An Electromagnetic Softening Spring: Experiment and Simulation

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Abstract. We present a simple, low-cost design of a nonlinear softening stiffness mechanism using electro-magnetic forces. An algebraic form for the stiffness force is obtained and close agreement between experimental and numerical time responses is illustrated.

Introduction

Applied scientists have started utilising nonlinearity to improve system performance, rather than considering it a menace to be avoided. Nonlinear stiffness mechanisms have found wide applications in various areas recently [1]. This has increased the need for new ways of fabricating nonlinear components. We present a simple, low-cost, electro-mechanical design of a nonlinear softening stiffness. It has the further advantage that variations to the stiffness curve can be brought about easily. Fig. 1(a) shows the experimental setup. It consists of a mass (1), supported on two aerostatic supports (2), and fitted with a magnet (3) and a helical spring (4). The magnet moves through an electro-magnetic coil (5) as the mass oscillates. A harmonic exciter (6) is mounted on the mass. Softening nonlinearity is generated by the force between the magnet and the electromagnetic coil when a current is passed through it.

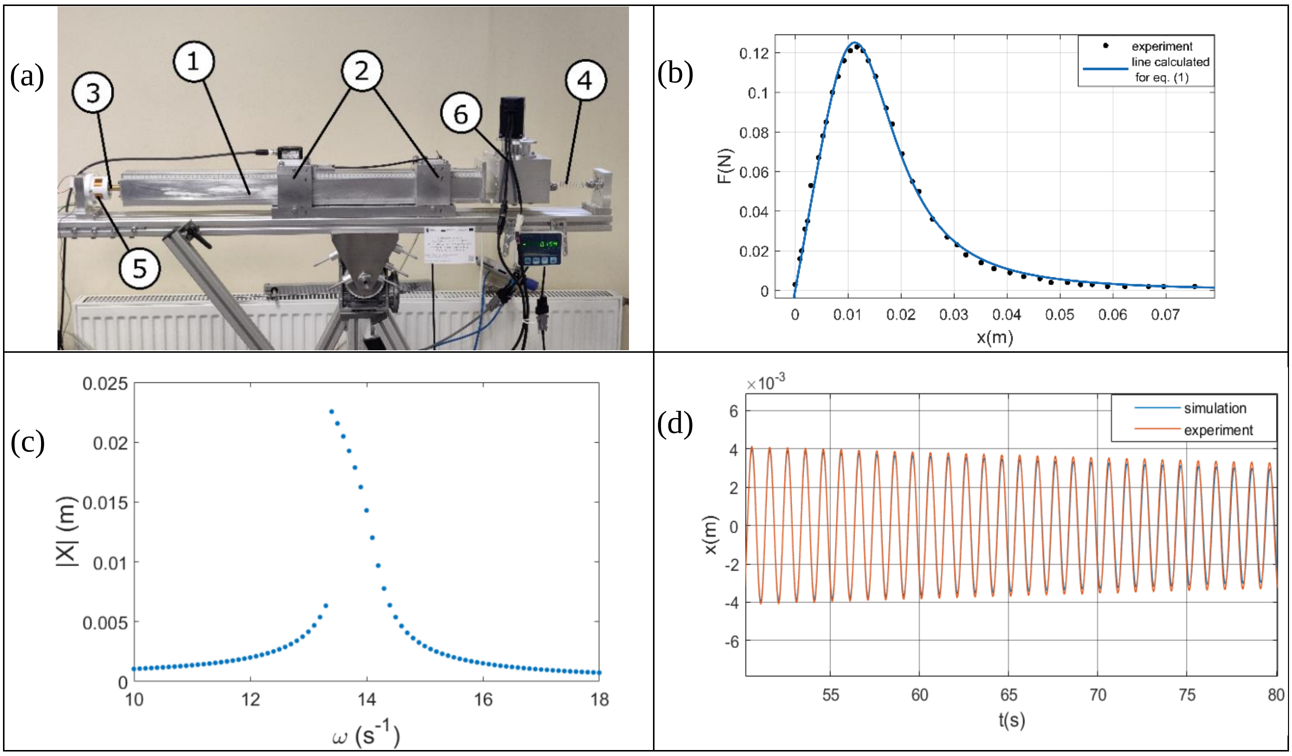

Figure 1: (a) The experimental setup, (b) Force – Displacement curve, (c) Frequency response curve, (d) Time response plot.

Results and discussion

Fig. 1(b) shows the force-displacement characteristic of the system without helical spring and the exciter. The experimental points are very closely approximated by the force function $F(x) = Ip\left(\frac{x/q}{1+(x/q)^4}\right)$ [2], where I is the current in coil and p and q are constant for a given coil-magnet pair. The numerically obtained frequency response curve with the above $F(x)$, shown in Fig. 1(c), clearly shows the softening character of the stiffness. Fig. 1(d) shows the close agreement between the experimental time response and the one obtained by numerically solving the governing equation of the system with above softening stiffness $F(x)$.

References

[1] D. J. Wagg, L. Virgin (Eds.), Exploiting Nonlinear Behavior in Structural Dynamics, Springer-Verlag GmbH Wien, 2012.
[2] M. Bednarek, D. Lewandowski, J. Awrejcewicz, Determining magnetic and electromagnetic springs forces and their usage damping vibrations, in: Advances in Nonlinear Dynamics, NODYCON Conference Proceedings Series, Springer, 2022.