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Output-only modal analysis of linear time-periodic systems with application to wind turbine simulation data

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ABSTRACT

Many important systems, such as wind turbines, helicopters and turbomachinery, must be modeled with linear time-periodic equations of motion to correctly predict resonance phenomena. Time periodic effects in wind turbines might arise due to blade-to-blade manufacturing variations, stratification in the velocity of the wind with height and changes in the aerodynamics of the blades as they pass the tower. These effects may cause parametric resonance or other unexpected phenomena, so it is important to properly characterize them so that these machines can be designed to achieve high reliability, safety, and to produce economical power. This work presents a system identification methodology that can be used to identify models for linear, periodically time-varying systems when the input forces are unmeasured, broadband and random. The methodology is demonstrated for the well-known Mathieu oscillator and then used to interrogate simulated measurements from a rotating wind turbine. The measurements were simulated for a 5 MW turbine modeled in the HAWC2 simulation code, which includes both structural dynamic and aerodynamic effects. This simulated system identification provides insights into the test and measurement requirements and the potential pitfalls, and simulated experiments such as this may be useful to obtain a set of time-periodic equations of motion from a numerical model, since a closed form model is not readily available by other means due to the way in which the aeroelastic effects are treated in the simulation code.

1. Introduction

Linear time-periodic (LTP) differential equations are important for quite a wide range of systems including wind turbines [1–3], helicopters [4–10], turbomachinery [11–13] and virtually any system that can be linearized about a periodic trajectory (see, e.g. [14–17]). Allen and Sracic have even proposed that an experimental model for a range of nonlinear systems may be most easily identified by exciting the system such that an LTP model is appropriate [18]. Other researchers have sought to exploit LTP effects to detect defects, such as a cracked shaft, in a rotating system [11–13].

This work extends operational modal analysis to linear time-periodic systems with the goal of enabling system identification for rotating wind turbines. Linear time-periodic differential equations are necessary to model wind turbine dynamics if the turbine has only two blades, or if the blades of a 3+ blade turbine are not identical. In practice there are always differences between the blades but these are often not considered in design, analysis or even when performing tests. Time-periodicity might also arise due to aeroelastic effects such as interaction between the flow around the blade

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