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Load Reduction of Floating Wind Turbines Using Tuned Mass Dampers

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Abstract: Offshore wind turbines have the potential to be an important part of the United States' energy production profile in the coming years. In order to accomplish this wind integration, offshore wind turbines need to be made more reliable and cost efficient to be competitive with other sources of energy. To capitalize on high speed and highquality winds over deep water, floating platforms for offshore wind turbines have been developed, but they suffer from greatly increased loading. One method to reduce loadsin offshore wind turbines is the application of structural control techniques usuallyused in skyscrapers and bridges. Tuned mass dampers are one structural control system that have been used to reduce loads in simulations of offshore wind turbines. This thesis adds to the state of the art of offshore wind energy by developing a set of optimum passive tuned mass dampers for four offshore wind turbine platforms and byquantifying the effects of actuator dynamics on an active tuned mass damper design. The set of optimum tuned mass dampers are developed by creating a limited degree-of-freedom model for each of the four offshore wind platforms.

I. INTRODUCTION

Offshore wind turbines have the potential to be a significant contributor to global energy production, due to the proximity of the high quality wind resource to coastal energy loads. However, due to the addition of wave and current loads, offshore struc- tures must be made stronger, and thus more expensive than their land based coun- terparts. The reliability of offshore turbines suffers due to the higher loading, and the inaccessibility of the turbines for maintenance compounds this problem. The abil- ity to reduce loads is therefore extremely important for offshore wind turbines, as it allows for increased reliability and possibly lighter and cheaper structures [31].

In order to access offshore winds far offshore over deeper water, floating platforms for windturbines are being designed and studied. With few water depth and sea floor restrictions, these platforms could be placed anywhere in the oceans with suitable electricity transmission. Also, since the platforms can be towed by boats, the wind turbines could be moved or brought to shore for maintenance. Floating wind turbines, however, have been shown to experience much higher fatigue and ultimate loading than onshore or fixed bottom offshore turbines, and could therefore benefit greatly from load reduction techniques.

II. OBJECTIVE OF THIS STUDY

Tuned mass dampers show great promise for use in offshore wind turbines. Both passive and active TMDs can reduce tower and mooring line loads significantly, whichleads to lighter and less expensive structures. This thesis contributes a set of opti- mized passive TMDs for fouroffshore wind turbines, as well as an analysis of an activecontroller for the barge platform.

The optimization of the passive tuned mass damper is completed for the monopile, barge, sparbuoy, and tension leg platform in Chapter 3.

This chapter includes the optimization of the spring and damping parameters using a genetic algorithm. The results of this genetic algorithm are then simulated in FAST-SC and compared to a baseline without a TMD. Each of the four platforms has a unique TMD configuration that results in the best load reduction.

The monopile achieves the best load reduction with both a fore-aft and a side-side TMD in the nacelle. With this configuration, fore-aft loads are reduced by up to 10%, and side-side fatigue loading is reduced by as much as 66%. Side-side ultimate loads are effected as well, with the 95th percentile load being reduced by 32%.

The barge benefits from the same TMD configuration, with a 15% fore-aft fatigue damage reduction and up to a 33% reduction in side-side fatigue loading. Even with theload reduction, the best barge fatigue damage values are approximately 4 times the baseline for the monopile.

III. LITERATURE REVIEW

A. Background

As onshore wind reaches a state of relative technical maturity, more offshore wind farms are being built. The low turbulence, high speed wind resource offshore is another benefit. Figure 2.1 shows the onshore wind resource map for the United States. The wind speeds are taken at a height of 80 meters. It can be seen from this map that most of the onshore wind resource is in the interior of the country, in areas of low population density and far from many of the major load centers on the coasts. Figure 2.2 shows the offshore wind resource. Not only are the wind speeds higher, but the high wind speeds regions are larger and more uniform. Also, the offshore wind resource is closer to the coastal population, which reduces electricity transmission distances. Offshore wind turbines also may be able to achieve more efficient designs due to a higher noise tolerance. Without the stringent noise requirements of onshore turbines, turbines can have higher tipspeed ratios, which in general leads to more efficient turbine designs.

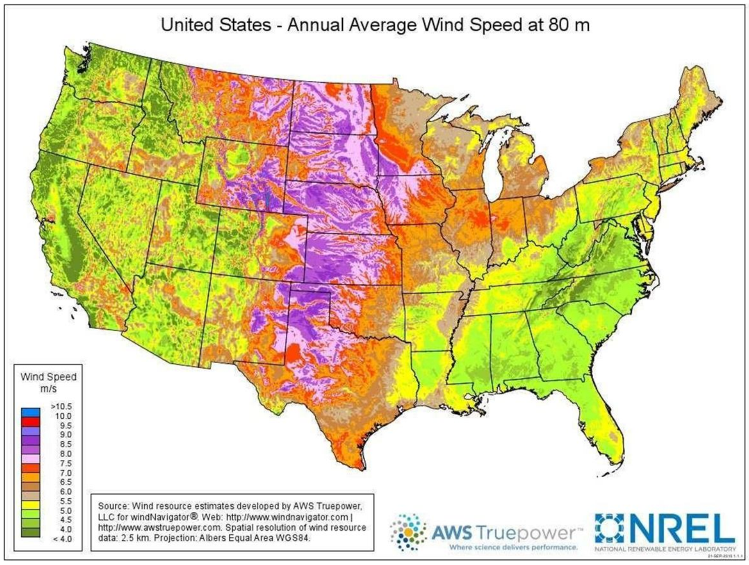


Figure 2.1. Onshore wind resource at 80m height

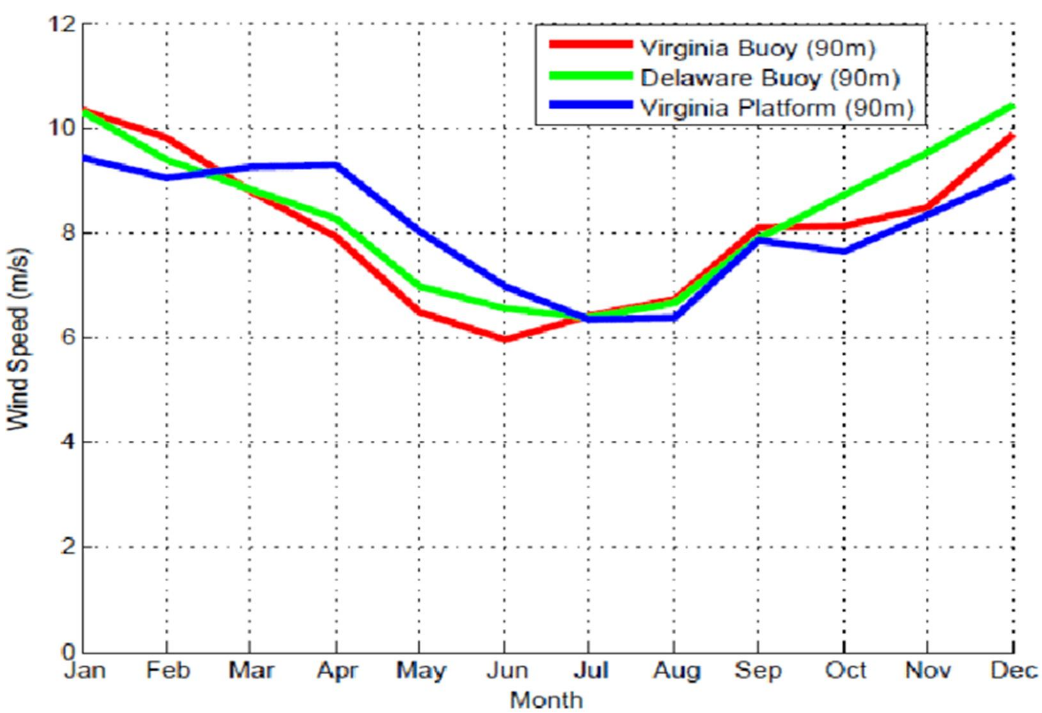


Figure 2.2. Offshore wind resource at 90m height

IV. EXPERIMENTAL DETAILS

The HMD combines the TMD and AMD, and features both a tuned mass, spring, and damper system as well as an actuator [35, 37]. With the addition of an actuator, the HMD gains the potential for improved performance over a passive system. Exam- ples of installed HMDs utilizing servomotor and hydraulic actuators can be found in the literature [12]. Both the AMD and HMD can add energy to the system, thus there is a potential for instability. The HMD, however, includes a passive system, so it can still provide load reduction with no actuation power.

In practical applications of active structural control, it is critical to understand and account for the dynamics of the actuator when modeling and designing the over- all system. Control-structure interaction (CSI) refers to the dynamic interaction between the structure and the actuator in active structural control applications, and is an unavoidable result of using a real actuator for generating active control forces. Control-structure interaction exists because there is a natural feedback path between the structure and the actuator. This feedback can be seen in the block diagramin Figure2.20 [8]. Note that in addition to the effect of the actuator on the struc- ture (indicated by "f" in Figure2.20), there is also an influence on the actuator by the structure. In the past, control systems for structures neglected CSI, which can severely limit performance and robustness [4, 8].

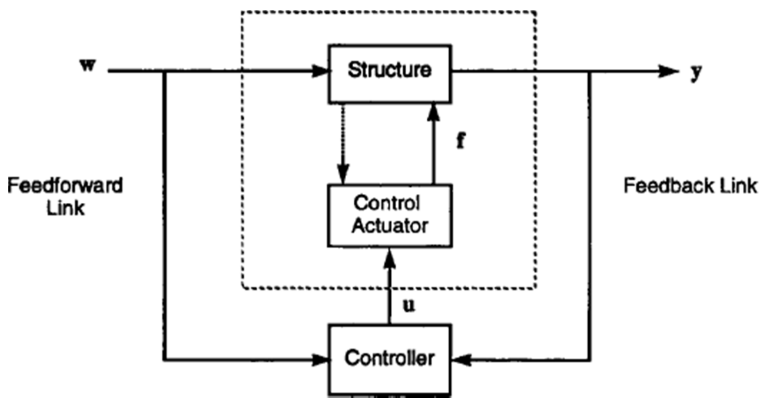
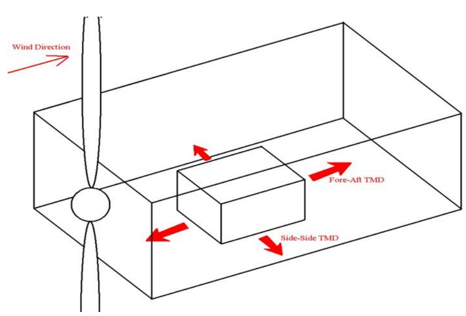


Figure 2.20. Block diagram showing CSI [8]

Research has been conducted on using passive TMDs for wind turbines, especially for offshore structures due to the larger loading [6, 7, 10, 30, 39]. Earlier studies focused on fixed bottom structures, but previous work also focused on floating structures [26, 28]. This research led to the development of FAST-SC, an updated version of the NREL wind turbine aero-elastic design code, which has the capability to simulate both passive and active tuned mass dampers. More details on the capabilities of the FAST-SC code are discussed below, and can be found in the literature [27, 28, 33].FAST is a fully coupled aero-hydro-servo-elastic code that simulates the perfor- mance of wind turbines [19]. It uses Blade Element- Momentum theory (BEM) orgeneralized dynamic wake theory to calculate aerodynamic loads, a linear modal rep-resentation for structural components, and a non-linear hydrodynamic subroutinethat calculates wave loading on the platform for offshore applications [16]. This codeis interfaced through Matlab/Simulink, and a controller can be implemented graphi-cally with Simulink.

A modification to FAST to accommodate structural control (FAST-SC) was de- veloped by Lackner and Rotea [28]. This code includes the capability to model two independent TMDs, one in the fore-aft direction and one in the side-side direction



(Figure 2.21).The TMDs can be located in the nacelle or the platform.

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The addition of locating the TMD in platform is mainly for the spar buoy and TLP platforms, in which it may be desired to move the TMD into the platform. This layout is attractive because there is little room in the nacelle for extraneous systems like the TMD, and since extra mass in the nacelle could create unwanted loading. It may also be feasibleto use a larger TMD in the platform than in the nacelle, which could increase per- formance. In addition to the spring and damping forces, an active force provided by an actuator can be applied to the mass [27, 33]. Position constraints known as stops are imposed on the stroke of the TMDs. These constraints were introduced because the nacelle has a limited amount of space, but the stops can be set to any distance.

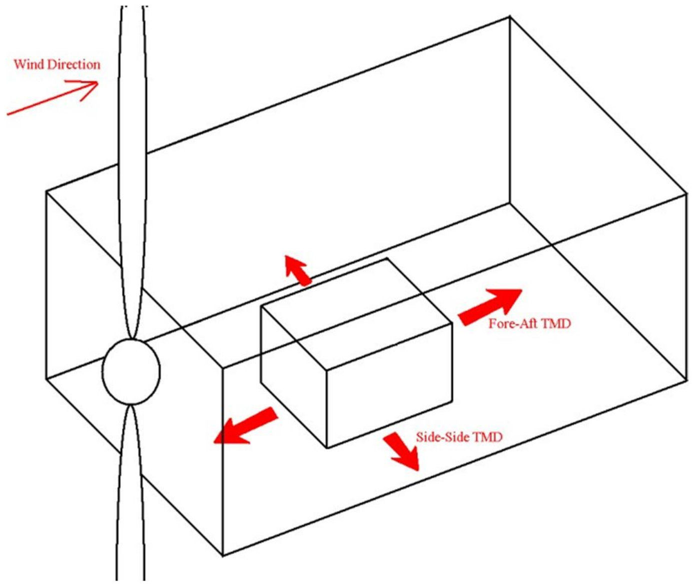

Figure 2.21. Diagram showing direction of Fore-Aft and Side-Side TMDs in anacelle.

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V. RESULTS AND DISCUSSION

Tuned mass dampers show great promise for use in offshore wind turbines. Both passive and active TMDs can reduce tower and mooring line loads significantly, which leads to lighter and less expensive structures. This thesis contributes a set of optimized passive TMDs for four offshore wind turbines, as well as an analysis of anactive controller for the barge platform. The optimization of the passive tuned mass damper is completed for the monopile,barge, spar buoy, and tension leg platform in Chapter 3. This chapter includes the optimization of the spring and damping parameters using a genetic algorithm. The results of this genetic algorithm are then simulated in FAST-SC and compared to a baseline without a TMD. Each of the four platforms has a unique TMD configurationthat results in the best load reduction.

The monopile achieves the best load reduction with both a fore-aft and a side-side TMD in the nacelle. With this configuration, fore-aft loads are reduced by up to 10%, and side-side fatigue loading is reduced by as much as 66%. Side-side ultimate loads are effected as well, with the 95th percentile load being reduced by 32%. The barge benefits from the same TMD configuration, with a 15% fore-aft fatigue damagereduction and up to a 33% reduction in side-side fatigue loading. Even with theload reduction, the best barge fatigue damage values are approximately 4 times the baseline for the monopile.

For the spar buoy, the best configuration involves a nacelle-based TMD as well.

With the TMD in the platform, low value of the spring constant combined with the thrust forcing on the turbine rotor caused the TMD to rest against the stop and contribute verylittle load reduction. The nacelle-based TMD reduced fore-aft damage by as much as 9%, and side-sidefatigue loads by 39%. Ultimate tower loads, however, were increased with the nacelle based TMD.This could be caused by the extra tower top mass from the TMD causing more tower bending due togravitational and inertial loading in the extremes of the pitching motion

The TLP was a complex structure to model; the genetic algorithm that was used for the other platforms could not be used for the TLP. However, the parametric study method that was used instead allowed a primary investigation into the effects of a TMD.

Since the surge motion of the TLP has the largest amplitude of the platform DOFs, this was initially assumed to have the largest effect on tower loading. Preliminary investigations showed that although a surge-tuned TMD reduces the amplitude of this motion, it does little to effect tower or mooring line loading. The platform pitching motion was found to influence both tower bending and line tension the most, so a TMD was developed to reduce this motion for use in the platform and nacelle. The nacelle based TMD once again proved to have a better effect on loading than the TMD in the platform. The nacelle TMD reduced tower fore-aft loads by almost 8%, and side-side loads by 20%. The TMD had little effect on fore-aft ultimate loads, but reduced side-side peak loads by 6%. Line loading wasalso effected; the TMD reduced line fatigue damage by 6%

VI. CONCLUSIONS AND FUTURE WORK

A design of an active control system for a mass damper in an offshore wind turbine using the barge floating platform is modified to include an actuator model. The addition of the actuator model creates a more realistic simulation, and motivates a controller redesign. When the actuator is added, the AMD uses 5-10 times more power in some cases, while reducing loads by only a few percent. In order to make an active controller viable for offshore wind turbines, actuator models must be included in future work. These load reductions for all of the platforms could have a beneficial effect on the cost of an offshore wind turbine as long as the TMD could be constructed at a reasonable cost. Future work on this topic should consider a preliminary economic feasibility study. This study should quantify the cost associated with the load reduction and compare this to the material and construction cost of a TMD, as well as the power usage in the case of an AMD. The monopile achieves the best load reduction with both a foreaft and a side-side TMD in the nacelle. With this configuration, fore-aft loads are reduced by up to 10%, andside-side fatigue loading is reduced by as much as 66%. Side-side ultimate loads are effected as well, with the 95th percentile load being reduced by 32%. The barge benefits from the same TMD configuration, with a 15% fore-aft fatigue damage reduction and up to a 33% reduction in side-side fatigue loading. Even with the load reduction, the best barge fatigue damage values are approximately 4 times the baseline for the monopile.

All of the studies in this thesis focused on using an ideal tuned mass damper. In practice, however, the mechanics of a tuned mass damper may be difficult to achieve.For example, with a stroke of ±8m, a spring would need to stretch 16m and a spring like this may not exist, or may prohibitively expensive. A tuned liquid column dampermay be a good alternative to the tuned mass damper for this application. The water which supplies the mass in a TLCD is essentially free for an offshore turbine, and there are no large scale springs and dampers involved. Further research should gointo developing a passive TLCD for use in an offshore wind turbine.

VII. ACKNOWLEDGMENT

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REFERENCES

[1] Aabid, A., Parveez, B., Raheman, M. A., Ibrahim, Y. E., Anjum, A., Hrairi, M., ... & Mohammed Zayan, J. (2021, May). A Review of Piezoelectric Material-Based Structural Control and Health Monitoring Techniques for Engineering Structures: Challenges and Opportunities. In Actuators (Vol. 10, No. 5, p. 101). Multidisciplinary Digital Publishing Institute.

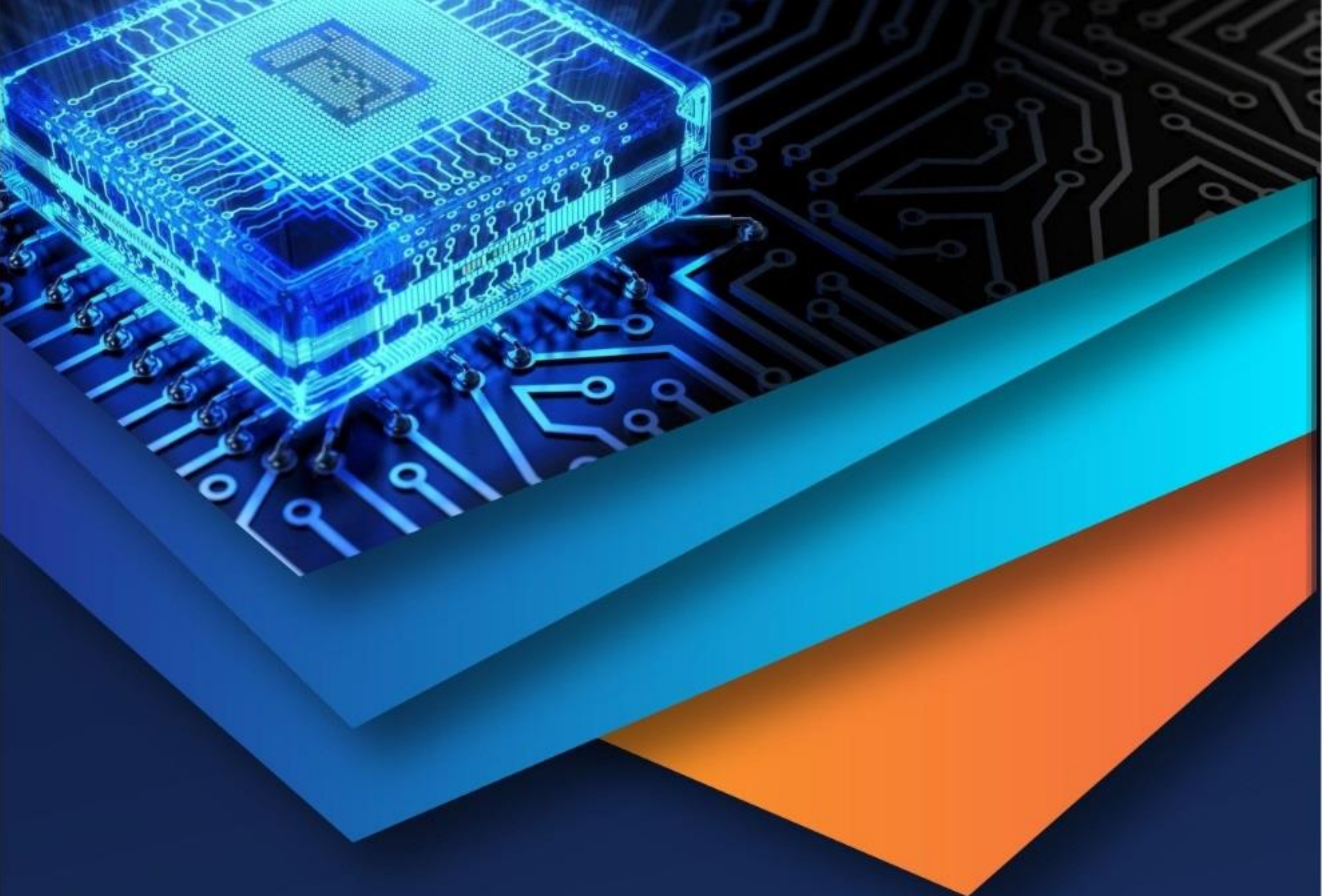
[2] Martin, Amory, and Gregory G. Deierlein. "Structural topology optimization of tall buildingsfor dynamic seismic excitation using modal decomposition." Engineering Structures 216(2020): 110717.

[3] Abdollahzadeh Jamalabadi MY. Active Control of Submerged Systems by Moving Mass. InAcoustics 2021 Mar (Vol. 3, No. 1, pp. 42-57). Multidisciplinary Digital Publishing Institute.

[4] Henderson, Will R., Guancen Liu, Khalil A. Abboud, and Ronald K. Castellano. "Tuning Supramolecular Polymer Assembly through Stereoelectronic Interactions." Journal of the American Chemical Society (2021).

[5] Miranda B, Moretta R, De Martino S, Dardano P, Rea I, Forestiere C, De Stefano L. A PEGDA hydrogel nanocomposite to improve gold nanoparticles stability for novel plasmonicsensing platforms. Journal of Applied Physics. 2021 Jan 21;129(3):033101.

[6] Fitzgerald, Breiffni, and Biswajit Basu. "Vibration control of wind turbines: recent advances and emerging trends." International Journal of Sustainable Materials and Structural Systems 4.2-4 (2020): 347-372.
[7] Fitzgerald, Breiffni, and Biswajit Basu. "Vibration control of wind turbines: recent advances and emerging trends." International Journal of Sustainable Materials and Structural Systems 4, no. 2-4 (2020): 347-372.Dyke, S.J., Spencer, B.F., Quast, P., and Sain,
[8] Sahin, Selmihan, et al. "Investigation of binding interaction behavior between antiemetic drugs and Trypsin by spectroscopy and molecular docking." Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 258 (2021): 119817.
[9] Abdollahzadeh Jamalabadi, Mohammad Yaghoub. "Active Control of Submerged Systems byMoving Mass." Acoustics. Vol. 3. No. 1. Multidisciplinary Digital Publishing Institute, 2021.
[10] Sun, H., Gao, X. and Yang, H., 2020. A review of full-scale wind-field measurements of the wind-turbine wake effect and a measurement of the wake-interaction effect. Renewable and Sustainable Energy Reviews, 132, p.110042.
[11] Grabowski, Andrzej. Virtual reality and virtual environments: a tool for improving occupational safetyand health. CRC Press, 2020.
[12] Xie, Feng, and Aly-Mousaad Aly. "Structural control and vibration issues in wind turbines: Areview." Engineering Structures 210 (2020): 110087.
[13] El-Dabaa, Rana, Sherif Abdelmohsen, and Yasser Mansour. "Programmable passive actuation for adaptive building facade design using hygroscopic properties of wood." Wood Material Science & Engineering 16, no. 4 (2021): 246-259.
[14] Ghaedi, Khaled, et al. "Invited Review: Recent developments in vibration control of building and bridge structures." Journal of Vibroengineering 19.5 (2017): 3564-3580.
[15] Koukoura, S., Scheu, M.N. and Kolios, A., 2021. Influence of extended potential-to-functional failure intervals through condition monitoring systems on offshore wind turbine availability. Reliability Engineering & System Safety, 208, p.107404.



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