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OPTIMAL PARAMETERS OF VIBRATION REDUCTION SYSTEM TMD-D AND DVA FOR AN INVERTED PENDULUM TYPE STRUCTURE

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Abstract. N. D. Anh, K. D. Dien and N. D. Chinh in [1] have studied the vibration of inverse pendulum system installed with the vibration reduction system TMD-D and DVA. These results implemented by numerical simulation for the articulated tower in the ocean show that the obtained oscillations in some cases with installed absorber increase the amplitude of vibration when compared to the case without absorber. It is a fact that when simulation is employed, the parameters of TMD-D and DVA are chosen arbitrarily without optimal design. In the paper, the authors investigate to find the optimal parameters of the TMD-D and DVA absorbers in order to optimally reduce the vibration for the inverse pendulum system. These research results are applied to reduce the vibration for the articulated tower in the ocean.

1. INTRODUCTION

In the paper [2] K. D. Dien and N. D. Chinh have studied the vibration of inverse pendulum system installed with the TMD-D (TMD acts to reduce the vertical vibration) and TMD-N (TMD acts in order to reduce the horizontal vibration). N. D. Chinh has investigated the inverse pendulum system installed only with TMD-N [3]. These researches are shown that if the TMD-N is installed in the inverse pendulum system, the horizontal vibration will be reduced without reducing the amplitude of vertical vibration. Therefore, if the inverse pendulum system has a horizontally acted force, the structure will have a horizontal oscillation. In this case, the TMD-N should be installed in the system.

On the opposite view, if the TMD-D is installed, this absorber only has the effectiveness of reducing the oscillation in vertical direction of inverse pendulum system without reducing the amplitude of horizontal vibration. In order to reduce the vertical oscillation. A TMD-D should be installed in the system. These results are shown in [4].

If structures have both the vertically and horizontally acted forces, the structures generate the oscillation in vertical and horizontal directions. In this case, the vibration reduction system TMD-D and TMD-N will have to be installed in the system. These results are shown in [5].

In some cases, the installation with TMD-N is very complicated. It is not suitable for daily activity of the human beings. So, the DVA shown in Fig. 1 should be installed.

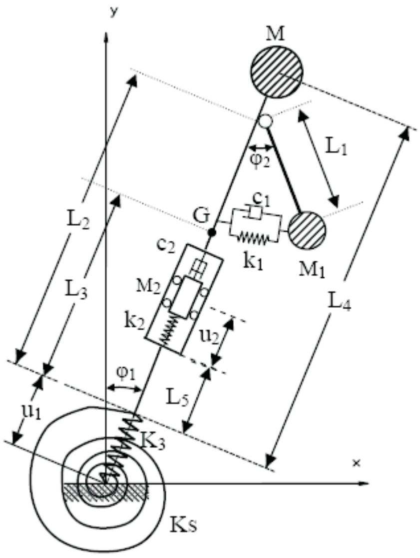

Fig. 1. The inverted pendulum installed with TMD-D and DVA

Nguyen Dong Anh, Khong Doan Dien and Nguyen Duy Chinh in [1] have studied the vibration of inverse pendulum system installed with the vibration reduction system TMD-D and DVA. These results implemented by numerical simulation for the articulated tower in the ocean show that the obtained oscillations in some cases with installed absorber increase the amplitude of vibration when compared to the case without absorber. It is a fact that when simulation is employed, the parameters of TMD-D and DVA are chosen arbitrarily without optimal design. In the paper, the authors investigate to find the optimal parameters of the TMD-D and DVA absorbers in order to optimally reduce the vibration for the inverse pendulum system. These research results are applied to reduce the vibration for the articulated tower in the ocean.

2. THE MOTION EQUATION OF THE INVERTED PENDULUM SYSTEM WITH INSTALLED TMD-D AND DVA

Fig. 1 shows the diagram of the inverse pendulum system with mass M and a distance L_4 from background, supported bar of inverse pendulum system with mass m with center at G and distance L_3. The link between ground and the inverse pendulum system is replaced by two springs with rigidity K_s and K_3.

In order to reduce the vibration for the inverse pendulum system, two TMD-D and DVA absorbers are installed in the system. TMD-D acts to reduce the vertical vibration and DVA acts to reduce the horizontal vibration of the system.

The DVA is assigned at a position up from horizontal platform at a distance L_2, with the mass of M_1, the length of L_1, the spring constant of k_1, and the damping constant of c_1.

The TMD-D assigned at a position up from horizontal platform with a distance L_5 consists of a mass M_2 and combines with the inverted pendulum by a spring with hardness k_2 and a damping system with coefficient c_2.

In [1], we have the following equations:

$$\mathbf{M}_H\ddot{\mathbf{X}} + \mathbf{C}_H\dot{\mathbf{X}} + \mathbf{K}_H\mathbf{X} = \mathbf{F}_H(t) \tag{1}$$

where

$$\mathbf{M}_H = \begin{bmatrix} (ML_4^2 + M_2L_5^2 + \frac{mL_3^2}{3} + M_1(L_2 - L_1)^2) & (M_1L_1L_2 - M_1L_1^2) & 0 & 0 \\ (M_1L_1L_2 - M_1L_1^2) & M_1L_1^2 & 0 & 0 \\ 0 & 0 & (M + M_1 + M_2 + m) & M_2 \\ 0 & 0 & M_2 & M_2 \end{bmatrix} \tag{2}$$

$$\mathbf{K}_H = \begin{bmatrix} (K_S - MgL_4 - \frac{mgL_3}{2} - M_1gL_2 - M_1gL_1 - M_2gL_5) & -M_1L_1g & 0 & 0 \\ -M_1L_1g & (K_1L_1^2 + M_1gL_1) & 0 & 0 \\ 0 & 0 & K_3 & 0 \\ 0 & 0 & 0 & K_2 \end{bmatrix} \tag{3}$$

$$\mathbf{C}_H = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & C_1L_1^2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix};\ \ddot{\mathbf{X}} = \begin{bmatrix} \ddot{\varphi}_1 \\ \ddot{\varphi}_2 \\ \ddot{U}_1 \\ \ddot{U}_2 \end{bmatrix};\ \dot{\mathbf{X}} = \begin{bmatrix} \dot{\varphi}_1 \\ \dot{\varphi}_2 \\ \dot{U}_1 \\ \dot{U}_2 \end{bmatrix};\ \mathbf{X} = \begin{bmatrix} \varphi_1 \\ \varphi_1 \\ U_1 \\ U_2 \end{bmatrix};\ \mathbf{F}_T = \begin{bmatrix} LQ(t) \\ 0 \\ P(t) \\ 0 \end{bmatrix} \tag{4}$$

Eq. (1) is the motion equation of the inverted pendulum with TMD-D and DVA.

3. STABILITY ANALYSIS

Introduce the following parameters:

$$\begin{gathered} u = L_4\varphi_1,\ \ u_d = L_1\varphi_2,\ \ L_3 = L_4 = L,\ \ \mu_{u1} = \frac{M_1}{M+m},\quad \mu_{\varphi 1} = \frac{M_1}{M + {}^{m}\!/_{3}}, \\ \gamma_1 = \frac{L_2 - L_1}{L_4},\quad \omega_u = \sqrt{\frac{K_3}{M+m}},\quad \omega_\varphi = \sqrt{\frac{6K_s - gL_4\,(6M+3m)}{2L_4^2\,(3M+m)}}, \\ \mu_{u2} = \frac{M_2}{M+m},\quad \mu_{\varphi 2} = \frac{M_2}{M + {}^{m}\!/_{3}},\quad \gamma_2 = \frac{L_5}{L_4},\ \omega_{d2} = \sqrt{\frac{k_2}{M_2}},\quad \xi_2 = \frac{c_2}{2M_2\omega_{d2}}, \\ \alpha_{d2} = \frac{\omega_{d2}}{\omega_\varphi},\quad \omega_{d1} = \sqrt{\frac{k_1}{M_1} + \frac{g}{L_1}},\quad \xi_1 = \frac{c_1}{2M_1\omega_{d1}},\ \alpha_{d1} = \frac{\omega_{d1}}{\omega_\varphi},\ \alpha_u = \frac{\omega_u}{\omega_\varphi},\ \eta = \frac{g}{\omega_\varphi^2 L_4} \end{gathered} \tag{5}$$

where μ_{u1}, $\mu_{\varphi 1}, \mu_{u2}$, and $\mu_{\varphi 2}$ are the mass ratios; γ_1 and γ_2 specify the position of the DVA and TMD-D, respectively; ω_φ is the natural frequencies in horizontal direction of the structure; ω_u is the natural frequencies in vertical direction of the structure; ξ_1 and ξ_2 are the damping ratios of DVA and TMD-D, respectively; ω_{d1} is the natural frequency of DVA; ω_{d2} is the natural frequency of TMD-D; α_{d1}, α_{d2} and α_u are the natural frequency ratios; η is the distribution of the mass of the structure.

Substituting (5) into (1) - (4), we have the following equations:

$$\mathbf{M}_{H*}\ddot{\mathbf{X}}* + \mathbf{C}_{H*}\dot{\mathbf{X}}* + \mathbf{K}_{H*}\mathbf{X}* = \mathbf{F}_{H*}(t) \tag{6}$$

$$\mathbf{M}_{H*} = \begin{bmatrix} (1+\mu_{\varphi 1}\gamma_1^2+\mu_{\varphi 2}\gamma_2^2) & (\mu_{\varphi 1}\gamma_1) & 0 & 0 \\ (\mu_{\varphi 1}\gamma_1) & (\mu_{\varphi 1}) & 0 & 0 \\ 0 & 0 & (1+\mu_{u1}+\mu_{u2}) & (\mu_{u2}) \\ 0 & 0 & \mu_{u2} & (\mu_{u2}) \end{bmatrix} \tag{7}$$

$$\mathbf{K}_{H*} = \begin{bmatrix} (1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\omega_\varphi^2 & -\mu_{\varphi 1}\eta\omega_\varphi^2 & 0 & 0 \\ -\mu_{\varphi 1}\eta\omega_\varphi^2 & \mu_{\varphi 1}\omega_\varphi^2\alpha_{d1}^2 & 0 & 0 \\ 0 & 0 & \alpha_u^2\omega_\varphi^2 & 0 \\ 0 & 0 & 0 & \mu_{u2}\alpha_{d2}^2\omega_\varphi^2 \end{bmatrix} \tag{8}$$

$$\mathbf{C}_{H*} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 2\xi_1\alpha_{d1}\mu_{\varphi 1}\omega_\varphi & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2\xi_2\alpha_{d2}\mu_{u2}\omega_\varphi \end{bmatrix};\ \mathbf{X}* = \begin{bmatrix} U \\ U_d \\ U_1 \\ U_2 \end{bmatrix};\mathbf{F}_T* = \begin{bmatrix} \frac{3Q(t)}{3M+m} \\ 0 \\ \frac{P(t)}{M+m} \\ 0 \end{bmatrix} \tag{9}$$

The matrix equation (6) can be used for the design of TMD-D and DVA.

There are some stability criteria. We use here the stability criterion according to Lyapunov matrix equation. The criterion is given by the following conditions:

- Damping matrix is a symmetric positive semi-definite matrix;
- Stiffness matrix is a symmetric positive definite matrix.

Using the matrices in Eq. (6), we can obtain the stability condition

$$\begin{aligned} &(1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\,\omega_\varphi^2 > 0 \\ &\mu_{\varphi 1}\alpha_{d1}^2\,(1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\,\omega_\varphi^4 - \left(\mu_{\varphi 1}\eta\omega_\varphi^2\right)^2 > 0 \\ &\alpha_u^2\omega_\varphi^2\,\left(\mu_{\varphi 1}\alpha_{d1}^2\,(1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\,\omega_\varphi^4 - \left(\mu_{\varphi 1}\eta\omega_\varphi^2\right)^2\right) > 0 \\ &\mu_{u2}\alpha_{d2}^2\alpha_u^2\omega_\varphi^4\,\left(\mu_{\varphi 1}\alpha_{d1}^2\,(1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\,\omega_\varphi^4 - \left(\mu_{\varphi 1}\eta\omega_\varphi^2\right)^2\right) > 0 \end{aligned} \tag{10}$$

Due to $\mu_{\varphi 1} > 0,\ \mu_{\varphi 2} > 0,\ \mu_{u2} > 0,\ \alpha_{d2}^2 > 0,\ \alpha_u^2 > 0,\ \omega_\varphi^4 > 0,\ \omega_\varphi^6 > 0,\ \omega_\varphi^8 > 0$, we can obtain the final stability condition of the inverse pendulum system in which two absorbers TMD-D and DVA are installed:

$$(1-\mu_{\varphi 1}\gamma_1\eta-\mu_{\varphi 2}\gamma_2\eta)\,\alpha_{d1}^2 - \mu_{\varphi 1}\eta^2 > 0 \tag{11}$$

From the stability criterion (11), we realize when designing the absorbers, the bigger their mass and the higher their assigning position is, the more to be unstable the structure gets. So, when designing the absorbers to make strutures stable, we have to choose the parameters such that it sastifies the equation (11).

4. THE CALCULATION OF PARAMETERS OF TMD-D AND DVA

The system of motion equations (6) - (9) is the same form of system of equations of motion of inverted pendulum with two installed absorbed mechanisms mentioned in [5]. Thus, the investigation results of vibration damping mechanism in case with two installed absorbers TMD-D and TMD-N can be applied completely with case of installed absorbers TMD-D and DVA.

From [5], we have:

$$\alpha_{d2opt} = \frac{\alpha_u\sqrt{1+\mu_{u1}}}{(1+\mu_{u1}+\mu_{u2})} \tag{12}$$

$$\xi_{2opt} = \sqrt{\frac{(1+\mu_{u1})(\mu_{u1}+\mu_{u2})}{(1+\mu_{u1}+\mu_{u2})}} \tag{13}$$

$$\alpha_{d1opt} = \sqrt{C\frac{B}{A^2}+\frac{\mu_{\varphi1}\eta^2}{B}}; \tag{14}$$

$$\xi_{1opt} = \sqrt{\frac{\mu_{\varphi1}CA^2\eta^2+ABC\left(B+2\mu_{\varphi1}\gamma_1\eta\right)-B^2C^2}{A\left(B^2C+\mu_{\varphi1}A^2\eta^2\right)}}; \tag{15}$$

$$A=\left(1+\mu_{\varphi1}\gamma_1^2+\mu_{\varphi2}\gamma_2^2\right);\ B=\left(1-\mu_{\varphi1}\gamma_1\eta-\mu_{\varphi2}\gamma_2\eta\right);\ C=\left(1+\mu_{\varphi2}\gamma_2^2\right) \tag{16}$$

We consider special case:

We consider the case with optimal parameters with one absorbed mechanism DVA of inverted pendulum and we only take attention in horizontal oscillation and ignore the vertical oscillation studied by *N. D. Anh, H. Matsuhisa, L. D. Viet, M. Yasuda* [6]. In this paper, the results of article will be compared with the existing ones.

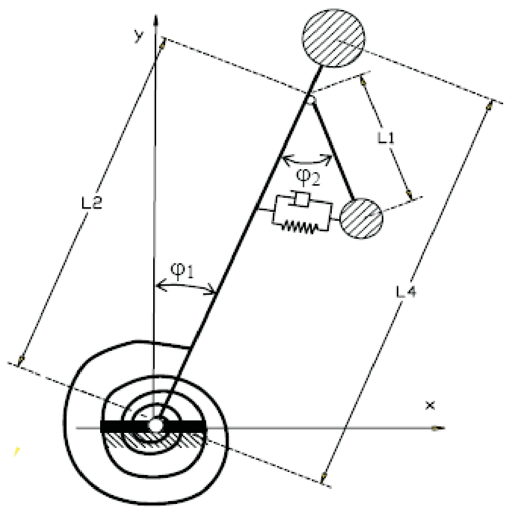

Fig. 2. Diagram of DVA for inverted pendulum mechanism with horizontal vibration

In this case, inverted pendulum is only installed with DVA with mass M_1, length L_1, and installed at position the background of distance L_2. The oscillation diagram of system is shown in Fig. 2. Thus, we have M_2=*zero*, K_2=*zero*, C_2=*zero*, K$_3$= $+\infty$, L_5=*zero*. By adding these values into (5) and (12 - 16), we obtain the optimal parameters in this case as follows:

$$\alpha_{d1opt} = \frac{\sqrt{\left(1-\gamma_1\eta\mu_{\varphi1}\right)^2+\mu_{\varphi1}\eta^2\left(1+\gamma_1^2\mu_{\varphi1}\right)^2}}{\left(1+\gamma_1^2\mu_{\varphi1}\right)\sqrt{1-\gamma_1\eta\mu_{\varphi1}}} \tag{17}$$

$$\xi_{1opt} = \frac{\sqrt{\mu_{\varphi1}\left(\gamma_1+\eta\right)^2}}{\sqrt{\left(1+\gamma_1^2\mu_{\varphi1}\right)\left[\left(1-\gamma_1\eta\mu_{\varphi1}\right)^2+\mu_{\varphi1}\eta^2\left(1+\gamma_1^2\mu_{\varphi1}\right)^2\right]}} \tag{18}$$

From [5] and (5), we have:

$$\mu = \mu_{\varphi1} = \frac{M_1}{M + m/3}, \quad \gamma = \gamma_1 = \frac{L_2 - L_1}{L_4} \tag{19}$$

$$\omega_s = \omega_\varphi = \sqrt{\frac{6K_s - gL_4\left(6M+3m\right)}{2L_4^2\left(3M+m\right)}} \tag{20}$$

Substituting (19, 20) into (17÷ 18), we have:

$$\alpha_{d1opt} = \frac{\sqrt{\left(1-\gamma\eta\mu\right)^2+\mu\eta^2\left(1+\gamma^2\mu\right)^2}}{\left(1+\gamma^2\mu\right)\sqrt{1-\gamma\eta\mu}} \tag{21}$$

$$\xi_{1opt} = \frac{\sqrt{\mu\left(\gamma+\eta\right)^2}}{\sqrt{\left(1+\gamma^2\mu\right)\left[\left(1-\gamma\eta\mu\right)^2+\mu\eta^2\left(1+\gamma^2\mu\right)^2\right]}} \tag{22}$$

The results (21), (22) are the same with the ones [6].

5. APPLICATION EXAMPLE

One of the examples of inverted pendulum is the articulated tower in the ocean. Compliant platforms such as articulated towers are economically attractive for deep-water conditions because of their reduced structural weight compared to conventional platforms. The foundation of the tower does not resist lateral forces due to wind, waves and currents; instead, restoring moments are provided by a large buoyancy force. The environmental loadings such as wind and wave one may occur or stop in random nature. Thus, the articulated tower has both horizontal and vertical vibrations; we should use TMD-D and DVA together.

Using the stability condition (6), we can check if the structure is statically stable or not. It is seen from Fig. 3, the restoring moment M_b generated by buoyancy force is determined by

$$M_b = \rho_w g \frac{\pi D^2}{4}\frac{l_s^2}{2}\sin\theta, \tag{23}$$

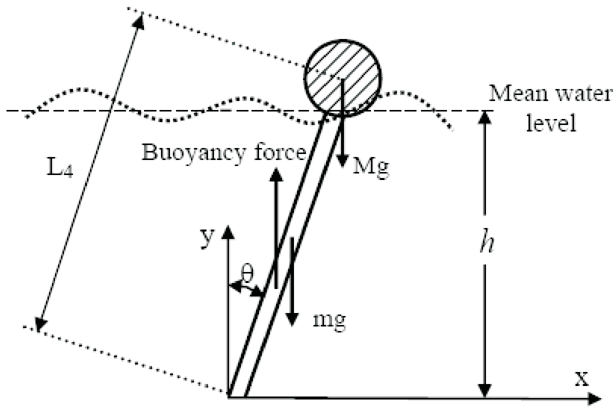

Fig. 3. Diagram of the articulated tower

where ρ_w is the mass density of fluid, l_s is the length of the submerged part of the tower, Considering that θ is small, length l_s is approximated by the height elevation h and $\sin\theta \approx \theta$. From (23) it is easy to find the spring constant of the equivalent torsion spring

$$K_S = \frac{1}{8}\pi\rho_w g h^2 D^2. \tag{24}$$

Material is steel rod concrete with the parameters: E=3.1×10^{10} N/m^2, $\rho = 2400$ kg/m^3.

- tower length $L_4 = 400$ m
- tower diameter: inside diameter $d = 14$ m, outside diameter $D = 15$ m
- end mass $M = 10 \times 10^5$ kg
- mean water level $h = 350$ m
- water density ρ_w= 1025 kg/m^3.

The mass m of supported bar is determined by formulae:

$$m = \pi\rho\left(\frac{D^2}{4} - \frac{d^2}{4}\right) L_4 = 2.2 \times 10^7 \text{ kg} \tag{25}$$

The coefficient of distorted torque K_S is calculated from (24):

$$K_s = 1.1 \times 10^{11} (\text{Nm}) \tag{26}$$

Let Z be deformation in vertical direction at installed position of TMD-D, we have:
* Z is determined as a function of K_3

$$Z = \frac{Q(t)}{K_3} \tag{27}$$

Z is determined throughout the tensile and compression characteristics of elastic materials, or

$$Z = \frac{Q(t)L_5}{EF} \tag{28}$$

where $Q(t)$: acting force at installed position of absorber; EF: tensile and compression rigidity of materials.

From the equations (24) and (28), we have:

$$K_3 = \frac{EF}{L_5}. \tag{29}$$

The TMD-D is put at position L_5= 400 m from the background

$$\Rightarrow K_3 = \frac{E\pi\left(\frac{D}{4}^2 - \frac{d}{4}^2\right)}{L_5} = 1.7\times 10^9 (\mathrm{N/m}) \tag{30}$$

By adding the equations (25), (26), (30) into (5), the natural frequency of tower is determined as follows:

$$\omega_\varphi = 0.234\ \mathrm{rad}/s; \quad \omega_u = 8.93\ (\mathrm{rad}/s) \tag{31}$$

The mass of DVA is designed as M_1= 30×10^4 kg, L_1= 15m, L_2 =350m. TMD–D is M_2 =4.42×10^5 kg. From the equations (12, 13, 14, 15, 16), we can calculate the nondimensional parameters of TMD-D and DVA

$$\xi_{1opt} = 0.2;\ \xi_{2opt} = 1.01;\ \alpha_{d1opt} = 0.948;\ \alpha_{d2opt} = 37.14 \tag{32}$$

These parameters must satisfy the stability condition in (11), we obtain:

$$\left(1 - \mu_{\varphi 1}\gamma_1\eta - \mu_{\varphi 2}\gamma_2\eta\right)\alpha_{d1}^2 - \mu_{\varphi 1}\eta^2 = 0.858 > 0 \tag{33}$$

The parameters of TMD-D and DVA are obtained from (5) and (31, 32) as follows:

$$\begin{aligned} c_1 &= 2M_1\xi_{1opt}\omega_\varphi\alpha_{d1opt} = 2.688\times 10^4\ (\mathrm{Ns/m}) \\ k_1 &= M_1\left(\omega_\varphi^2\alpha_{d1opt}^2 + g/L_1\right) = 2.158\times 10^5\ (\mathrm{N/m}) \\ c_2 &= 2M_2\xi_{2opt}\omega_\varphi\alpha_{d2opt} = 7.746\times 10^6\ (\mathrm{Ns/m}) \\ k_2 &= M_2\alpha_{d2opt}^2\omega_\varphi^2 = 3.35\times 10^7 (\mathrm{N/m}) \end{aligned} \tag{34}$$

By using the MAPLE software and the above results, the simulation results of oscillation of inverse pendulum with two absorbers TMD-D and DVA are as follows:

Case 1: Vibrational simulation of offshore tower with initial condition: $\varphi_1 = 0.007$ (rad), $\dot{\varphi}_1 = 0.00$ (rad/s), $U_1 = 0.008$ (m), $\dot{U}_1 = 0.00$ (m/s): see Fig. 4, Fig. 5, Fig. 6, Fig. 7.

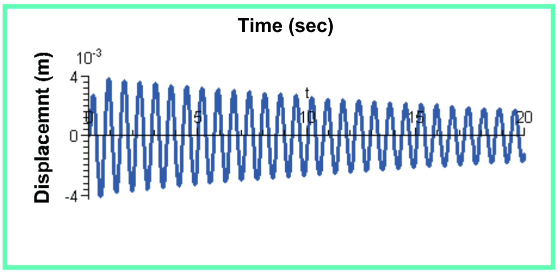

Fig. 4. Time response of the absorber TMD-D with the following initial conditions: φ_1= 0.007 (rad), $\dot{\varphi}_1 = 0.00$ (rad/s), U_1=0.008 (m), $\dot{U}_1 = 0.00$ (m/s)

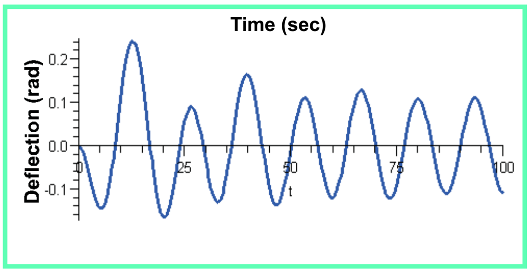

Fig. 5. Time response of the absorber DVA with the following initial conditions: φ_1= 0.007 (rad), $\dot{\varphi}_1 = 0.00$ (rad/s), U_1=0.008 (m), $\dot{U}_1 = 0.00$ (m/s)

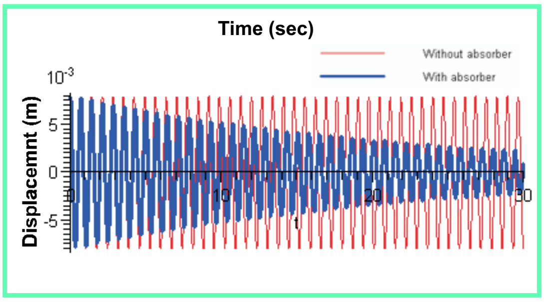

Fig. 6. Displacemnt U_1 with the following initial conditions: φ_1= 0.007 (rad), $\dot\varphi_1$ = 0.00 (rad/s), U_1=0.008(m), $\dot U_1$ = 0.00 (m/s)

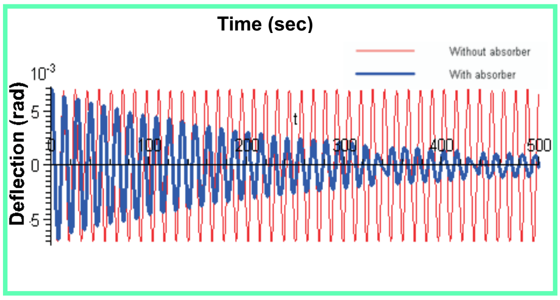

Fig. 7. Deflection φ_1 with the following initial conditions: φ_1= 0.007 (rad), $\dot\varphi_1$ = 0.00 (rad/s), U_1=0.008(m), $\dot U_1$ = 0.00 (m/s)

Case 2: Vibrational simulation of offshore tower with initial condition: $\varphi_1 = 0.007$ (rad), $\dot\varphi_1$= 0.002 (rad/s), U_1 = 0.008 (m), $\dot U_1$ = 0.003 (m/s): see Fig. 8, Fig. 9, Fig. 10, Fig. 11.

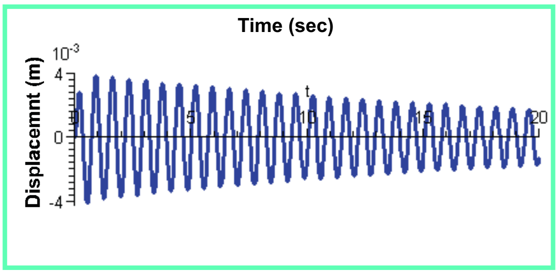

Fig. 8. Time response of the absorber TMD-D with the following initial conditions: φ_1 = 0.007 (rad), $\dot\varphi_1$=0.008 (rad/s), U_1 = 0.008 (m), $\dot U_1$ = 0.003 (m/s)

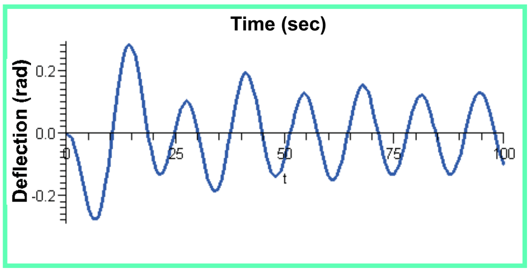

Fig. 9. Time response of the absorber DVA with the following initial conditions: φ_1 = 0.007 (rad), $\dot\varphi_1$ = 0.002 (rad/s), U_1=0.008 (m), $\dot U_1$ = 0.003 (m/s)

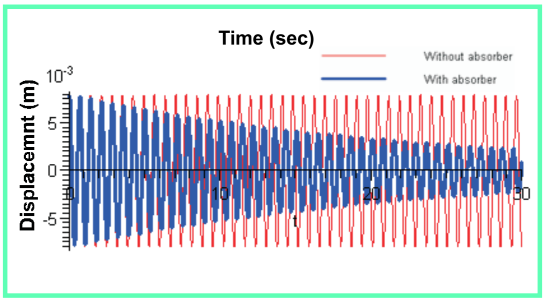

Fig. 10. Displacemnt U_1 with the following initial conditions: φ_1 = 0.007 (rad), $\dot\varphi_1$=0.008 (rad/s), U_1 = 0.008 (m), $\dot U_1$ = 0.003 (m/s)

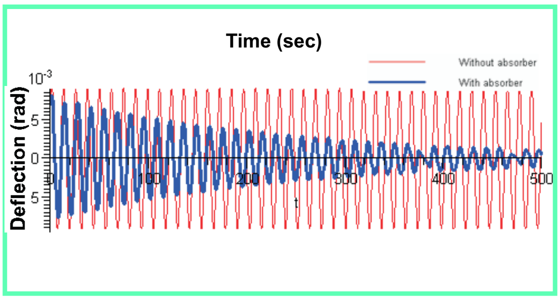

Fig. 11. Deflection φ_1 with the following initial conditions: φ_1 = 0.007 (rad), $\dot\varphi_1$ = 0.002 (rad/s), U_1=0.008 (m), $\dot U_1$ = 0.003 (m/s)

It is seen from Figs. 6, 7, 10 and 11 that if the absorbers TMD-D and DVA are installed in the system, the amplitude of oscillation of offshore tower reduces considerably in time when compared to ones without the absorbers.

6. CONCLUSION

The paper investigates the vibration of inverse pendulum system installed with TMD-D and DVA. The following is some conclusions:

- The paper gives a method for determining generally the optimal parameters of oscillational absorber for the inverse pendulum model system with installed TMD-D and DVA. This model can be applied to different structures.
- In reality of installation with TMD-D and DVA, although it has advantages to reduce the amplitude of oscillation of structure, the structure may be damaged. The damage is due to different reasons such as unstability of structure. Both parameters of TMD-D and DVA and stability parameters in technical criterion of structure must be determined simultaneously.
- The target of designing the TMD-D and DVA absorbers is to reduce optimally the oscillation of inverse pendulum model system. From the above results, we conclud that the amplitude of oscillation of offshore tower is reduced considerably in time with calculated parameters of installed TMD-D and DVA absorbers when compared to case without absorbers.

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NGHIÊN CỨU TÌM CÁC THÔNG SỐ TỐI ƯU CỦA HỆ THỐNG GIẢM DAO ĐỘNG TMD VÀ DVA ĐỐI VỚI HỆ COM LẮC NGƯỢC VÀ ÁP DỤNG KẾT QUẢ NGHIÊN CỨU GIẢM DAO ĐỘNG CHO THÁP KHỚP NỐI ĐẠI DƯƠNG

Trong bài báo khoa học [1] Nguyễn Đông Anh, Khổng Doãn Điền, Nguyễn Duy Chinh đã nghiên cứu dao động của hệ con lắc ngược có lắp đặt hệ thống giảm dao động TMD-D và DVA. Các kết quả nghiên cứu này khi mô phỏng số cho tháp canh ngoài biển ta thấy các dao động thu được trong một số trường hợp lắp đặt bộ hấp thụ dao động thì biên độ dao động của con lắc ngược lại tăng lên so với trường hợp không lắp bộ hấp thụ dao động, sở dĩ như vậy là vì khi mô phỏng, các thông số của bộ TMD-D và DVA ta chọn một cách ngẫu nhiên, chưa qua thiết kế tối ưu. Trong bài báo này tác giả tiếp tục nghiên cứu, tính toán tìm các tham số tối ưu của hệ thống giảm dao động TMD-D và DVA để giảm dao động cho hệ con lắc ngược một cách tốt nhất, đồng thời tác giả áp dụng các kết quả nghiên cứu, tính toán để giảm dao động cho tháp khớp nối đại dương.