Wide Band Frequency Response in Multi-Degree-of-Freedom Vibration System Using Electropermanent Magnet Actuator

Kazufumi MAKABE, Masayuki KATO, and Fumiya KITAYAMA

Graduate School of Science and Engineering, Ibaraki University,
Hitachi, 316-8511, Ibaraki, Japan

Abstract

This paper proposes a new multi-degree-of-freedom (DOF) vibration system using electropermanent magnet (EPM) to achieve wide band frequency response of the system. A five-DOF system with four EPMs can operate with 16 different frequency response curves. Numerical calculation reveals that the proposed system significantly broadens its operational range by using the MAX function.

1 Introduction

Frequency response curve of a mass-spring-damper system is invariant because it is intrinsically determined by mechanical parameters. For example, a vibrational energy harvester (VEH) significantly decreases its generated electrical power if the resonant frequency of VEH does not match the frequency of ambient vibration. Therefore, many existing VEHs compensate the mentioned drawback by introducing a wide band frequency response mechanism [1]. Authors have proposed a linear oscillatory actuator with switchable frequency response and verified wider operational range through finite element analysis and experiment [2]. In the literature, electropermanent magnet (EPM) can effectively switch between one and two degree-of-freedom (DOF) of the actuator with a slight electrical power.

For the purpose of achieving much wider band frequency response, this paper extends our technique by connecting multiple EPMs in series. Numerical computation revealed that a five-DOF vibration system with four EPMs broadens its operational range significantly, compared to one-DOF system and five-DOF system without the EPMs.

2 Multi-Degree-of-Freedom Vibration System Using Electropermanent Magnet Actuator

Figure 1 shows the basic configuration of the proposed N–DOF vibration system using EPMs. N–1 EPMs are connected to a main system via spring and damper elements. The EPM can switch its electromagnetic attractive force by changing a magnetization of a low-coercivity (AlNiCo) magnet, as shown in the right figure. Once a short-time pulsed current is applied to a coil wound around the two magnets, the magnetization of AlNiCo magnet is easily reversed. This allows the proposed N-DOF system to degenerate into an $N - N_c$ DOF system and recover into the original N-DOF system because the EPM can absorb and desorb the adjacent EPMs. Since we can select N_c EPMs to be absorbed without constraints, the combination of the switchable vibration system N_{resp} is

$$N_{\mathrm{resp}} = \sum_{N_c=N-1}^{0} ({}_{N-1}C_{N_c}) = 2^{N-1}. \tag{1}$$

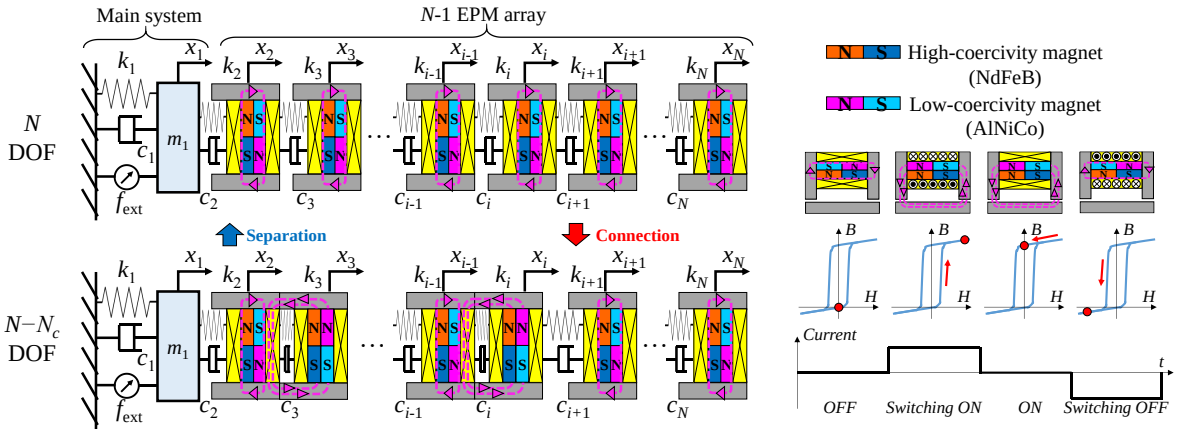

Figure 1: Multi-degree-of-freedom vibrational system using EPM array, (a): Basic configuration, (b): operational principle of EPM

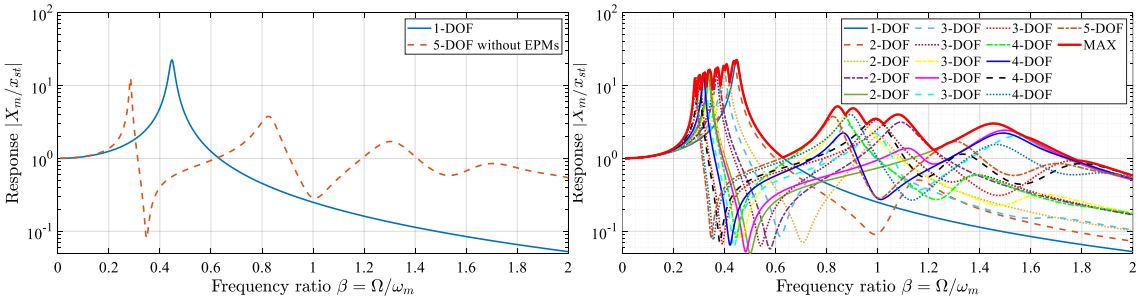

Figure 2: Numerical results of frequency response curve (a): 1-DOF and 5-DOF without EPMs, (b): 5-DOF with four EPMs

In this paper, five-DOF vibration system with four EPMs is employed. It can switch $2^{5-1} = 16$ different frequency response curves, depending on its operational frequency.

3 Numerical Results of Wide Band Frequency Response

Figure 2 compares the frequency response for three conditions: one-DOF, five-DOF without EPMs, and five-DOF with four EPMs. The left graph in Figure 2 indicates that increasing the DOF broadens the operational range. However, this is not a new finding, but a well-known solution in the field of mechanical engineering. The right graph suggests that 16 frequency response curves significantly broaden the operational range by the usage of MAX function (red solid line). In the full paper, more detailed design methodology, optimization of mechanical parameters, and experimental verification will be presented.

References

[1] D. Zhu, Michael J Tudor, and Stephen P Beeby, Strategies for increasing the operating frequency range of vibration energy harvesters: a review, *Meas. Sci. and Technol.* **21** (2010) 1-29.

[2] M. Kato and F. Kitayama, Switchable Frequency Response Based on Electropermanent Magnet Actuator for Wide-range Operation of Electromagnetic Devices, *IEEE Trans. Magn.* **Early Access** (2023) 1-5.