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Experimental and Numerical Investigations of Vortex-Induced Vibrations of Wind Turbine Towers

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ABSTRACT

Tower structures of wind turbines are often installed in various configurations at the port before being transported by ships. Considerable vortex-induced vibrations can occur when the natural frequency of the structure corresponds to flow vortex frequency. This leads often to a considerable reduction of their fatigue life. The flow around a vibrating cylinder is complex and sensitive to the inflow and the structure deformation, whereby turbulence effects need to be considered properly to obtain realistic predictions. To study vortex-induced vibrations of a cylinder with a high aspect ratio, we performed extensive physical tests, Raynolds-averaged Navier-Stokes (RANS) solver and Detached Eddy Simulations (DES). Results comprised damping, acceleration and flow velocity. High-speed photography helped to visualize the flow. Additionally, we present test rig set-ups, instrumentation, and experimental procedures.

First, we computed the flow around a submerged rigid hollow cylinder with a length diameter ratio of 15.6 using RANS and DES. The Reynolds number was $1.6 \cdot 10^4$. We performed a grid and time step study to quantify the discretization errors. Second, we performed the same computation by considering the elastic deformations of the structure. We used an implicit coupling between the Navier-Stokes solver and the structure solver based on a Timoshenko beam model. The hydroelastic effects on forces and vortices are discussed.

Further on, we performed physical tests using two different methods to measure the structure deformations. One method mounted classical three-dimensional accelerometers at various positions inside the hollow cylinder to measure the induced accelerations in the vertical and transverse flow directions. From these accelerations, we calculated motion trajectories of the cylinder. High-speed videos yielded comparative optical measurements that validated our calculations.

The second experimental method relied on the digital image correlation (DIC) technique to measure optically the displacements of the tube at several positions. Using the contactless measuring technique enabled us to consider an arbitrary body shape because no additional masses needed to be accounted for which may have influenced the structure's response, such as natural frequency, mass distribution, and damping. Also, the amount of observed positions of a structure depended only on the camera's view frame. From the spatial resolutions we calculated not only velocities and accelerations, but also strains inside the structure itself. Thus, the DIC technique turned was efficient to measure and analyse VIV and FSI without influencing the structure or the flow.