Ocean Engineering 160 (2018) 449–460

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Multiple tuned mass damper for multi-mode vibration reduction of offshore wind turbine under seismic excitation

Mosaruf Hussan[a], Mohammad Sabbir Rahman[a], Faria Sharmin[a], Dookie Kim[a,*], Jeongyun Do[b]

[a] Department of Civil Engineering, Kunsan National University, 558 Daehak-ro, Kunsan, Jeonbuk, 54150, Republic of Korea
[b] Industry-University Cooperation Foundation, Kunsan National University, 558 Daehak-ro, Kunsan, Jeonbuk, 54150, Republic of Korea

ARTICLE INFO

Keywords:
Multiple tuned mass dampers
Vibration control
Response surface method
Jacket supported offshore wind turbine
Multi-mode approach

ABSTRACT

With the wide spreads of the wind energy production industry, the demand for the safe and feasible design of wind turbine structures is growing swiftly. The magnificent deployment of wind turbines in hostile environments with high seismic hazard, has lead engineers to consider more comprehensive way of seismic design, and control technics of a gigantic structure like jacket supported offshore wind turbine (OWT). The current research provides an overview to alleviate the dynamic structural responses of the jacket supported OWT due to the seismic loads associated with static wind and wave loads. Multiple tuned mass damper (MTMD) has been installed at the top and base of the turbine tower corresponding to the mode shapes of the structure. The MTMD parameters have been optimized based on response surface methodology (RSM). The performance of MTMD following the multi-mode control strategy seems to be prominent in suppressing the first two vibrational modes. To evaluate the proposed strategy, frequency response function (FRF), fast Fourier transforms (FFT), peak and lateral displacements of the tower, root mean square (RMS), shear and moment have been investigated through the uncontrolled and controlled structures. In addition, the practicability of the MTMD system is also compared with the single tuned mass damper (STMD).

1. Introduction

During the last decades, wind turbine technology has become remarkable in the field of renewable energy. Offshore wind turbines (OWTs) have the potential to be a wealthy contributor to global energy production, due to the presence of higher-quality wind resource for coastal energy loads. Many researchers have focused on the study of the OWTs because of their enormous resources (Jonkman, 2009; Wandji et al., 2016). Various substructures and superstructures are available for the OWTs namely, monopile, gravity-based structure, tripod, suction bucket, jacket and a floating platform (Butterfield et al., 2007). For an offshore support structure to be viable for wind turbines, it must safely withstand the offshore environment, which includes the combined effects of wind and wave loads (Jonkman, 2007; Antonutti et al., 2014). Offshore structures in hostile environments are always exposed to not only the wind and wave loadings but also most violent seismic loadings. It is required to evaluate the impact of seismic loads on the OWT structure to derive effective vibration reduction systems or technics. Lots of researchers have recently devoted their attention for understanding the behaviors of OWTs under seismic loading condition (Witcher, 2005; Prowell et al., 2009; Bae and Kim, 2014; Sharmin et al., 2017, 2018). Therefore, the response of the OWT is attained through the seismic analysis including the wind and wave loadings, it is obliged to control for increasing the efficiency of the structure.

In recent decades, vibration control technologies for structures have achieved significant success to reduce the vibration of slender structures. In order to reduce the response of structure owing to a different type of loads, many devices have been proposed such as a hybrid mass damper (HMD) (Lackner and Rotea, 2011), active mass damper (AMD) (Gattulli and Ghanem, 1999), semi-active control system (Symans and Constantinou, 1997), damping isolation system (Ou et al., 2007), tuned liquid column damper (TLCD) (Colwell and Basu, 2009), viscoelastic damper (Tezcan and Uluca, 2003), friction damper (Patil and Jangid, 2005). Passive vibration control might be considered as one of the most suitable and feasible strategies for vibration control in offshore platforms. A passive tuned mass damper (TMD) is generally used for controlling the dynamic response of structures, because of their effectiveness, robustness and relative ease of installation (Wang and Lin, 2007). The TMD can be

* Corresponding author.
E-mail addresses: razib.mosaruf@gmail.com (M. Hussan), sabbir.cee@gmail.com (M.S. Rahman), fariasharmin07@gmail.com (F. Sharmin), kim2kie@kunsan.ac.kr (D. Kim), arkido@gmail.com (J. Do).

https://doi.org/10.1016/j.oceaneng.2018.04.041
Received 10 October 2016; Received in revised form 9 April 2018; Accepted 13 April 2018

0029-8018/© 2018 Elsevier Ltd. All rights reserved.

defined as the combination of a mass, a spring and a viscous damper incorporated with the structural system. TMDs are mostly effective when the first mode contribution to the response is dominant (Soong and Dargush, 1997). Multiple tuned mass dampers (MTMDs) have been confirmed to be more effective than a single TMD in the dynamic response control of structures (Iwanami and Seto, 1984). The MTMDs with distributed natural frequencies have been proposed by several researchers previously (Abe and Fujino, 1994; Kareem and Kline, 1995; Joshi and Jangid, 1997). The effectiveness of the distributed TMD to control the across wind vibration of a 76-storey benchmark building has been studied (Elias and Matsagar, 2014).

The researches on the seismic response control of jacket supported OWTs with MTMD have been rarely conducted. Even though, some researches have been driven to control the vibration of monopile wind turbine using passive TMDs due to multiple hazards (wind, wave and earthquake loads) (Yilmaz, 2014; Zuo et al., 2017), nacelle and spar vibrations of floating OWT have been controlled using MTMDs (Dinh and Basu, 2015) and using TLCD (Jaksic et al., 2015). Some scaled models and experimental studies on an OWT have been done using TMD (Wu et al., 2016) and TLCD (Chen et al., 2015). In addition, many vibration control methods for marine offshore structures have been reviewed by Kandasamy et al. (2016). To achieve the attribute responses from the TMDs to mitigate the maximum displacements, story drifts, shear force, the various harmonic responses for earthquake excitations, different optimization techniques have been introduced to optimize TMD parameters. TMD parameters have been optimized using a hybrid coded genetic algorithm (GA) considering the location of the TMD (Arfiadi and Hadi, 2011). Other optimization methods have also been proposed such as developed by Lee et al. (2006) that employing a frequency domain approach, a mathematical optimization method using harmony search (Bekdas and Nigdeli, 2011) and for the limitation of the TMD response using two-stage optimizations (Wang et al., 2009). Response surface methodology (RSM) widely applied in the optimization field is a powerful and efficient mathematical approach. The effective use of RSM for structures has been shown in Box and Draper (1987, 2007) and Khan et al. (2016a, 2016b). The RSM is one of the new approaches for applying the jacket supported OWT structure to optimize damping parameters for controlling and mitigating vibration.

The intention of the present study is to mitigate the seismic responses through MTMD system based on the mode shapes and frequencies of the structure under static wind and wave loads. TMDs have been placed at the locations corresponding to the maximum mode shape amplitudes of the structure at the particular locations. Because, at the first mode, the tower top shows the maximum displacement response while at the second mode, the tower base shows the maximum. The frequency and damping ratios have been optimized through the central composite design (CCD) based on RSM and multi-objective optimization desirability function to increase the efficiency of the MTMD. Then the result of the MTMD performance has been evaluated with different aspects under the different ground motions. Moreover, MTMD performance has been compared with STMD to check the plausibility of the system. Finally, this observation shows that the RSM based design of MTMD is applicable to control the vibration response of the structure under the seismic, and other operational loads, and to suppress the maximum responses of the first two modes significantly.

2. Structural model

2.1. Equation of motion

The governing equation of motion of the structure placed with TMDs at the top and base of the tower has been obtained considering the equilibrium of forces as shown in Eq. (1).

$$[\mathrm{M}_S]\{\ddot{u}_S\} + [\mathrm{C}_S]\{\dot{u}_S\} + [\mathrm{K}_S]\{u_S\} = -[\mathrm{M}_S]\{r\}\,\ddot{u}_g \tag{1}$$

where $[\mathrm{M}_S]$, $[\mathrm{K}_S]$, and $[\mathrm{C}_S]$ are the mass, stiffness and damping matrices of the structure, of order $(N + d) \times (N + d)$, and N and d are the degrees of freedom (DOF) for the structure and MTMD, respectively. $\{\ddot{u}_S\}$, $\{\dot{u}_S\}$, $\{u_S\} = \{u_1, u_2, \cdots, u_{N-1}, u_N, u_1, \cdots, u_d\}^{\mathrm{T}}$ are the unknown relative nodal acceleration, velocity, and displacement vectors, respectively. The earthquake ground acceleration can be depicted by $\ddot{u}_g$, and $\{r\}$ is the vector of influence coefficients. The stiffness (K_d) and damping (C_d) parameters of the TMD ($d = 1, \cdots, n$) can be computed based on the modal frequencies. For the MTMD, the mass matrix is of order $(N + d) \times (N + d)$ as in Eq. (2).

$$[\mathrm{M}_S] = \begin{bmatrix} [\mathrm{M}_N]_{N\times N} & [0]_{N\times d} \\ [0]_{d\times N} & [\mathrm{m}_d]_{d\times d} \end{bmatrix} \tag{2}$$

Where $[\mathrm{M}_N]_{N\times N}$ is the mass matrices of the structure, and $[\mathrm{m}_d]_{d\times d}$ is the mass matrices of the MTMD. The concise stiffness matrix is $[\mathrm{K}_N]_{N\times N}$ corresponding to the sway degrees of freedom performed as the dynamic DOF. The damping matrix $[\mathrm{C}_N = \alpha \mathrm{M}_N + \beta \mathrm{K}_N]_{N\times N}$ is not explicitly known, but has been obtained by using the same Rayleigh's damping ratio in all modes and α and β are the damping constants having a unit of $\sec^{-1}$ and sec. The $[\mathrm{K}_d]_{d\times d}$ and $[\mathrm{C}_d]_{d\times d}$ has been expressed corresponding to the degrees of freedom associated with the TMDs. The stiffness and damping of the MTMD are the input in the $[\mathrm{K}_S]$and $[\mathrm{C}_S]$ as follows in Eqs. (3) and (4).

$$[\mathrm{K}_S] = \left[\begin{bmatrix} [\mathrm{K}_N]_{N\times N} & [0]_{N\times d} \\ [0]_{d\times N} & [0]_{d\times d} \end{bmatrix} + \begin{bmatrix} [\mathrm{K}_d]_{N\times N} & -[\mathrm{K}_d]_{N\times d} \\ -[\mathrm{K}_d]_{d\times N} & [\mathrm{K}_d]_{d\times d} \end{bmatrix}\right]_{(N+d)\times(N+d)} \tag{3}$$

$$[\mathrm{C}_S] = \left[\begin{bmatrix} [\mathrm{C}_N]_{N\times N} & [0]_{N\times d} \\ [0]_{d\times N} & [0]_{d\times d} \end{bmatrix} + \begin{bmatrix} [\mathrm{C}_d]_{N\times N} & -[\mathrm{C}_d]_{N\times d} \\ -[\mathrm{C}_d]_{d\times N} & [\mathrm{C}_d]_{d\times d} \end{bmatrix}\right]_{(N+d)\times(N+d)} \tag{4}$$

The coupled differential equations of Eq. (1) for the structure installed with TMDs have been thus derived using Newmark- β integration method, wherein, 5% damping ratio has been considered. Fig. 1 **(a)** illustrates the typical jacket supported OWT with the allocation of the TMDs.

2.2. Loads

The upwind National Renewable Energy Laboratory (NREL) jacket supported 5 MW OWT (Jonkman et al., 2009) has been subjected to the static wind and wave loads, and the dynamic seismic loads. The wind and wave loads have been estimated by FAST (2016) originated by NREL. Then, those outcomes have been transferred to the OpenSees model. The FAST is an aero-hydro-servo-elastic solver that is proficient in performing a fully coupled analysis of a floating OWT. The wind and wave loads have been applied as a static force on the tower and jacket nodes respectively. These loads are a total six components of forces and moments in x, y, and z-direction. FAST follows subsequent equations to determine the tower top thrust force and torque (Moriarty and Hansen, 2005):

$$\mathrm{dT} = \mathrm{B}\ \frac{1}{2}\rho_a \mathrm{V}_{\mathrm{total}}^2 (\mathrm{C}_l \mathrm{Sin}\varphi + \mathrm{C}_d \cos\varphi)\mathrm{cdr} \tag{5}$$

$$\mathrm{dQ} = \mathrm{B}\ \frac{1}{2}\rho_a \mathrm{V}_{\mathrm{total}}^2 (\mathrm{C}_l \mathrm{Sin}\varphi - \mathrm{C}_d \cos\varphi)\mathrm{crdr} \tag{6}$$

where $\mathrm{V}_{\mathrm{total}}$ = relative wind velocity, B = number of blades, C_l = lift coefficients, and C_d = drag coefficients that represent aerodynamic damping, ρ_a = air density, c, and r is the chord length and local radius of the annular plane, dr = thrust distributed around an annulus of width, dT = thrust force, and dQ = torque. The structure has been assumed to be rigid and inactive operationally during the dynamic seismic simulation. The gravity of the structure has been considered in the OpenSees analysis.

Download English Version:

https://daneshyari.com/en/article/8062273

Download Persian Version:

https://daneshyari.com/article/8062273

Daneshyari.com