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Damping based on electromagnetic induction: A comparison of different minimal models

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Damping of structural vibrations is a crucial part of modern engineering. Using electromagnetic interactions for this purpose is a modern and promising approach. To gain better understanding of phenomena involved in this technique investigations on minimal models of a B-field modulation dampers are shown. Therefore two different setups are compared. One uses a permanent magnet as the source for the magnetic field, one uses a coil, respectively an electro-magnet as the source. The contribution focuses on differences that occur, due to the different designs. Therefore the static behavior is analyzed as well as the system response on a harmonic force excitation.

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1 Introduction

Due to higher demands on comfort and noise damping of structural vibrations becomes a more and more important part of mechanical engineering. Because electromagnetic damping devices are adjustable, almost free of wear and even could be used in combination with energy harvesting systems, they offer a high potential. Thus, the use of electro-mechanical interactions for this purpose is a growing field of research. To gain a better understanding of the fundamental effects occurring in such systems, investigations on minimal models based on the analysis in [1] are presented. At first the compared models are proposed. Afterwards some results are shown and compared. A static analysis, focusing on the stability behavior of the systems, is presented as well as a dynamic analysis, showing the damping possibilities of such systems.

2 Modeling

The investigated models are shown in figure 1 and 2. Both consist of a mass connected to the environment via a spring and an electric system featuring an Ohmic resistor and a coil. Between the electrical and the mechanical system the magnetic circuit mediates. In the model shown in figure 1 a permanent magnet is used to generate the magnetic field. The model shown in figure 2 uses an electromagnet to produce the mangetic field. The electromagnet is fed by a constant current source.

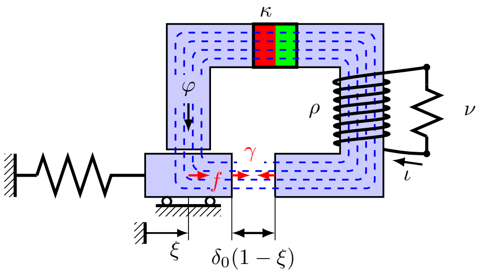

Fig. 1: B-field modulation damping device with permanent magnet

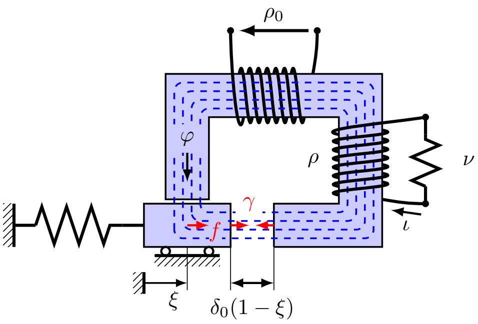

Fig. 2: B-field modulation damping device with electromagnet

The governing equations of motion for both models are given in non-dimensional form by

$$\xi'' + \xi - \gamma\varphi^2 = \hat{f}\cos(\eta\tau) - f_0(\varphi) \tag{1}$$

$$\nu\varphi' + \iota = 0. \tag{2}$$

Herein ξ is the displacement of the mass, ι is the electric current and φ is the magnetic flux. γ is a coupling coefficient between the magnetic and the mechanical system, ν relates the electrical time constant to the mechanical eigenfrequency. $\hat{f}\cos(\eta\tau)$ is an harmonic external force, oscillating with the frequency η and f_0 is a static external force, keeping the mass in the rest

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position $\xi = 0$ in the case of no excitation. Equation 1 describes the mechanical movement of the systems, while equation 2 depicts the electrical behavior.

These differential equations are accompanied by an algebraic expression for the magnetic field. This expression differs between the models. It is

$$\begin{aligned} g_p(\xi_p, \iota_p, \varphi_p) &: (\kappa + \delta_0(1-\xi))\varphi - (\kappa + \rho\iota - h(\varphi)) = 0 \\ g_e(\xi_p, \iota_p, \varphi_p) &: \delta_0(1-\xi)\varphi - (\rho_0 + \rho\iota - h(\varphi)) = 0 \end{aligned} \tag{3}$$

where δ_0 is the length of the airgap, ρ is a coupling parameter of the magnetic and the electric system. $h(\varphi)$ is a term considering the magnetic saturation. For the saturation an analytic model is used as proposed in [2]. κ respectively ρ_0 are the source terms of the magnetic field applied by the permanent magnet respectively the electromagnet. The index p/e indicates whether the expression belongs to the model with the permanent magnet (p) or the one featuring the electromagnet (e).

3 Results

stationary: Figures 3 and 4 show the stability maps of the rest position $\xi = 0$ for the proposed models. In the colored regions the rest position is unstable and in the uncolored areas it is stable. For the permanent magnet (fig. 3) it can be seen, that only for values of $\gamma > 3.38$ instabilities might occur. For the model with the electromagnet instabilities occur for much lower values of γ (see figure (4).

The rest position becomes unstable, if the slope of the magnetic forces $f_{mag} = \gamma\varphi^2$ becomes higher than 1 ($\frac{\partial f_{mag}}{\partial \xi} > 1$). In that case a thought negative magnetic stiffness as e.g. used in the analysis of electrical machines [3] is higher than the mechanical stiffness of the spring.

force excitation: In figure 5 the first harmonics of the transfer functions of the models are shown. Furthermore the system response without magnetic forces is drawn. The frequency response is calculated using the harmonic balance method. The used parameters for γ, κ and ρ_0 are marked in the stability cards. In both simulations $\gamma = 0.5$ is used. The value for ρ_0 is chosen in a way, that the magnetic flux in the model featuring the electromagnet is equal to the magnetic flux in the model with the permanent magnet in the rest position. Both models damp the resonance frequency and lead to a shift of the resonance peaks to lower frequencies. This means, that the electromagnetic coupling softens the systems. This can also be realized by the higher amplitudes for low excitation frequencies. Furthermore it can be seen, that the model featuring the electromagnet has a much stronger damping behavior than the model using the permanent magnet. This can be explained by the fact, that the magnetic permeability of the permanent magnet is equal to the permeability of the airgap. Thus, a change of the airgap length has less effect on the magnetic conductivity of the complete magnetic circuits and therefore, the change in flux is less if the amplitudes of the moving mass are equal.

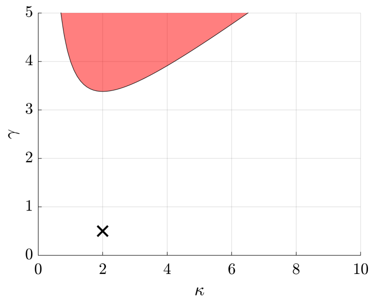

Fig. 3: stability map of the damping device with permanent magnet

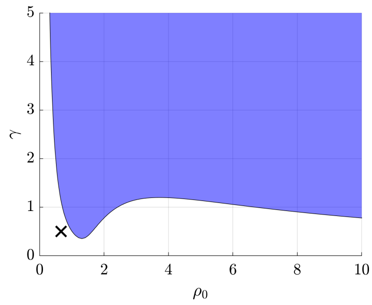

Fig. 4: stability map of the damping device with electromagnet

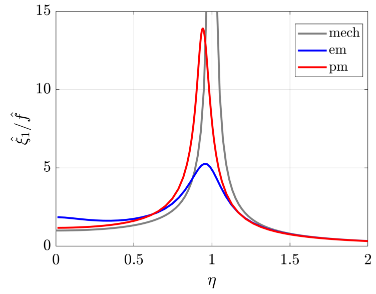

Fig. 5: transfer functions of the proposed models: em - device with electromagnet, pm - device with permanent magnet

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