of a velocity profile & support structure on tidal stream turbine performance.* Renewable Energy 52 (2013) 23-30

[2] McCann GN. (2007) *Tidal current turbine fatigue loading sensitivity to waves and turbulence – a parametric study.* 7th EWTEC

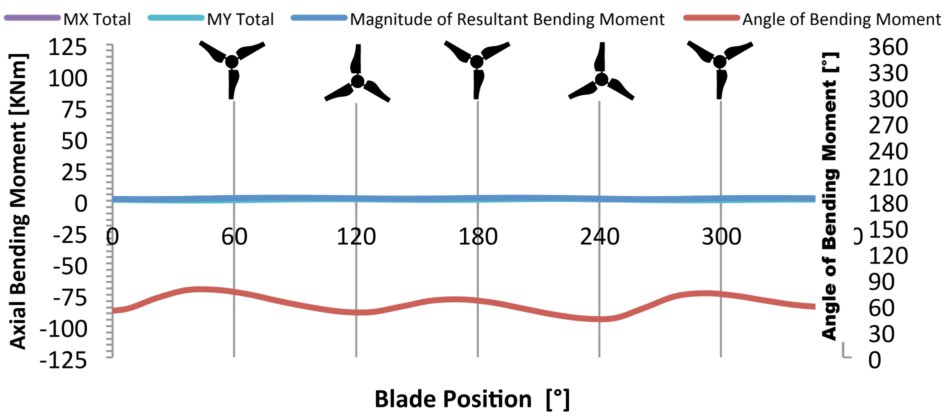

Figure 1 Axial Bending Moment over a rotational cycle of the turbine a) No Stanchion

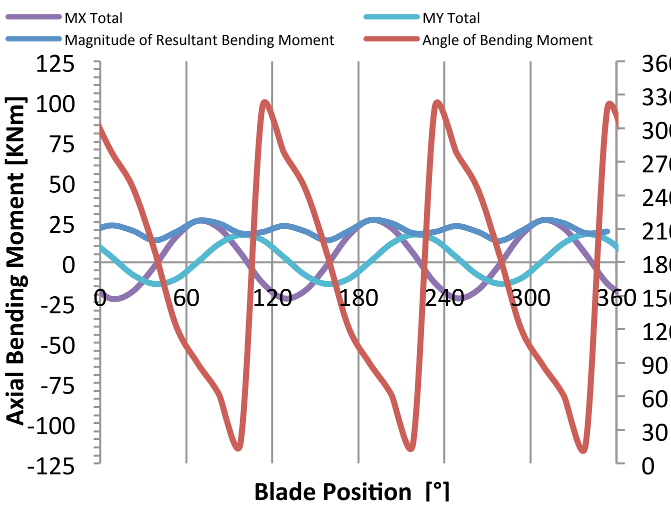

Figure 2 Axial Bending Moment over a rotational cycle of the turbine. b) Turbine in Front of the Stanchion

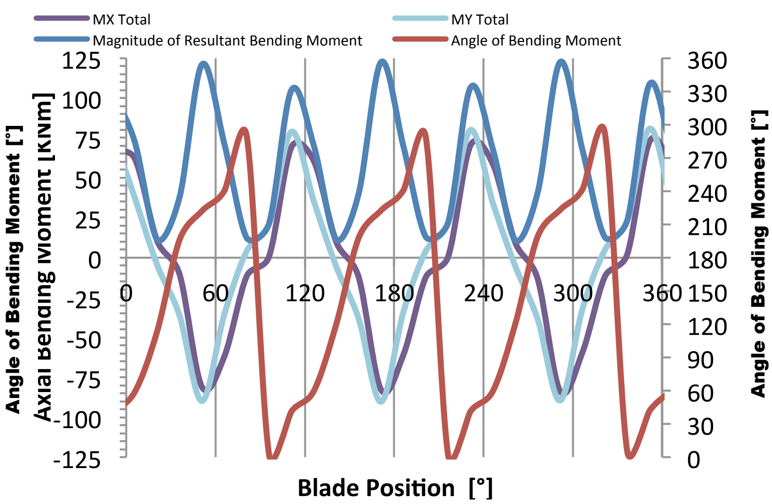

Figure 3 Axial Bending Moment over a rotational cycle of the turbine. c) Turbine in Behind the Stanchion