PASSIVE AND SEMI-ACTIVE CONTROL OF SELF-EXCITED OSCILLATIONS BY TRANSFER OF INTERNAL ENERGY TO HIGHER MODES OF VIBRATION

University of Tokyo　Student Member　Thomas LE DIOURON
University of Tokyo　Fellow　Yozo FUJINO
University of Tokyo　Member　Masato ABE

INTRODUCTION

This paper presents a remedy to control wind-induced self-excited oscillations of long and flexible structures with low internal damping, such as cables. A simple magnetic or mechanical device is used to disturb the motion in the lower modes of vibration in order to transfer a portion of the internal energy to higher modes. It is assumed that the aerodynamic damping of the higher modes of vibration is positive for the wind velocities at which the lower modes develop aeroelastic instabilities. This assumption is reasonable with vortex-induced vibration (the lock-in phenomenon occurs when the vortex shedding frequency approaches a natural frequency of the vibrating structure) and with galloping, if the modal damping is in the same orders in all modes of vibration. In these cases, the onset wind velocity increases with the natural frequency of the mode. Because of the positive aerodynamic damping of the higher modes of vibration, the energy transferred from lower modes to higher modes is dissipated in high frequency decay, thus reducing the overall amplitude of oscillation of the cable. In an analytical study of a two-degree-of-freedom model[1], the authors gave the main characteristics of a passive control using energy transfer. To improve the performance by optimizing the energy transfer, semi-active control schemes are proposed and tested on a cable via simulation, in the case of galloping forces.

MODELING OF CABLE

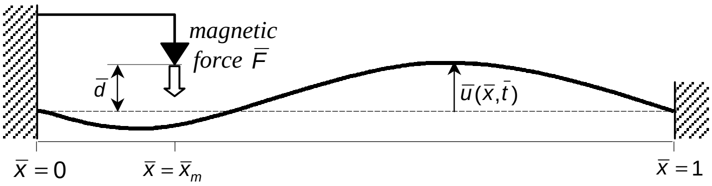

Fig. 1. Model of cable and location of the control device

Sag, gravity, inclination, flexural rigidity are neglected and the cable is modeled as a taut string under small deflections (Fig. 1). The transverse deflection is noted u, the longitudinal position x, the mass per unit length ρ, the tension T, the length L, the diameter of cable h, the longitudinal location of the magnet x_m, the transverse location of the magnet d, the magnetic force F, the concentrated load induced by the magnet F_m and the crosswind velocity V_{air}. It is assumed that the magnet does induce any force as long as the cable is not in contact ($u(x_m,t)<d$). The galloping forces acting on the cable are modeled from the quasi-steady approach presented by Novak[2]. After introducing the following non-dimensional variables:

$$\omega_1 = \pi\sqrt{\frac{T}{\rho L^2}}, \quad \bar{t} = \omega_1 t, \quad \bar{x} = \frac{x}{L}, \quad \bar{u}(\bar{x},\bar{t}) = \frac{u(x,t)}{h}, \quad \bar{d} = \frac{d}{h}, \tag{1a,b,c,d,e}$$

$$\bar{F}_m = \frac{L}{hT\pi^2}F_m, \quad \bar{F} = \frac{L}{hT\pi^2}F, \quad \bar{V} = \frac{V_{air}}{h\omega_1}, \quad \bar{\rho} = \frac{\rho_{air}}{4\rho/h^2} \tag{1f,g,h,i,j}$$

the non-dimensional equation of motion for the galloping oscillations is:

$$\ddot{\bar{u}}(\bar{x},\bar{t}) + \bar{f}_{damping}(\bar{x},\bar{t}) - \frac{1}{\pi^2}\bar{u}''(\bar{x},\bar{t}) = 2\bar{\rho}\bar{V}^2\sum_{k=1}^{\infty} a_k\left(\frac{\dot{\bar{u}}(\bar{x},\bar{t})}{\bar{V}}\right)^k + \bar{F}_m\delta(\bar{x}-\bar{x}_m) \tag{2}$$

where $\bar{f}_{damping}$ is the internal damping force and the a_k are the coefficients of the polynomial approximation to lateral aerodynamic force coefficient. The air velocity required for the onset of instabilities in a given mode n is:

$$\bar{V}_n^c = n\frac{\zeta_n}{\bar{\rho}a_1} \tag{3}$$

where ζ_n is the inherent modal damping of mode n. Based on experimental results[3], the modal damping can be assumed in the same order in all modes $(\zeta_n \cong \zeta)$ and the onset wind velocity increases with the natural frequency of the mode.

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Address: Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan, Tel: 03-5841-6099; Fax: 03-5841-7454
Email: Thomas.Le-Diouron@polytechnique.org, Fujino@bridge.t.u-tokyo.ac.jp, Masato@bridge.t.u-tokyo.ac.jp

PASSIVE MAGNETIC DEVICE

Fig. 2 shows a simulated time history of the modal components for a wind velocity $\bar{V} = 2.\bar{V}_1^c$ with a passive magnetic device ($\bar{x}_m = 0.1$, $\bar{F} = 15$, $\bar{d} = 10$) for $\zeta = 0.01$ and $a_1=2.69$, $a_3=-168$, $a_5=6270$, $a_7=-59900$. Each time the magnet releases the cable, higher modes of vibration are excited. These modes decay and the amplitude of oscillation is kept smaller than without control. However, several periods $T_1 = 2\pi/\omega_1$ are required to have the cable released.

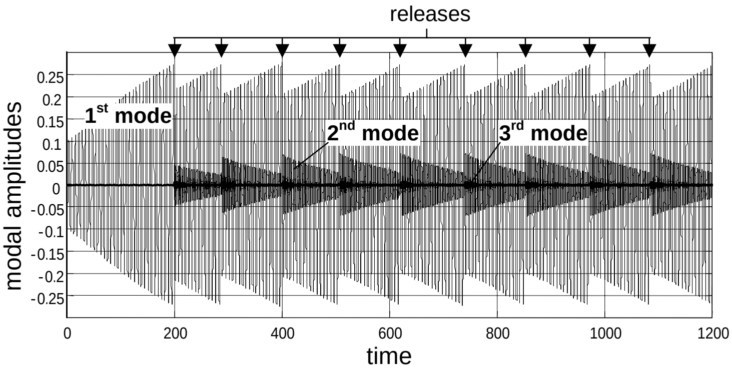

Fig. 2. Time history with passive magnetic device

SEMI-ACTIVE DEVICE

To improve the energy transfer, the magnet is replaced by a mechanical device that can block the cable when $u(x_m,t)$ is maximal and that can release the cable when the tension force $\bar{F}_c(\bar{t})$ within the device is maximal (Fig. 3). This ensures that the release occurs at each period T_1 with a maximized energy transfer. Fig. 4 gives a time history for a wind velocity $\bar{V} = 2.\bar{V}_1^c$ with a semi-active device located at $\bar{x}_m = 0.1$ for $\zeta = 0.01$ and $a_1=2.69$, $a_3=-168$, $a_5=6270$, $a_7=-59900$.

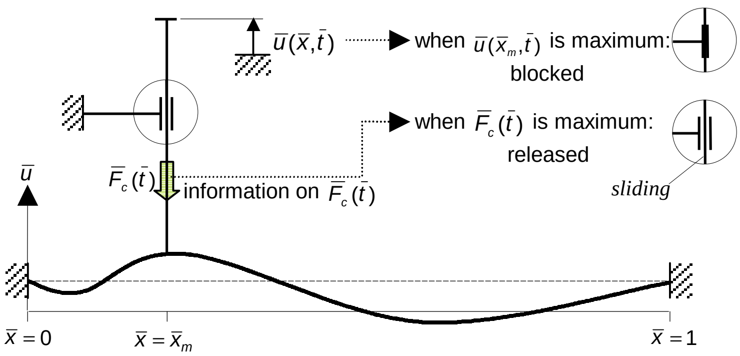

Fig. 3. Cable with semi-active control scheme

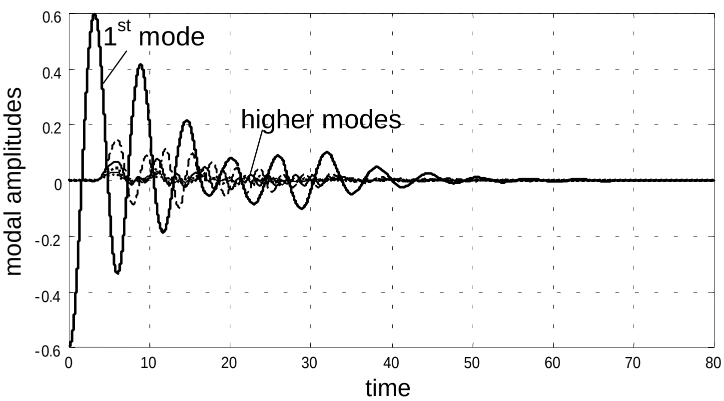

Fig. 4. Time history with semi-active device

CONCLUSION

The passive magnetic device is efficient to reduce the amplitude of oscillation of the cable. However, the control performance is dependent on the tuning of parameters (F,d). The semi-active control scheme commands the times of contact and release in order to maximize the energy transfer and to have a release at each period T_1. The control performance is dramatically improved and no tuning of parameters is required.

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