Fatigue Life Evaluation for Mooring Line and Tower of Floating Wind Turbine

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ABSTRACT

In this study, fatigue lives of mooring line and tower of a floating wind turbine structure were investigated. A SPAR type wind turbine with three catenary mooring lines, a rotor-supporting tower, and three blades is considered as an example structure. Mooring line tension and tower base stress are calculated through a time-domain coupled analysis. Boundary element method (BEM) and convolution are applied to floating body formulation. The mooring lines, tower, and blades are formulated with catenary elements, elastic beam elements, and aerodynamic elastic rotating beam elements, respectively, using finite element method (FEM). By analyzing the mooring line tensions with fatigue curves according to API-RP-2SK and statistical methods such as simple summation (SS), combined spectrum (CS), and combined spectrum with dual narrow band (CSDN), fatigue life of a mooring line is obtained. Fatigue life of a tower is obtained by analyzing the tower base stress with fatigue curves according to API-RP-2A-WSD and the statistical methods SS, CS, and CSDN. From the numerical results, fatigue lives of the mooring lines and tower are evaluated using statistical methods such as SS, CS, and CSDN. The results of the three methods are compared. In case of mooring line, reference break strength (RBS) is one of the main parameters in fatigue analysis. The variation of fatigue life is investigated by changing the RBS of the mooring line.

INTRODUCTION

Floating wind turbine is one of the new topics in the ocean engineering field, and it has been studied by many researchers (Shim and Kim, 2008; Jonkman et al., 2009, 2010; Bae et al., 2011, 2012, 2013, 2014). Because wave loads are applied to a wind turbine repeatedly, fatigue failure is critical in a mooring system or rotor-supporting tower. Hence, the fatigue life is one of the key parameters in turbine design. The objective of this study is to evaluate fatigue lives of mooring line and tower of a floating wind turbine and discuss the fatigue features. The wind turbine studied by Jonkman et al. (2009, 2010) was used as an example in this study. The sample turbine has catenary mooring lines and a rotor-supporting tower. Mooring line tensions and tower base stress are calculated through the time-domain analysis considering the coupled behavior of the body, mooring line, tower, and blade. BEM (Hone et al., 2005), convolution (Cummins, 1962), and FEM (Kim et al., 2010, 2013) are used in the numerical analysis. From the numerical results, fatigue lives of the mooring lines and tower are evaluated using statistical methods such as SS, CS, and CSDN. The results of the three methods are compared. In case of mooring line, reference break strength (RBS) is one of the main parameters in fatigue analysis. The variation of fatigue life is investigated by changing the RBS of the mooring line.

COUPLED ANALYSIS FOR BODY, MOORING, TOWER, AND BLADE

The first step in a fatigue analysis is to determine the mooring line tensions and tower base stresses. They are obtained by solving the two equations as follows.

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\begin{align*}
[M_B + M_{idt}(\omega)]\ddot{x} + \int_0^T \{R(t-\tau)\}[\dot{x}(\tau)]d\tau + [K_B]x &= \{f_B\} \\
[M]u + [C]u + [K]u &= \{f\}
\end{align*}
\]

Eq. (1) is the equation of motion of a floating body. \([M_B]\), \([M_{idt}(\omega)]\), and \([K_B]\) are the coefficient matrices of mass, infinite frequency added mass, and hydrostatic stiffness, respectively. \(\{x\}\) is the vector of body motion. \(\{f_B\}\) is the force vector due to waves, drift, and connection force at mooring fairlead and tower base. \(R\) is the memory function. BEM (Hong et al., 2005) and convolution (Cummins, 1962) are used to derive Eq. (1), in this study.

Eq. (2) is the equation of motion of mooring lines, tower, and blade. \([M]\), \([C]\), and \([K]\) are the mass, damping, and stiffness matrices, respectively, and \(\{u\}\) is the displacement vector. \(\{f\}\) is the force vector due to mooring weight, underwater particle force, and aerodynamic blade force. In the formulation, FEM (Kim et al., 2010, 2013) was used. Elastic catenary elements are used in the FEM model for the mooring lines. Elastic beam and rotating elastic beam elements are used in the FEM model for the tower and the blades, respectively. Morison-type formulation is used for underwater particle force of the mooring lines. Drag, mass, and added mass coefficients are applied and the relative velocity or acceleration due to line movement is considered in the calculation of wave-particle velocity or acceleration. Hence, damping and added mass effects due to line vibration are included in the analysis.