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Pulse Excitation of a System Containing a Textile Layer

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Abstract

In this paper the problem of the vibration of a mass supported on a textile layer and subjected to pulse excitation is analysed. A mathematical model of a system containing an elastic spring and electromagnet is formulated. The numerical simulation shows that the electromagnet may ensure the maintenance of a compressive force acting on the textile layer provided that the period of natural oscillations is shorter than the time duration of the pulse.

Key words: *pulse excitation, textile layer.*

Introduction

A broad discussion of the vibration of a mechanical system subjected to pulse excitation can be found in book [1]. The compression characteristics of fibre masses were presented in paper [2]. The relationship between the force and magnitude of the layer compression was defined in paper [3], in which the reaction of the layer to an impacting body was analysed. The vibration of an elastic system that contains textile layers was studied in work [4]. The problem of the transmission of vibration through a textile layer was studied. The purpose of this paper is to study the response of the textile layer to a pulse excitation. Examples of such loadings of textiles are feed mechanisms in sewing machines [5] and grippers for textiles [6].

Equations of motion

The system considered is shown in ***Figure 1***. It consists of a steel bar of mass *m,* a textile layer *k,* springs of stiffness *s* and an electromagnet of inductance *L*. *e* is the distance from the centre of the core to the centre of the coil at rest*; w* denotes the core displacement, *x* the position of the core centre, and *y* the displacement of the textile layer support if it is moving.

Summing up all forces acting on the mass, one obtains an equation of motion – ***Equation (1)***, where *t* denotes time, and *g* is the gravity acceleration.

$$m\frac{\mathrm{d}^2 w}{\mathrm{d}t^2}+sw+F_{kc}-F_E-mg=0. \qquad (1)$$

The relationship between the force F_{kc} acting on the fibrous layer and its deflection *w* can be found in work [1] in the form of ***Equation (2)***.

The constants (k, L_1) denote the elastic parameters resulting from the bending of individual fibres under compression of the layer and (c, H_1) are the damping parameters resulting from squeezing air out of the layer, defined in paper [3]. The dimensionless function sgn( ) extracts the sign of its argument to (-1, 0, +1) for negative, zero or positive argument, respectively, and it assures that the direction of the resistance force is opposite to the air velocity.

$$F_{kc}=k\frac{(w+y)}{\left(1-\frac{w+y}{L_1}\right)^3}+c\frac{\operatorname{sgn}\left(\frac{\mathrm{d}(w+y)}{\mathrm{d}t}\right)\left(\frac{\mathrm{d}(w+y)}{\mathrm{d}t}\right)^2}{\left(1-\frac{w+y}{H_1}\right)^3} \quad \textit{if } F_{kc}>0,\ \textit{otherwise } F_{kc}=0,\quad w+y<H_1,\quad w+y<L_1. \qquad (2)$$

$$L\frac{\mathrm{d}i}{\mathrm{d}t}+\frac{\mathrm{d}L}{\mathrm{d}x}i+Ri=u,\qquad F_E=-\frac{1}{2}i^2\frac{\mathrm{d}L}{\mathrm{d}x},\qquad x=e-w. \qquad (3)$$

$$L(x)=\frac{L_{\max}-L_{\min}}{2}\sqrt{\left(\frac{r_0}{l}\right)^2+1}\left(\frac{1+\frac{x}{l}}{\sqrt{\left(\frac{r_0}{l}\right)^2+\left(1+\frac{x}{l}\right)^2}}+\frac{1-\frac{x}{l}}{\sqrt{\left(\frac{r_0}{l}\right)^2+\left(1-\frac{x}{l}\right)^2}}\right)+L_{\min},$$

$$\frac{\mathrm{d}L}{\mathrm{d}x}=\frac{L_{\max}-L_{\min}}{2}\sqrt{\left(\frac{r_0}{l}\right)^2+1}\left(\frac{\frac{1}{l}}{\sqrt{\left(\frac{r_0}{l}\right)^2+\left(1+\frac{x}{l}\right)^2}}\left(1-\frac{\left(1+\frac{x}{l}\right)^2}{\left(\frac{r_0}{l}\right)^2+\left(1+\frac{x}{l}\right)^2}\right)+\frac{\frac{1}{l}}{\sqrt{\left(\frac{r_0}{l}\right)^2+\left(1-\frac{x}{l}\right)^2}}\left(-1+\frac{\left(1-\frac{x}{l}\right)^2}{\left(\frac{r_0}{l}\right)^2+\left(1-\frac{x}{l}\right)^2}\right)\right). \qquad (4)$$

Equations (2), (3) *and* ***(4).***

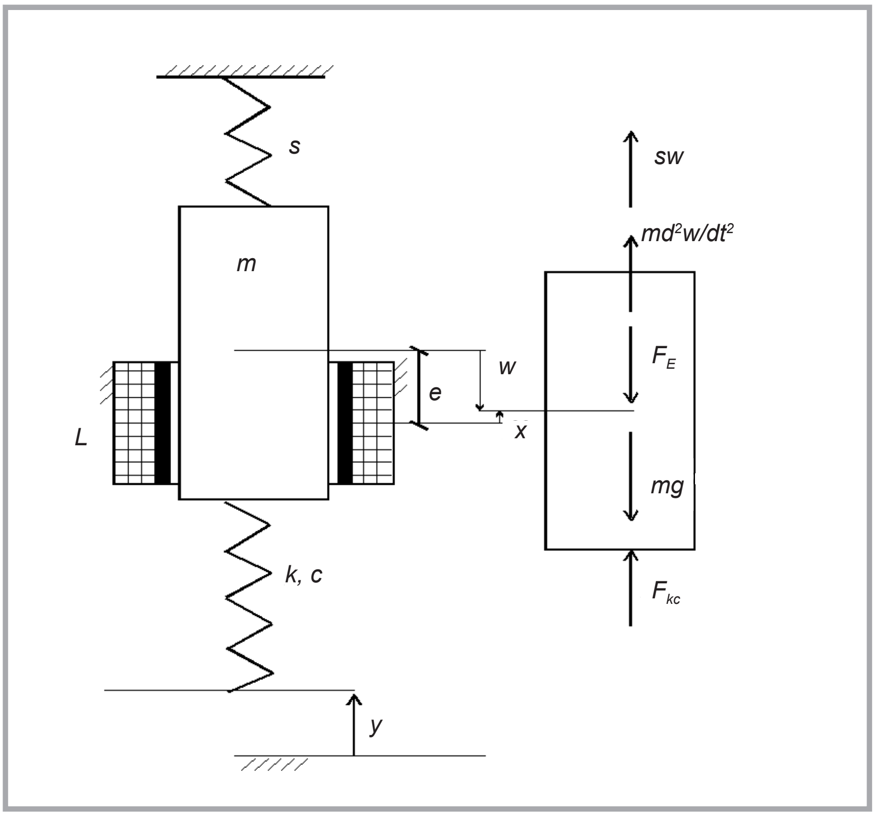

Figure 1. Model of vibrating mass supported on the textile layer, excited to vibrate by the electromagnet.

The electromagnetic force can be found from ***Equation (3)***. Here, L [4] is the inductance of the electromagnet approximately found from ***Equation (4)***, i the current intensity, R the resistance of the circuit, and u denotes the feed voltage.

The inductance L and its derivative dL/dx can be calculated as explained in paper [7] or approximately [4] from ***Equation (4)***. In ***Equation (4)*** r_0 denotes the computational radius of the coil, l half of the computational length of the coil, and L_{min} & L_{max} denote the minimum and maximum inductance of the coil measured.

Results

Calculations were performed for $g = 9.81$ m/s^2, mass $m = 0.1$ kg, spring stiffness s = 500 N/m, textile layer parameters $k = 500$ N/m, $c = 100$ Ns^2/m^2, $L_1 = 0.03$ m & $H_1 = 0.03$ m, excitation circular frequency and period $\omega = 0.125((s+k)/m)^{0.5}$, $T = 2\pi/\omega$, electromagnet parameters: maximum inductance of the coil, that is when the centre of the core coincides with the centre of the coil $L_{max} = 0.364319$ H; the minimum

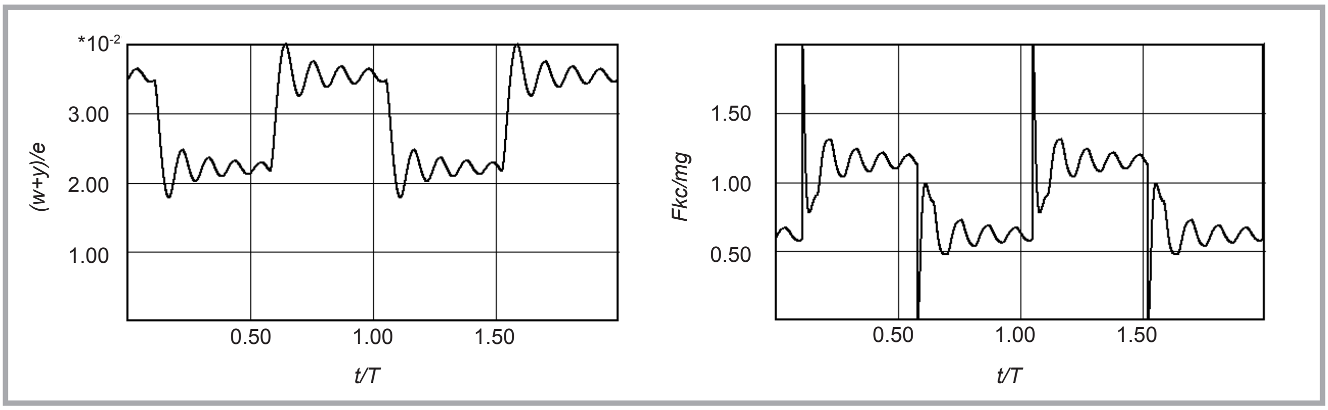

Figure 2. Magnitude of compression of the textile layer w + y and compressive force F_{kc} for constant voltage u = U_m and for a rectangular pulse of motion defined as y = Y_m for sin(ωt) > 0 and y = 0 for sin(ωt) < = 0, Y_m = 0.002 mm.

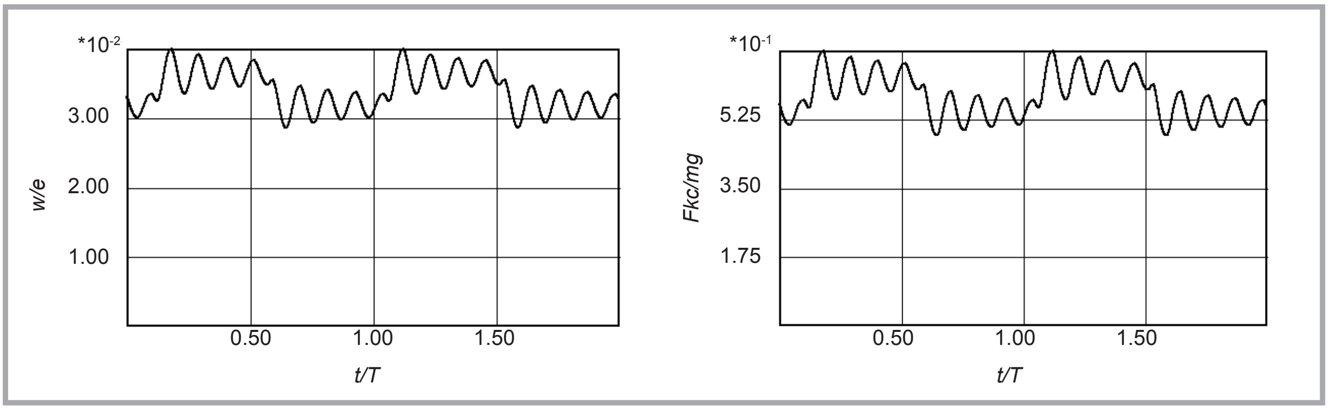

Figure 3. Magnitude of compression of the textile layer w and compressive force F_{kc} for a motionless support of the textile layer y = 0 and the rectangular pulse of the voltage defined as u = U_m for sin(ωt) > 0 and u = 0 for sin(ωt) < = 0.

inductance of the coil, that is when core is in the end position $L_{min} = 0.04$ H; resistance of the coil $R = 40\ \Omega$, computational radius of the coil $r_0 = 0.032$ m, half of the computational length of the coil $l = 0.028$ m, mass position at rest $e = 3l$ and voltage $U_m = 24$ V.

The layer compression $w+y$ or w versus time t, the time derivative dw/dt versus the layer compression, the electromagnetic force F_E and the layer compression force F_{kc} versus time t are shown in ***Figures 2*** for the motion pulse and in ***Figure 3*** for the voltage pulse.

Conclusions

From ***Figures 2*** and ***3*** it can be concluded:
1. The electromagnet ensures that the compressive force acting on the layer is maintained.
2. In order to maintain the pulse type response, the frequency of natural vibration of the system should be higher than that of the excitation.
3. The rectangular pulse excitation results in a decreasing oscillatory force acting on the layer.

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