[BR-05]
[KPA-06]

Switchable Frequency Response Based on Electropermanent Magnet Actuator for Wide-range Operation of Electromagnetic Devices

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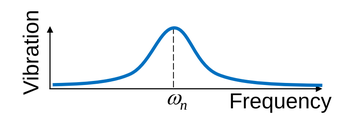
Intermag 2023
Sendai, Japan
May 15 - 19, 2023

Introduction

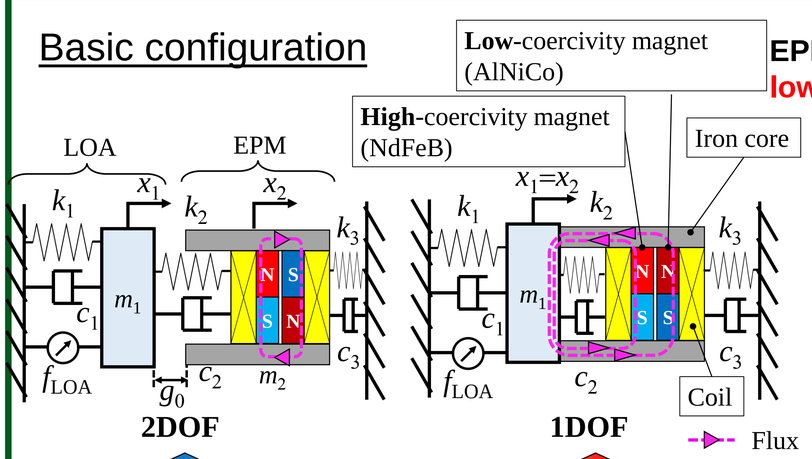
Linear oscillatory actuator (LOA) is an electromagnetic actuator that has been used in a wide range of industrial applications due to its simple structure and high efficiency.
Frequency response of LOA is **invariant** because it is intrinsically determined by mechanical parameters of a mass-spring-damper system.
If the frequency response can be switched, the LOA can be operated over a wider range of frequencies.



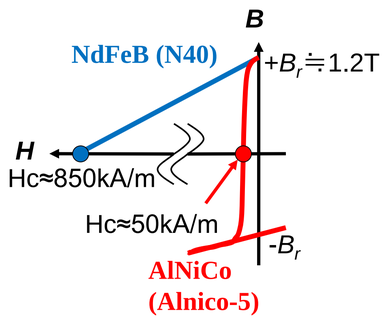
This paper proposes **a new LOA with switchable frequency responses**.
The proposed LOA switches its **degree-of-freedom (DOF)** by connecting and separating an **electropermanent magnet (EPM)**.

Linear Oscillatory Actuator with Detachable Electropermanent Magnet

Basic configuration



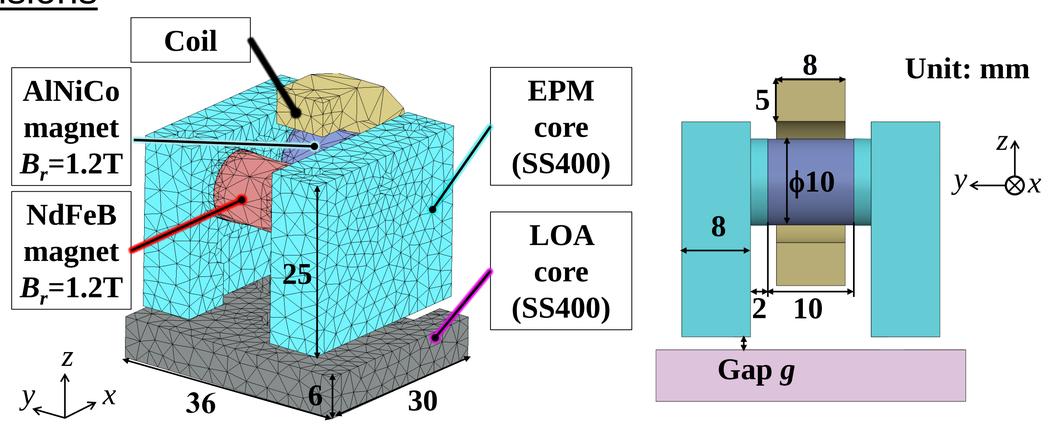
EPM uses both **low-** and **high-**coercivity magnets



Connect
Separate

The magnetization of low-coercivity magnet is **easily reversed** by the **short-time pulsed current**

Dimensions



Cylindrical NdFeB and AlNiCO magnets (ϕ10mm x H10mm) are attached to the EPM cores
Copper wire (ϕ0.4mm , 150 turns) is wound around the two magnets

Switchable Frequency Response Curve

Motion equations

2DOF

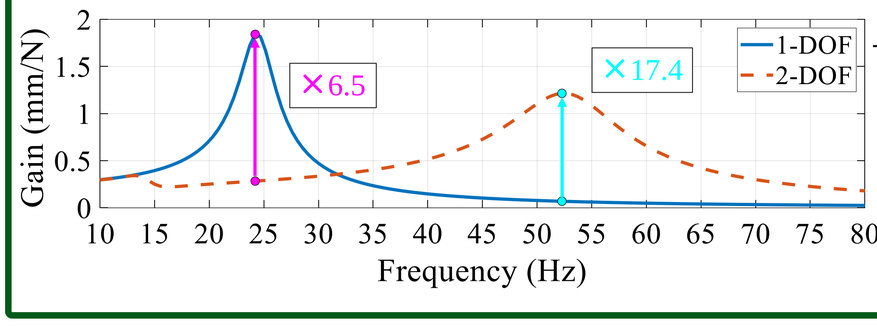
$$\begin{cases} m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 + c_2(\dot{x}_1 - \dot{x}_2) + k_2(x_1 - x_2) \\ \quad = f_{\mathrm{LOA}}(t) + f_{\mathrm{EPM}}(t) \\ m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) + c_3\dot{x}_2 \\ \quad + k_2(x_2 - x_1) + k_3x_2 = -f_{\mathrm{EPM}}(t). \end{cases}$$

f_{EPM} is neglible because the EPM doe not interact with the LOA

1DOF

$$m_c\ddot{x}_1 + (c_1 + c_3)\dot{x}_1 + (k_1 + k_3)x_1 = f_{\mathrm{LOA}}(t).$$

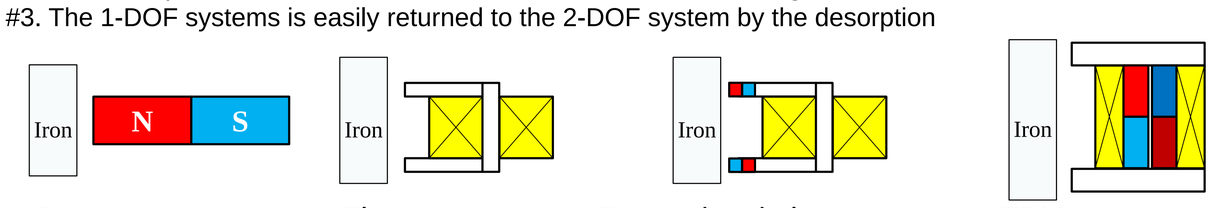
Frequency response curve of the proposed LOA



The proposed LOA achieves **wider operational range** by switching its DOF, involving only a slight copper loss during the switching.

Selection of Absorption/Desorption Device

The switchable frequency response curve requires the following three properties:
#1. Unnecessary electromagnetic force does not occur during the 2-DOF oscillation
#2. The absorption between the mover and EPM is maintained during the 1-DOF oscillation
#3. The 1-DOF systems is easily returned to the 2-DOF system by the desorption



Permanent magnet	Electromagnet	PM-assisted electromagnet	EPM
#1 NG	**#1 OK**	#1 NG	**#1 OK**
#2 OK	**#2 OK**	**#2 OK**	**#2 OK**
#3 NG	**#3 OK**	**#3 OK**	**#3 OK**

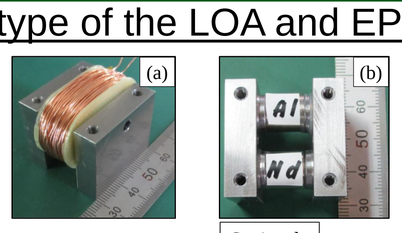
Continuous Joule loss during absorption

Slight Joule loss during absorption/desorption

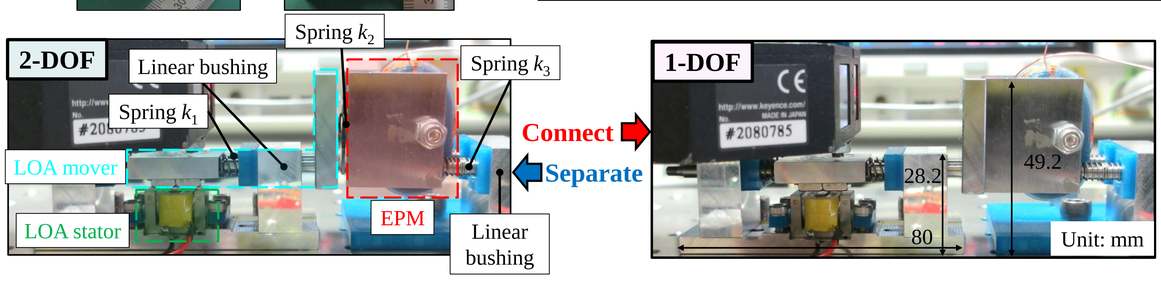
➢ **EPM is suitable because it meets all the three requirements**

Experimental Verification

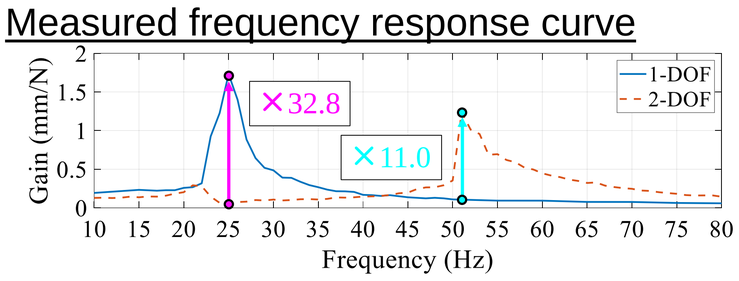
Prototype of the LOA and EPM



Number of turns	150
Coil resistance	2.47Ω
Coil inductance (same magnetization)	973μH
Coil inductance (opposite magnetization)	995μH

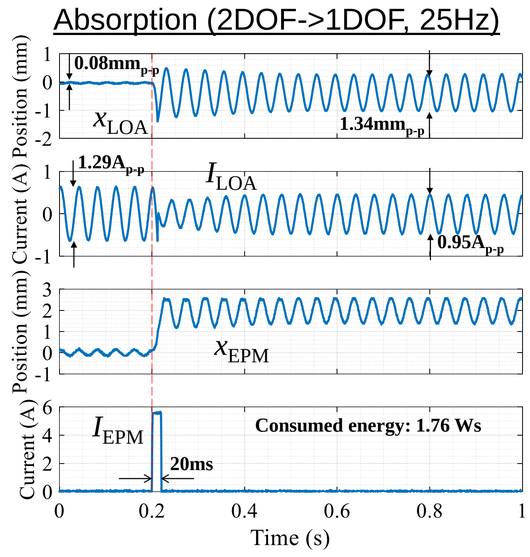


Measured frequency response curve

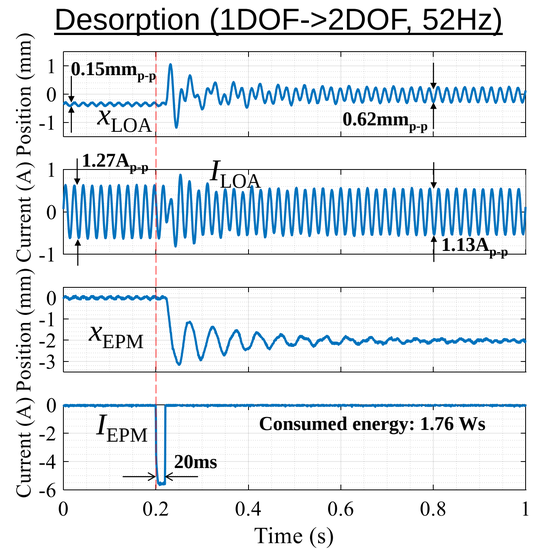


Measured results are in good agreement with theoretical ones

Absorption (2DOF->1DOF, 25Hz)



Desorption (1DOF->2DOF, 52Hz)



Conclusion and Future Works

- This paper presented a new LOA that **switches its frequency response curve** by **changing its DOF**.
- An **EPM** was suitable device to switch the DOF because the EPM was able to turn on/off its attractive force with a **slight power consumption**.

■ The proposed technique is applicable to **vibrational energy harvesters(VEHs)**. We will design a new **wideband VEH** using our technique.
■ We will also extend our technique by connecting **multiple EPMs in series**. The extended ***N* DOF system** (one LOA and N-1 EPMs) is able to switch $\mathbf{2^{N-1}}$ frequency response curves → significant improvement on the overall frequency response

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