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Passive Vibration Control of the Fluid Conveying Pipes Using Dynamic Vibration Absorber

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ABSTRACT: In this paper, by using a semi-analytical method, the effect of dynamic vibration absorber on amplitude reduction of the fluid conveying pipe is investigated. Considering the Euler-Bernoulli beam theory, the governing equations of motion are derived. By using the first four vibration modes of the fluid conveying pipe, the Galerkin method is applied to discretize the equations, and then the discretized equations are solved numerically. Moreover, simple approximate analytical expressions are proposed for prediction of the natural frequencies of the simply supported fluid conveying pipe and the dynamic vibration absorber parameters. After validating the results of the proposed method, some proper curves are plotted to characterize the effects of system parameters on the reduction of pipe vibration amplitude. The results indicate that around the first critical fluid velocity, by using an appropriate vibration absorber, the vibration amplitude can be reduced by 80%. Therefore, this type of absorber due to its simplicity of installation and high energy absorption capacity, can be considered as a benefit method to reduce/eliminate unwanted vibrations of the fluid conveying pipes.

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1- Introduction

During the past decades, the vibration behavior of fluid conveying pipes has been vastly investigated [1-3]. Yau et al. [4] controlled the vibration of fluid conveying pipes by using piezoelectric actuators. Doki et al. [5] investigated both theoretically and experimentally the stability of cantilever fluid conveying pipes by using a Proportional–Integral–Derivative (PID) controller. Bao [6] studied the vibration behavior and stability of cantilever fluid conveying pipe by using piezoelectric actuators.
Considering the conducted studies about the vibration control of the fluid conveying pipes, it is found out that the applicability of the tuned-mass-damper absorbers in vibration control of these systems is not investigated. In the current study, the effect of using the tuned-mass-damper system on vibration behavior of fluid conveying pipes is studied by using a semi-analytical method. To this end, the differential equations governing the system vibrational motion are derived and discretized using the Galerkin method. Finally, the effects of the system parameters, including the fluid velocity and the vibration absorber characteristics on the system vibration behavior are studied.

2- Equations of Motion

Fig. 1 shows a simply supported fluid conveying pipe and the attached vibration absorber. The governing differential equations and the corresponding boundary conditions can be expressed in terms of the dimensionless parameters as [7]:

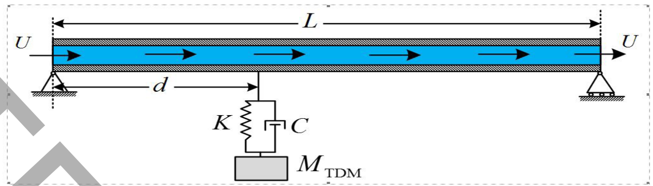

Figure 1. Fluid conveying pipe and the attached tuned-mass-damper vibration absorber.

$$\varepsilon\alpha\frac{\partial^5 y(\xi,\tau)}{\partial\xi^4\partial\tau}+\frac{\partial^4 y(\xi,\tau)}{\partial\xi^4}+u^2\frac{\partial^2 y(\xi,\tau)}{\partial\xi^2}+\left\{c\left[\frac{\partial y(\xi_a,\tau)}{\partial\tau}-\frac{\partial q(\tau)}{\partial\tau}\right]+k\left[y(\xi_a,\tau)-q(\tau)\right]\right\}\delta(\xi-\xi_a)=0 \quad (1)$$

$$\mu\frac{d^2 q(t)}{d\tau^2}+c\left[\frac{\partial q(\tau)}{\partial\tau}-\frac{\partial y(\xi_a,\tau)}{\partial\tau}\right]+k\left[q(\tau)-y(\xi_a,\tau)\right]=0 \quad (2)$$

$$y(\xi)=0,\ \frac{\partial^2 y(\xi,\tau)}{\partial\xi^2}=0,\qquad \xi=0,1 \quad (3)$$

By using the Galerkin method, Eqs. (1) and (2) may be expressed as:

$$\Omega_r^2\delta_{sr}\eta_r(\tau)+u^2R_{sr}\eta_r(\tau)+\left(2u\sqrt{\beta}B_{sr}+\varepsilon\alpha\,\Omega_r^2\delta_{sr}\right)\dot{\eta}_r(\tau)+\delta_{sr}\ddot{\eta}_r(\tau)+\left\{c\left[\sum_{r=1}^{N}\phi_r(\xi_a)\dot{\eta}_r(\tau)-\frac{\partial q(\tau)}{\partial\tau}\right]+k\left[\sum_{r=1}^{N}\phi_r(\xi_a)\eta_r(\tau)-q(\tau)\right]\right\}\phi_r(\xi_a)=0 \quad (4)$$

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$$\mu \frac{d^2 q(t)}{d\tau^2} + c\left[\frac{\partial q(\tau)}{\partial \tau} - \sum_{r=0}^{N} \phi_r(\xi_a)\dot{\eta}_r(\tau)\right] + k\left[q(\tau) - \sum_{r=1}^{N}\phi_r(\xi_a)\eta_r(\tau)\right] = 0 \qquad (5)$$

3- Results and Discussion

In order to study the effect of vibration absorber on the system behavior, a comparison between the time response of the pipe with and without vibration absorber is made and the result is shown in Fig. 2. This figure shows that the vibration absorber reduces vibration amplitude of the system significantly. By increasing the stiffness of the vibration absorber, k, the effect of the absorber on amplitude reduction decreases. For instance, for k=1000 and k=1 the vibration amplitude of the system decreases by 15.6% and 31.5%, respectively. According to the results, the vibration absorber with a nondimensional stiffness of k=10 can decrease the maximum vibration amplitude up to 75%, which has the best performance. Moreover, at u=2, the dimensionless natural frequency of the fluid conveying pipe becomes equal to that of the vibration absorber, $\text{Ù}_{Abs.} = \sqrt{k / \mu} = 7.07$. In this case, the highest amount of energy is absorbed by the vibration absorber and therefore, the system vibration amplitude decreases considerably.

4- Conclusions

In the present work, the vibration analyses of the fluid conveying pipe with a tuned-mass-damper vibration absorber was conducted. Results show that by utilizing the vibration absorber, the vibration amplitude of the system can be reduced significantly. The amount of the amplitude reduction depends on the vibration absorber parameters and the fluid velocity. For u=2, by increasing the absorber stiffness, the effect of the absorber on the vibration amplitude reduction decreases. For example, for k=1000 and k=1, the vibration absorber decreases the system vibration amplitude by 15.6%, 31.5%, respectively. Investigating the effect of the absorber stiffness on the system vibration amplitude at u=2 shows that the absorber with a stiffness of k=10 has the best performance, and decreases the maximum amplitude by 75%.

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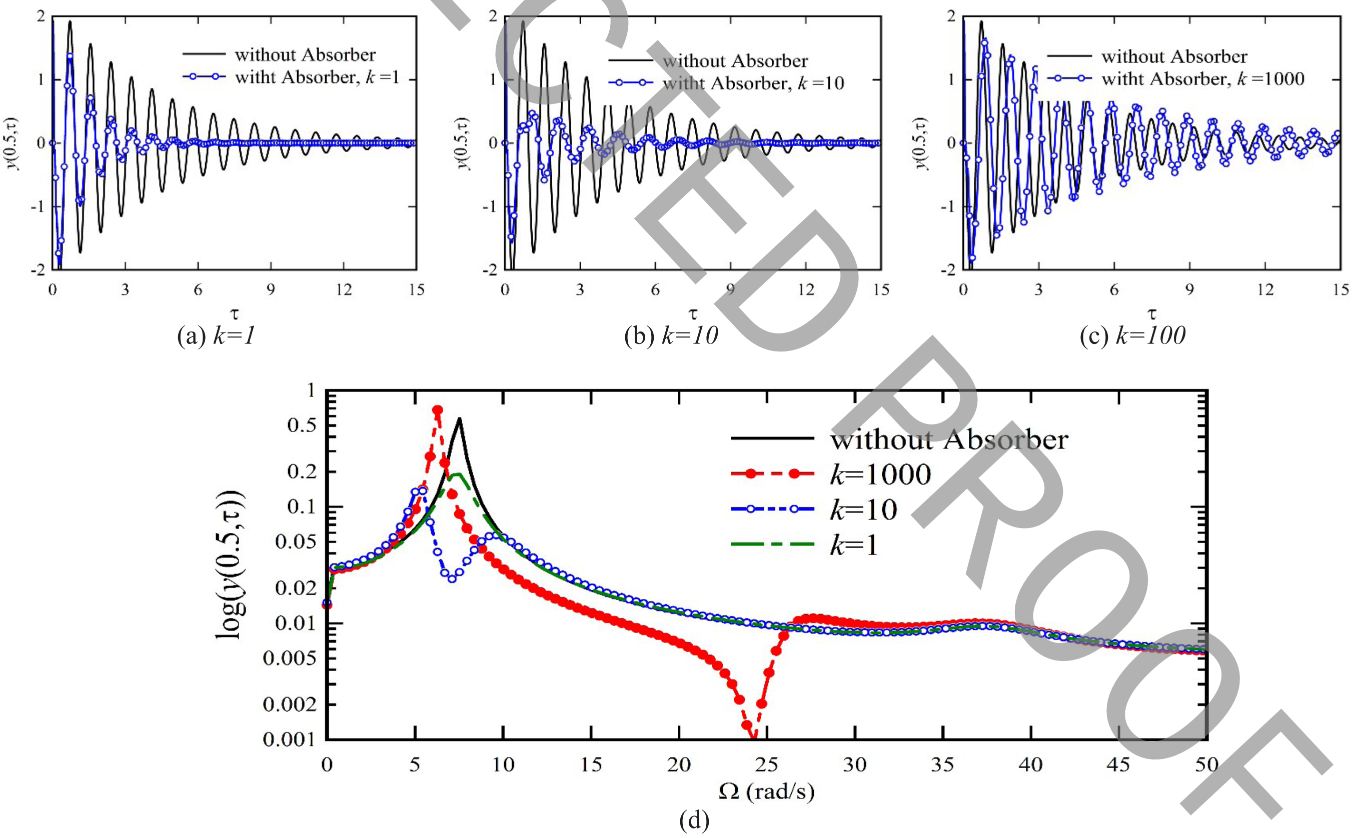

Figure 2. The time responses at mid-point of the simply supported fluid conveying pipe with and without the vibration absorber for (a) k=1, (b) k=10, (c) k=100 , and (d) The system frequency response for different values of the vibration absorber stiffness.

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