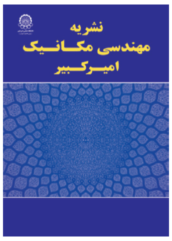

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Edgewise Vibration Reduction of a Small-Scale Wind Turbine Blade with Considering Vibration Coupling

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ABSTRACT: Edgewise vibration in wind turbine blades is one of the important factors that results in reducing the performance of wind turbines. In this paper, an optimally tuned mass damper is proposed to reduce edgewise vibration of a small-scale horizontal axis wind turbine blade (5 kW) with considering the coupling between edgewise and flapwise vibrations. For this purpose, partial differential equations governing dynamics of the system are derived using the Lagrange method. These equations are completely nonlinear and linearization is not performed to avoid possible errors in the analysis and also, the blade is considered as a flexible member. In deriving governing equations, coupling effect between in-plane and out-of-plane vibrations of the blade, and effect of centrifugal forces and gravity are considered. In order to reduce vibration of the blade, a tuned mass damper is used and its parameters are optimized using one of the genetic algorithm methods for a real blade sample. Finally, with applying wind force as a sweep sine excitation, effectiveness of the optimized tuned mass damper in vibration reduction of the blade is investigated and the related results are presented. Results show that the wind turbine blade vibration reduction is achieved properly using the optimally tuned mass damper.

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1- Introduction

These New and renewable energies have an increasing impact on human societies. Wind energy is one of these new energies that have many benefits like cheap and renewable. Wind turbine blade edgewise vibrations can be considered as one of the most important concerns in wind turbines [1]. Therefore, the control or reduction of these vibrations can be of great help in more efficient wind turbines. Qiao et al. [1] investigated the vibration analysis and wind turbine blade vibration reduction by applying piezoelectric and introducing a kind of intelligent active control method. Chen et al. [2] reduced the edgewise vibration of a wind turbine blade under severe wind conditions by applying a semi-active phase-controlled fuzzy method to give a voltage corresponding to the amount of vibration to the magnetic damper to reduce vibrations.
Ikeda et al [3] reduced wind turbine blade vibrations by using an inactive tuned mass damper. Using optimal values tuned mass damper, they reduced blade vibrations to an acceptable level.
In this study, we tried to reduce the edgewise vibrations by using an optimally tuned mass damper. Optimization of tuned mass damper based on a relatively complete dynamic model of the wind turbine blade, taking into account the effect of coupling edgewise and flapwise vibrations, as well as the effect of variations along the length of the blade (centrifugal forces and gravity).

2- Methodology

The Lagrange method is used to find the dynamical equations governing the system. A horizontal axis turbine blade with three blades is shown in Fig. 1. with the corresponding coordinate system. Fig. 2. shows how the tuned mass damper is located in the wind turbine blade.

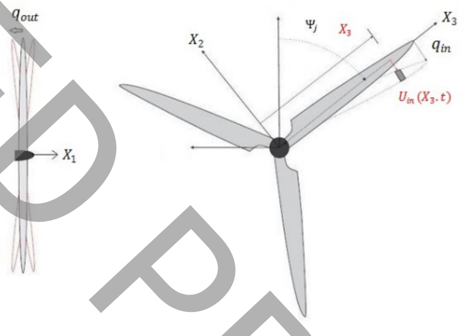

Fig. 1. Wind turbine blade and related coordinates in edgewise and flapwise vibration

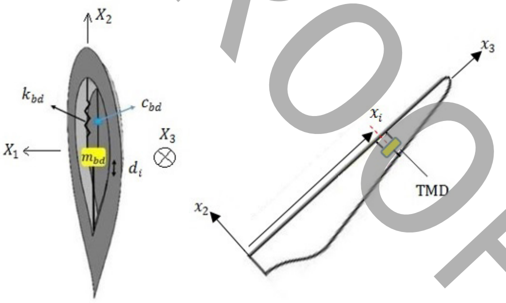

Fig. 2. Packaging of a tuned mass damper in wind turbine blade

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The vibrational equations of motion of the blade with tuned mass damper are obtained as follows:

$$\left(m_{in}+m_{bd}\varphi_{in}^{2}(x_i)\right)\ddot{q}_{in}+m_{bd}\varphi_{in}(x_i)\ddot{d} +c_{in}\dot{q}_{in}+\left(k_{in}-\left[m_{in}+m_{bd}\varphi_{in}(x_i)\right]\right)q_{in} +k_c q_{out}=f_{in}+g\sin\Psi_j\int_{0}^{L}\mu(x_3)\varphi_{in}(x_3)dx_3 +m_{bd}\varphi_{in}(x_i)g\sin\Psi_j \quad (1)$$

$$\left(m_{out}+m_{bd}\varphi_{out}^{2}(x_i)\right)\ddot{q}_{out}+c_{out}\dot{q}_{out} +k_c q_{in}+k_{out}q_{out}=f_{out} \quad (2)$$

$$m_{bd}\ddot{d}_i+m_{bd}\varphi_{in}(x_i)\ddot{q}_{in}+c_{in}\dot{d}_i+ k_{bd}d_i=-m_{bd}\varphi_{in}(x_i)g\cos\Psi_j \quad (3)$$

Also:

$$m_{in}=\int_{0}^{L}\mu(x_3)\varphi_{in}^{2}(x_3)dx_3 \quad (4)$$

$$m_{out}=\int_{0}^{L}\mu(x_3)\varphi_{out}^{2}(x_3)dx_3 \quad (5)$$

In which is the unit mass of the blade per length, the spring coefficient of the tuned mass damper, first normalized mode shape for the in-plane vibrations, first normalized mode shape for the out-plane vibrations, The Azimus angle for the jth blade, The mass of the damper, The amount of displacement of the damper mass relative to the blade, , and , respectively, represents the damping of the structure in the edgewise direction, flapwise direction and also the damper damping. and , respectively, represent the wind force components in-plane and out-plane of the blade.

To calculate the function of unit mass per length, cross-section and second moment of the area by entering the profile of different parts of the blade in the software and fitting the curve on it, the curve equation is considered as the corresponding equation for the continuation of the analysis. In order to find the mode shape of the blade, the fix-free vibration equation of a non-uniform beam is used based on Euler-Bernoulli beam assumptions. In order to ensure the accuracy of dynamic modeling, the results of solving the dynamic equations of the blade with the corresponding results of the Cad software have been compared. The type of algorithm used for optimization in this study is based on the NSGA-II multi-objective function genetic algorithm.

The variation of the target function (maximum displacement of the blade tip) in terms of the variations of the optimization variables (spring and damping coefficient of mass fragmentation) in the optimization process is presented in Fig. 3. The optimization constraints, as well as the values obtained from optimization, are presented in Table 1.

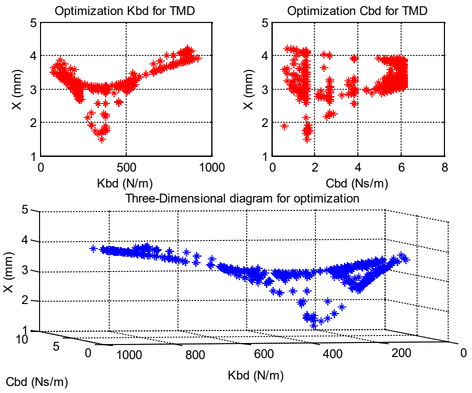

Fig. 3. Variations of the objective function (maximum displacement of the tip of the blade) in terms of variation of optimization variables (spring and damping coefficient of the tuned mass damper) in the optimization process

Table 1. Optimization constraints and optimal values

Optimization Variable	Constraint	Optimal Value
(Ns/m)	0.6< <6	1.724
(N/m)	80< <930	360
(cm)	-2< <2	1.53

3- Results and Discussion

In this study, wind excitation in the form of a sweep sine wave with linearly increasing frequency from 30 up to 250 rad/s is applied. Edgewise vibration at the tip of the blade with and without tuned mass dampers in the presence of wind speeds of 5 m/s, 10 m/s, 15 m/s and 20 m/s is done. The simulation result at 10 m/s is shown in Fig. 4.

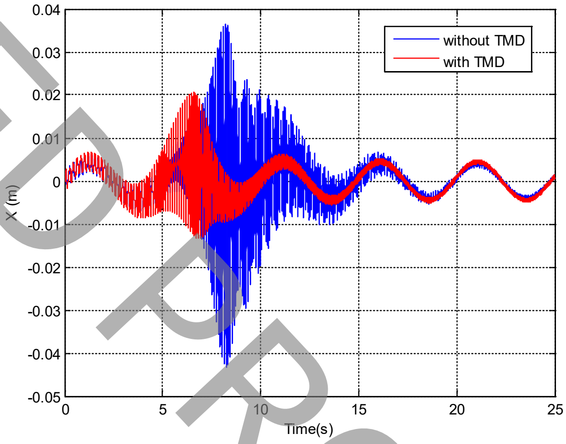

Fig. 4. Edgewise vibration at the tip of the blade with and without employing of an optimally tuned mass damper in the presence of a sweep sine wind excitation with speed of 10 m/s

The percentage of the root mean square of the edgewise vibration reduction of the blade with a tuned mass damper relative to the alone blade is given in Table 1. As shown in Table 1, the effect of the tuned mass damper on the reduction of the root mean square of the edgewise vibration at the tip of the wind turbine blade is small at low wind speeds. But at high wind speeds, the tuned mass dampers have a very effective effect on reducing wind turbine blade vibrations.

Table 2. Effect of employing the tuned mass damper on edgewise vibration reduction (rms) of a wind turbine blade in the presence of a sweep sine wind excitation from 30 to 250 radians per second

Wind speed	Root mean square vibrations reduction at the tip of the blade
5 m/s	11.34
10 m/s	40.21
15 m/s	48.6
20 m/s	53.7

4- Conclusion

In order to study the effect of the applied control method, the comparison between the root mean square values of the vibrations at the tip of the wind turbine blade with and without the tuned mass damper was investigated. The results indicate that the tuned mass damper was more effective in reducing vibrations for high wind speeds. Therefore, based on this study, it can be stated that the use of tuned mass dampers to reduce the vibrations of wind turbine blades can be effective. Also, the use of these dampers in areas with a high average wind speed has a significant effect on reducing vibrations.

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