2021 DSTA dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Energy flow control in a system of coupled pendulums using magnetic field

Valery Pilipchuk[1a], Krystian Polczyński[2b], Maksymilian Bednarek[2c*], Jan Awrejcewicz[2d]

1. Department of Mechanical Engineering Wayne State University 5050 Anthony Wayne Drive, Detroit, Michigan 48202, U.S.A. [a] pilipchuk@wayne.edu [0000-0001-7051-3539]
2. Department of Automation, Biomechanics and Mechatronics Lodz University of Technology 90-924 Lodz, 1/15 Stefanowskiego Str., A22, Poland [b]krystian.polczynski@dokt.p.lodz.pl [0000-0002-1177-6109], [c]maksymilian.bednarek@dokt.p.lodz.pl [0000-0002-7669-119X], [d]jan.awrejcewicz@p.lodz.pl [0000-0003-0387-921X]

* Presenting Author

Abstract: In the presented work, we proposed a methodology of controlling the resonance energy exchange in mechanical systems by creating appropriate electromagnetic fields around the system's structural subcomponents. It has been shown theoretically and confirmed experimentally that properly guided magnetic fields can effectively change mechanical potentials in such a way that the energy flow between the oscillators takes the desired direction. In particular, a model of two weakly coupled pendulums subjected to an electromagnetic load using a specific set of descriptive functions was considered. The developed control strategies are based on the observation that, in the case of antiphase oscillation, the energy is moving from the pendulum, which is in the repelling magnetic field, to the oscillator not subjected to magnetic field. The advantage of the suggested control strategy is that the temporal rate of inputs is dictated by the speed of beating, which is relatively slow compared to the carrying oscillations.

Keywords: Resonance energy exchange, magnetic pendulums, beating control, feedback loop

1. Introduction

Passive control of the energy flow between a recipient and a donor has been considered in both physics and engineering based on different physical principles [1-4]. In the presented work, we suggest to actively guide the direction of energy flow by generating appropriate magnetic fields around the interacting mechanical oscillators. In the present illustrating example, two pendulums are weakly coupled with torsion spring (see Fig. 1). One of the pendulums is endowed with a magnet which is placed above an electric coil. A specific electric current in a form of $i(t) = 0.001 + 0.1\sin^2\left(\pi t / 10.31\right)$ was chosen to enhance passive transition of energy from one pendulum 1 to pendulum 2. System is described by equations (1) and (2).

$$\frac{d\phi_j}{dt} = v_j, \quad \frac{dv_j}{dt} = -\Omega^2\phi_j - f_j; \quad j = 1,2 \ , \tag{1}$$

$$f_1 = 2\Omega\left[\zeta_1 \operatorname{sgn}\dot{\phi}_1 + \nu(\dot{\phi}_1 - \dot{\phi}_2)\right] + \Omega^2\left[\beta(\phi_1 - \phi_2) - \frac{1}{6}\phi_1^3\right] - \frac{i_1(t)}{J}\frac{dU_{mag}(\phi_1)}{d\phi_1}, \quad f_2 = 2\Omega\left[\zeta_2 \operatorname{sgn}\dot{\phi}_2 + \nu(\dot{\phi}_2 - \dot{\phi}_1)\right] + \Omega^2\left[\beta(\phi_2 - \phi_1) - \frac{1}{6}\phi_2^3\right] \tag{2}$$

2. Results and Discussion

The sample results of direct simulations and comparison with experimental data are illustrated in Fig 2. The solution of numerical integration of eqs. (1)-(2) are represented by Fig. 2b. At this point, we make preliminary remarks on some effects already observed from simulations. In particular, fragments (c), (d) of Fig. 2 show the response quite different compared to the response of a free system (b) under zero input currents. It is confirmed that in the case of free vibration, the total energy is gradually dissipating while its very small portion keeps moving from one pendulum to another in beat wise manner. In contrast, the gradually increasing currents eventually break the symmetry in such a way that the energy is almost completely transferred from the pendulum 1 with positive input current to the pendulum 2. The effect becomes most explicit in case of two magnets combining both attracting and repelling properties.

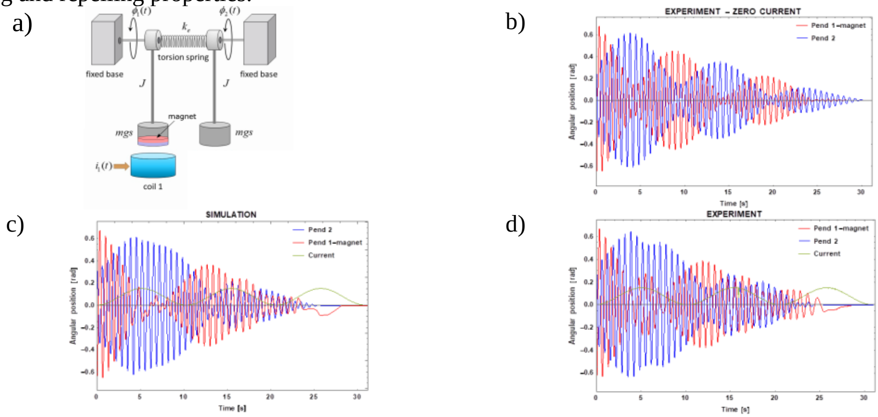

Fig. 2. Model (a), sample free motion (b), and the response on input current (c-d).

3. Concluding Remarks

Open-loop control strategy is suggested in this paper for guiding the energy flow between two interacting oscillators by means of magnetic fields. Control strategy is based on the observation that, in the case of antiphase oscillation, the energy is moving from the oscillator, which is in the repelling magnetic field, to the oscillator not subjected to magnetic field.

Acknowledgment: The construction of the experimental setup presented in the work was supported by the Polish National Science Centre under the grant OPUS 14 No. 2017/27/B/ST8/01330.

References

[1] Aubry, S., Kopidakis, G., Morgante, A. M., & Tsironis, G. P. (2001). Analytic conditions for targeted energy transfer between nonlinear oscillators or discrete breathers. *Physica B: Condensed Matter*, *296*(1–3), 222–236.

[2] Vakakis, A. F., Gendelman, O. V., Bergman, L. A., McFarland, D. M., Kerschen, G., & Lee, Y. S. (2008). Nonlinear targeted energy transfer in mechanical and structural systems I. Solid Mechanics and its Applications (1st ed., Vol. 156). Springer.

[3] Li, T., Gourc, E., Seguy, S., Berlioz, A. Dynamics of two vibro-impact nonlinear energy sinks in parallel under periodic and transient excitations. *International Journal of Non-Linear Mechanics*, 2017, **90,** 100–110.

[4] Ture Savadkoohi, A., Lamarque, C. H., Dimitrijevic, Z. Vibratory energy exchange between a linear and a nonsmooth system in the presence of the gravity. *Nonlinear Dynamics*, 2012, **70**(2), 1473–1483.