Control of Offshore Jacket Platform under Wave loads Using Self-Powered Semi-Active Tuned Mass Damper

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ABSTRACT

Offshore jacket platforms play an important role in the oil and energy industry, so controlling the vibrations of these structures and increasing their useful life is of great interest. In this study, the dynamic response of an offshore jacket platform has been investigated under the effect of wave load with a return period of 100 years. To reduce the dynamic response of the platform deck, a self-powered semi-active mass damper (SP-SATMD) was used and its mass ratio was set to 3% by default. The magneto-rheological damper (MR) energy in the semi-active tuned mass damper is supplied by the vibration of the tuned mass damper (TMD) through an energy harvesting system. This system includes DC direct current generator, rack, and pinion. The rack and pinion convert the linear motion of the TMD into an angular motion and apply it to a DC generator to generate the required electrical energy. The energy harvesting system can also act as an electromagnetic damper (EM) and a proportional control algorithm in determining the damping of the magneto-rheological damper. The results show that the maximum displacement and absolute acceleration of the deck of the controlled platform with a semi-active control strategy decreased by 15 and 16.24%, respectively, compared to the uncontrolled structure.

KEYWORDS

Jacket Platform, Self-Powered Semi-Active Tuned Mass Damper, Magneto-Rheological Damper, Wave Load, DC Generator

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1. Introduction

Offshore jacket platforms are affected by various dynamic loads such as: waves, wind, ice, sea currents and earthquakes due to being in harsh and variable weather conditions. These loads cause vibration of the structure and damage to the energy extraction facilities which reduce the service life of the structure and security of the workers on the oil platform [1]. A 15% reduction in the vibration amplitude of an oil platform doubles its service life [2].

Energy harvesting is a process through which energy is extracted and stored from external sources such as solar, thermal, wind, and kinetic energy [3]. Mechanical vibrations are among the most available sources of energy that exist in various systems and devices and are usually unused [4, 5]. The concept of energy harvesting from the vibrations of civil structures was first proposed by Scruggs et al. [6]. The conversion of the kinetic energy of a TMD into electrical energy was used for generating the required energy of a mounted semi-active and active control system [7]. In his research, Tang [8] estimated that the TMD of the Taipei 101 tower can produce a maximum of 208 kW of electrical energy under the effect of wind load vibrations. Gonzales et al. [9] presented a semi-active TMD and harvested electrical energy from its vibrations using an energy harvester. Marian and Giaralis [10] used Tuned Mass Damper Inerter to control an SDOF structure and investigated the capacity of this system to harvest energy.

In this research, the performance of a semi-active tuned mass damper has been discussed to control the vibrations of the Ressalat offshore jacket platform under dynamic wave loads. The damping of the semi-active tuned mass damper is provided by the Magneto-Rheological (MR) damper. The MR damper needs external energy which is why the DC generator and the rack and pinion mechanism are employed to supply the electrical energy required by the vibration of the mass damper and the structure of the electrical energy needed by the MR damper.

2. Methodology

The TMD is a mass-spring-damper system that is usually added to the top level of the host structure. The design variables of TMD are determined using the equations provided by Ioi and Ikeda [11] for structures with inherent damping in such a way that its natural frequency is tuned with the first mode frequency of the structure and its behavior is out of phase with the host structure [12]. An MR damper provides the damping of the TMD which is connected between the platform deck and the mass of the TMD. The differential equation of a linear multi-degree-of-freedom (MDOF) shear structure under the effect of wave load in matrix forms is Eq. (1):

$$\mathbf{M}\ddot{\mathbf{U}}(t)+\mathbf{C}\dot{\mathbf{U}}(t)+\mathbf{K}\mathbf{U}(t)=\mathbf{F}_{w}+\mathbf{\Lambda}\mathbf{F}_{MR} \qquad (1)$$

Where **M**, **C**, and **K** are the N×N dimensions mass, damping, and stiffness matrices for an N-degree-of-freedom structure, respectively. $\dot{\mathbf{U}}(t)$,$\ddot{\mathbf{U}}(t)$ and $\mathbf{U}(t)$ are acceleration, velocity, and displacement vectors, and $\mathbf{F}_w$ is the wave force on the structure, which is calculated according to Morrison's equation. $\mathbf{F}_{MR}$ is the MR damping force and $\mathbf{\Lambda}$ is the 1×N matrix that indicates the position of the control force. The structure studied in this research is the Ressalat oil platform with 4 fixed foundations located at a depth of 68.2 meters in the Persian Gulf under the dynamic loads of the sea waves. To control the dynamic vibrations of the jacket platform, a self-power semi-active tuned mass damper (SP-SATMD) has been designed with a mass ratio of 3% and an MR damper with a capacity of 1000 kN. Figure 1 shows the operational details of the damper added to the offshore jacket platform deck.

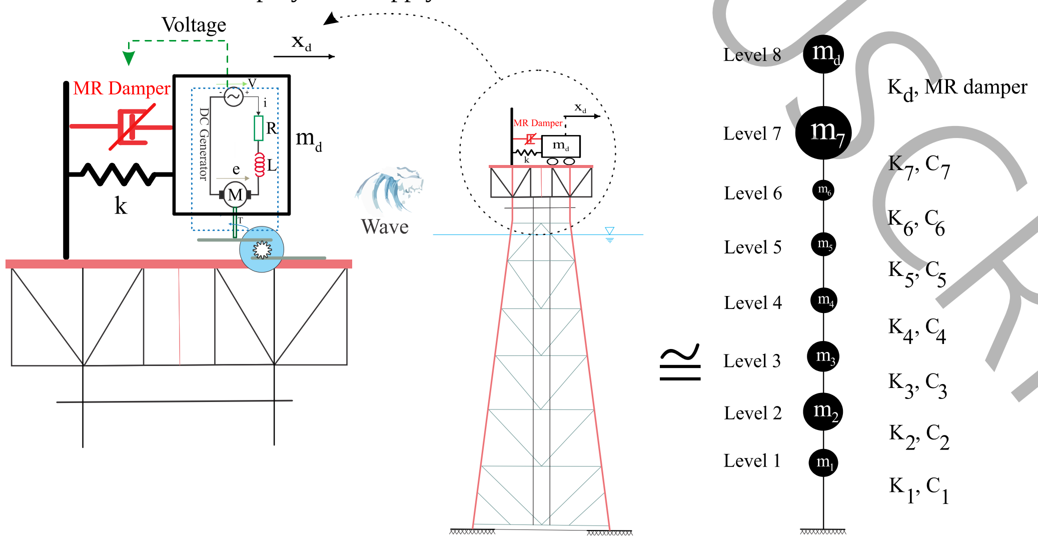

Figure 1. Controlled offshore jacket platform with SP-SATMD and its implementation details

The Simulink environment of MATLAB software and the ode45 solver were applied to solve the equation of motion under the dynamic wave load and prepare the time history responses. The deck displacement and absolute acceleration of the jacket platform as well as the voltage and the electric power produced by the energy harvesting system are investigated Using time history analysis.

3. Results and Discussion

The results of the response history analysis of the displacement and absolute acceleration of the deck of the Ressalat offshore platform are shown in Figures 2 and 3, respectively under wave load with a 100-year return period. These results show a decrease in the maximum displacement and acceleration of the platform deck controlled with a semi-active self-power system compared to the uncontrolled platform by 15% and 16.24%, respectively.

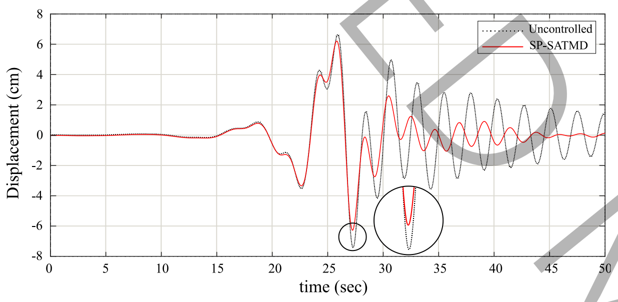

Figure 2. Displacement of the deck of the jacket platform under the wave load

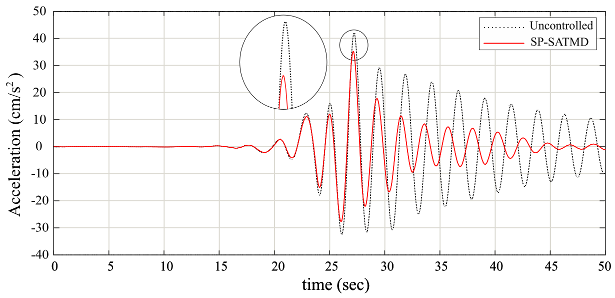

Figure 3. Absolute acceleration of the deck of the jacket platform under the wave load

During dynamic loads, the possibility of damage to the facilities and interruption of the energy source is very high. In the SP-SATMD control system, the energy harvesting system has optimally provided the electric energy required by the MR damper and eliminated its need for an external energy source. Since the performance of the energy harvesting system is based on the vibration velocity of the SP-SATMD, by increasing its velocity, this system produces more electrical energy and vice versa. Notably, this system has acted as a velocity-based proportional continuous controller algorithm. Also, this damper has no time delay and because its damping is variable and depends on the structure's excitations, it can act intelligently against uncertain dynamic loads and has a wider performance range.

4. Conclusions

The results showed that the maximum displacement and acceleration of the platform deck controlled with the SP-SATMD is reduced by 15% and 16.24%, respectively. Considering that a 15% reduction in the vibration of the deck doubles the useful life of the structure, it can be said that the proposed control method is economical and very efficient in terms of energy extraction costs. The energy harvesting system has been able to provide the electrical energy optimally needed by the SP-SATMD damper and act like a proportional control algorithm and provides the required external energy for SP-SATMD. Therefore, SP-SATMD works like a passive damper and has its advantages, based on not needing external energy. Also, unlike other semi-active controllers, it has no time delay because the energy harvesting system itself is a part of the energy transfer circuit to the MR damper.

5. References

[1] B.-L. Zhang, Q.-L. Han, X.-M. Zhang, G.-Y. Tang, Active control of offshore steel jacket platforms, Springer, 2019.
[2] B.-L. Zhang, Q.-L. Han, X.-M. Zhang, Recent advances in vibration control of offshore platforms, Nonlinear Dynamics, 89(2) (2017) 755-771.
[3] R. Maroofiazar, M.F. Farzam, Experimental investigation of energy harvesting from sloshing phenomenon: Comparison of Newtonian and non-Newtonian fluids, Energy, 225 (2021) 120264.
[4] A. Munaz, B.-C. Lee, G.-S. Chung, A study of an electromagnetic energy harvester using multi-pole magnet, Sensors and Actuators A: Physical, 201 (2013) 134-140.
[5] D.W. Oh, D.Y. Sohn, D.G. Byun, Y.S. Kim, Analysis of electromotive force characteristics and device implementation for ferrofluid based energy harvesting system, in: 2014 17th International Conference on Electrical Machines and Systems (ICEMS), IEEE, 2014, pp. 2033-2038.
[6] J. Scruggs, W. Iwan, Control of a civil structure using an electric machine with semiactive capability, Journal of Structural Engineering, 129(7) (2003) 951-959.
[7] X. Tang, L. Zuo, Simultaneous energy harvesting and vibration control of structures with tuned mass dampers, Journal of Intelligent Material Systems and Structures, 23(18) (2012) 2117-2127.
[8] X. Tang, Simultaneous energy harvesting and vibration control of tall buildings using electricity-generating tuned mass dampers, State University of New York at Stony Brook, 2013.

[9] A. Gonzalez-Buelga, L.R. Clare, A. Cammarano, S.A. Neild, S.G. Burrow, D.J. Inman, An optimised tuned mass damper/harvester device, Structural Control and Health Monitoring, 21(8) (2014) 1154-1169.
[10] L. Marian, A. Giaralis, The tuned mass-damper-inerter for harmonic vibrations suppression, attached mass reduction, and energy harvesting, Smart structures and systems, 19(6) (2017) 665-678.
[11] T. IOI, K. IKEDA, On the dynamic vibration damped absorber of the vibration system, Bulletin of JSME, 21(151) (1978) 64-71.
[12] A. Yakut, Overview of seismic performance assessment procedures for rc buildings in Turkey , (2020).