Modelling a passive self-tuning vibration neutraliser based on nonlinear coupling

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Abstract. Vibration neutralisers, extensively used to attenuate the vibration levels of a host structure, have an inherent limitation regarding the frequency range in that they are effective. This limitation is troublesome since the frequency of a vibration source is not constant. A solution would require self-tuning vibration neutralisers that could adapt to the excitation frequency, maintaining their performance. The ongoing work concerns a self-tuning vibration neutraliser that can passively adapt to one of the two frequencies of an external harmonic force. The main objectives are to explain the physics governing the mechanism and open the possibility of improving the robustness of vibration neutralisers.

Introduction

Vibration neutralisers attenuate the vibration on a host structure which is mostly related to an external harmonic force. Neutralisers are designed with relatively low damping, when compared to vibration absorbers, and behave as a mechanical notch-filter. An adaptation mechanism that allows the neutraliser to adjust to the excitation frequency would overcome this limitation. Self-tuning vibration neutralisers and absorbers can be found in the literature with extensive mechanisms [1, 2] however, most of them require an external source to adapt. The specific interest of this work is to explain the physics governing the self-tune mechanism of the neutraliser shown in Fig 1(a) using the schematic model in Fig. 1(b). The device can rotate to adapt showing different FRF behaviours (Fig 1(c,d)).

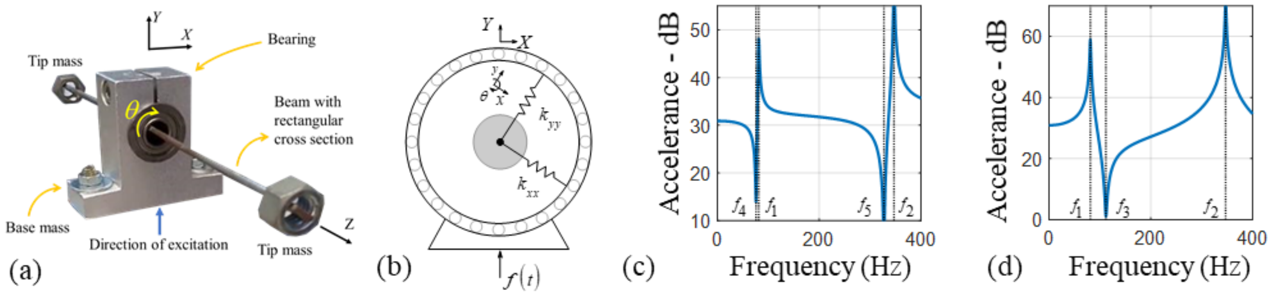

Figure 1: (a) Photograph of the neutralizer (b) schematic of the lumped parameter model and magnitudes of the accelerance for $\theta = 45^{\circ}$ for (c) base and (d) tip mass (dB ref. $1\mathrm{Ns^2/m}$).

Neutraliser modelling

A device was built and tested [3] and a new model is proposed. A possible auto-parametric mechanism to explain the rotation behavior is under investigation. This model envisages the possibility of improving the robustness of neutralisers. Considering $\tilde{k}=(k_{yy}-k_{xx})$, $\tilde{c}=(c_{yy}-c_{xx})$, $z_y=(y_b-y_m)$, $z_x=(x_b-x_m)$, $\dot{z}_y=(\dot{y}_b-\dot{y}_m)$, $\dot{z}_x=(\dot{x}_b-\dot{x}_m)$, the equations of motion as defined as

$$I\ddot{\theta}+c_t\dot{\theta}-\tilde{k}\left(z_xz_y\cos(2\theta)+\frac{1}{2}\left(z_y{}^2-z_x{}^2\right)\sin(2\theta)\right)=0 \tag{1}$$

$$m\ddot{x}_m+\tilde{c}\dot{z}_x\sin^2(\theta)+\tilde{k}z_x\cos^2(\theta)+\frac{1}{2}\left(\tilde{c}\dot{z}_y+\tilde{k}z_y\right)\sin(2\theta)-k_{yy}z_x=0 \tag{2}$$

$$m\ddot{y}_m-\left(\tilde{c}\dot{z}_y+\tilde{k}z_y\right)\cos^2(\theta)+\frac{1}{2}\left(\tilde{c}\dot{z}_x+\tilde{k}z_x\right)\sin(2\theta)-c_{xx}\dot{z}_y-k_{xx}z_y+gm=0 \tag{3}$$

$$m_b\ddot{x}_b-\left(\tilde{c}\dot{z}_x+\tilde{k}z_x\right)\cos^2(\theta)-\frac{1}{2}\left(\tilde{c}\dot{z}_y+\tilde{k}z_y\right)\sin(2\theta)+c_{yy}\dot{z}_x+k_{yy}z_x=0 \tag{4}$$

$$m_b\ddot{y}_b+\left(\tilde{c}\dot{z}_y+\tilde{k}z_y\right)\cos^2(\theta)-\frac{1}{2}\left(\tilde{c}\dot{z}_x+\tilde{k}z_x\right)\sin(2\theta)+c_{xx}\dot{z}_y+k_{xx}z_y+gm_b=f(t) \tag{5}$$

References

[1] Brennan, M. J. (2006) Some recent developments in adaptive tuned vibration absorbers/neutralisers, Shock Vib. **13**, 531–543, https://doi.org/10.1155/2006/563934.

[2] R.R.A. Ibrahim (2008), Recent advances in nonlinear passive vibration isolators, J. Sound Vib. **314**, 371–452, https://doi.org/10.1016/j.jsv.2008.01.014.

[3] Nehemy, G. F., Rustighi, E., Gonçalves, P. J. P., Brennan, M. J. (2023). A passive self-tuning vibration neutraliser using nonlinear coupling between the degrees of freedom. Mech Syst Signal Process, **185**, 109786. https://doi.org/10.1016/j.ymssp.2022.109786