Damage Detection for Tripod-type Offshore Wind Turbine Structures Using Modal Strain Energy Methods

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ABSTRACT
In this paper, a thorough damage detection study for tripod-type offshore wind turbine (OWT) structure is investigated. First, two damage locations are chosen based on the strength analysis results. Damages are simulated according to the likely damage patterns of each member. Modal strain energy (MSE) method and modal strain energy decomposition (MSED) method are applied for the damage detection procedure where the “measured” data are generated from a finite-element model while adding the simulated measurement noise. Both complete and incomplete measured modal data cases are considered during various damage scenarios. The numerical results suggest that damage members can be diagnosed exactly with complete modal data. When spatial incomplete modal data is available, the damage area can be identified.

KEY WORDS: Offshore wind turbine; tripod-type foundation; damage detection; modal strain energy; spatial incomplete.

INTRODUCTION
Offshore wind energy has a broad prospect of application as a green pollution-free clean energy to ease global warming. The offshore wind turbine structures are the basic facilities for offshore wind energy exploitation. During the service life, damages of the foundation structures are unavoidable as a result of the action of various loads including operational and environmental forces. The structural health monitoring (SHM) system is very necessary to ensure the safety of the structures, lower the maintenance cost and prolong the service lives. A SHM system is defined as the process of implementing a damage detection strategy for engineering infrastructure related to aerospace, civil and mechanical engineering (Farrar and Sohn, 2000).

Damage may cause the change on the mass and/or stiffness distribution of the structural system, consequently the modal properties of the structural system, such as natural frequencies and mode shapes, may alter as well (Doebling et al., 1998). The alteration of modal properties, or properties derived from these quantities, can be used as damage indicators in various vibration-based damage detection methods. Stubbs et al. (1995) presented a method based on the relationship between the modal strain energy (MSE) properties of the undamaged and damaged members of a structure. Then both numerical and experimental studies are demonstrated the feasibility of MSE to offshore platforms (Kim and Stubbs, 1995; Wang and Li, 2006). An improved damage index algorithm outperforming the original Stubbs damage index algorithm was developed by Kim and Stubbs (2002). Li et al. (2006) proposed modal strain energy decomposition (MSED) method to identify damage for three-dimensional frame structures. The MSED method defined two damage indicators, axial damage indicator and transverse damage indicator and was tested on a three-dimensional five-story frame structure and a complicated offshore platform. Damage detection using modal strain energy has several characteristics including (1) a few modes are needed; (2) mode shapes don’t need normalization; (3) not all degrees of freedom are measured (Wang and Li, 2006).

The purpose of this paper is to conduct a damage detection study on offshore wind turbine structure. First, a finite element model of a tripod-type offshore wind turbine in 20m water depth is established to be taken as baseline (undamaged) structure. Then the strength analysis under operation wind turbine load and environment loads is performed to find out the hot spots of the structure, which are considered to be the most likely damage members. Several damage scenarios including different damage types and different damage severities are simulated to generate the “measured” modal data. Two sensor arrangements are considered, one is complete modal information available and the other is only modal data of above water locations are accessible. The latter one is often termed as spatial completeness of measured data and can be solved by reducing the analytical model order (model reduction) or expending the measured mode shapes (modal expansion). Guyan reduction and Kidder expansion schemes are applied to achieve either