PROPERTIES OF THE ELECTROMAGNETIC SOFTENING AND HARDENING SPRING: EXPERIMENT AND SIMULATION

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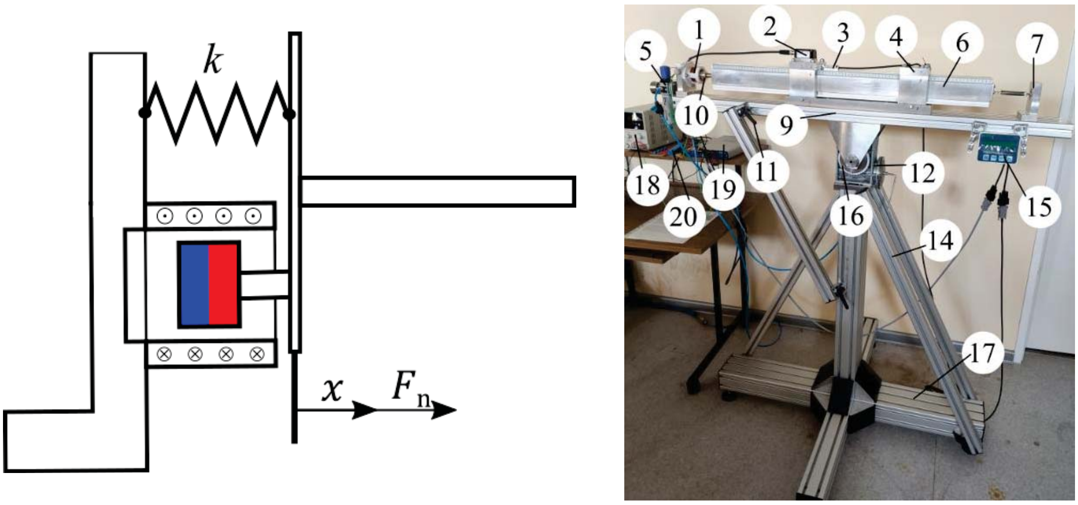
1. ABSTRACT

This work presents a method of achieving four different stiffness characteristics by combining mechanical and electromagnetic spring in a specific configuration. Such kind of combined spring has been modeled mathematically and validated experimentally.

2. INTRODUCTION

Applied scientists have begun to leverage nonlinearity as a means to enhance system performance, rather than viewing it as a threat to be avoided. Nonlinear springs and elastic elements can be found e.g. in structural engineering, robotics, vibration isolation systems and automotive suspension systems [1]. Nonlinear stiffness mechanisms have been used extensively across various domains in recent times, leading to a growing demand for innovative methods of producing nonlinear components. Nowadays, a common method to achieve nonlinear stiffness is to use a springs with variable winding diameter, angled beams [2] or harnessing magnetic effects. Here, we introduce a straightforward and economical electro-mechanical design for achieving a springs with potential of manifest four different stiffness characteristic (depicted in Fig. 1(a)). Additionally, this design offers the convenience of easily adjusting variations in the stiffness curve. The experimental setup has been shown in Fig.1(b). It consists of a moving mass **6**, supported by the aerostatic supports **4**, and kept in the operating range by helical spring **7** and electromagnetic spring made of coil **1** and magnet **10**, which has been supplied by the power supply **18**. The rig has been equipped with position **3** and inclination **2** sensor. The data has been collected by the National Instruments data acquisition card **19**.



(a) (b)

Figure 1. Scheme of the combined spring consisting of mechanical and electromagnetic spring (a), and photo of experimental rig (b).

3. RESULTS AND DISCUSSION

The combined spring has been modeled by the following equation

$$F_n(x) = kx + \frac{Ipq^3}{q^4+x^4} \cdot x. \tag{1}$$

Parameter k represents a linear stiffness (spring constant), p and q are constant parameters for a given pair of coil and magnet which are identified experimentally. Electric current is represented by I, and x denotes a displacement. As can be observed on Fig. 3, by keeping the linear stiffness constant and changing the value of electric current, the four different stiffness characteristic can be differentiated (from left to right): bistable, hardening, linear and softening.

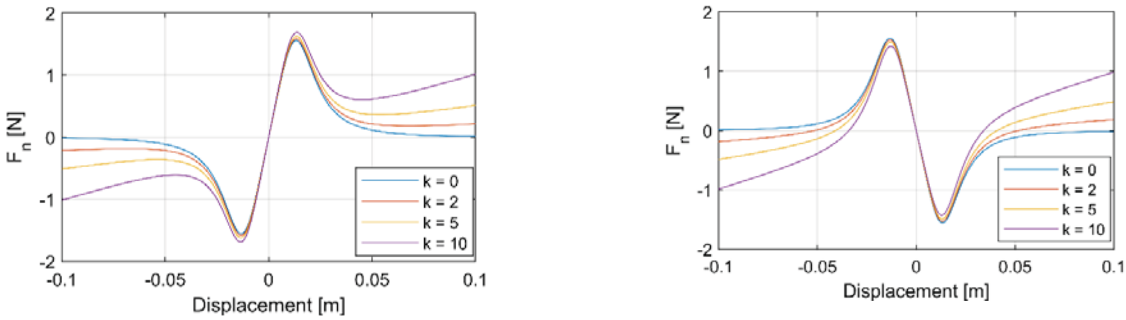


Figure 2. Chart showing force vs displacement of the combined spring for different value of linear component k, for positive (a) and negative (b) electric current.

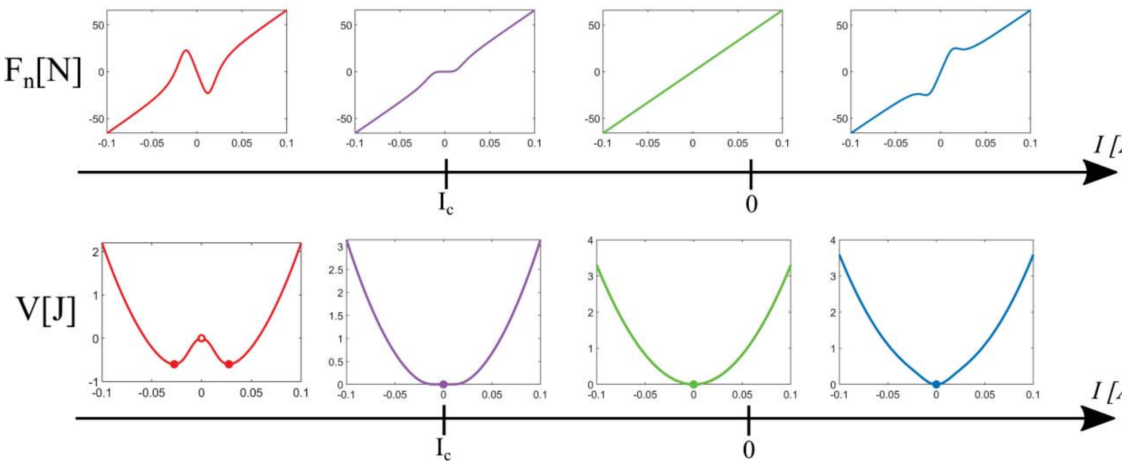


Figure 3. Chart representing qualitative change in force and potential energy vs electric current $I < I_c$ (red chart), $I_c < I < 0$ (purple chart), $I = 0$ (green chart), $I > 0$ (blue chart).

Usage of this kind of spring can be helpful in various research that consider dynamic of nonlinear systems [3,4].

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