[VP5-09]

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Sensorless Magnetization Current Control for Stable Connection and Separation of Electropermanent Magnet

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Introduction

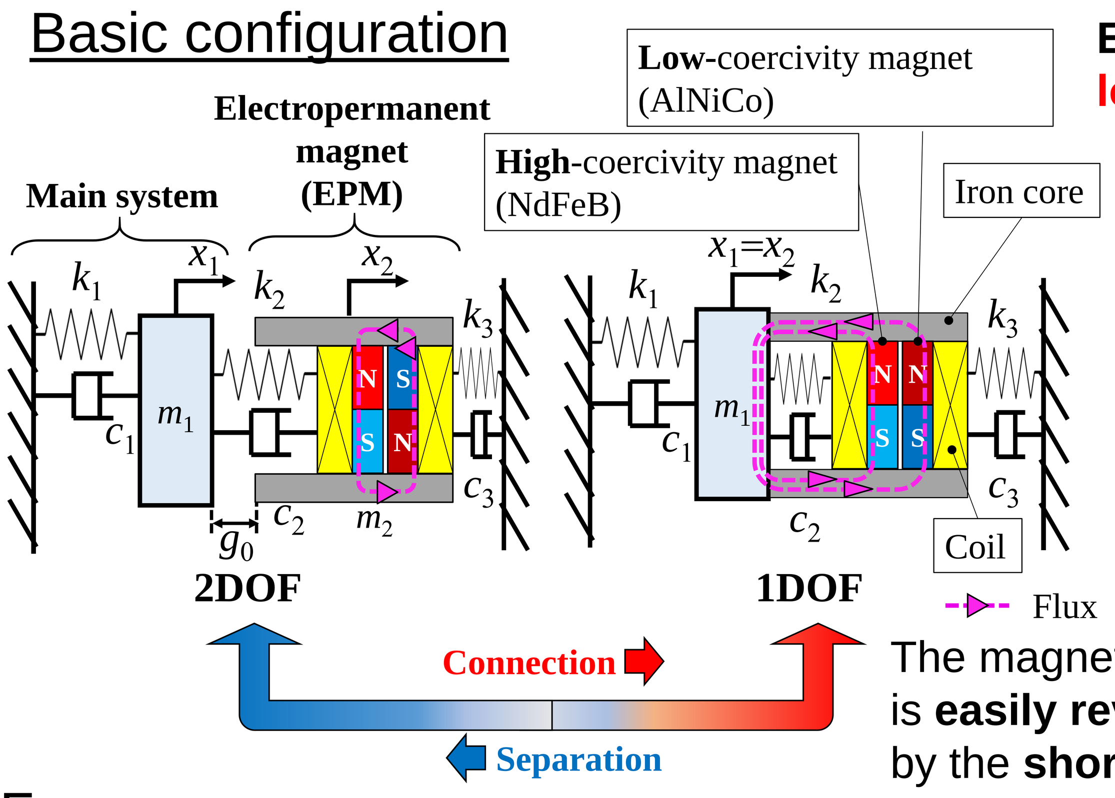
Electropermanent magnets (EPMs) are special electromagnets incorporating a high coercivity magnet (NdFeB) and a low coercivity magnet (AlNiCo). A magnetic attractive force of the EPM can be turned on and off by applying an instantaneous external magnetic field to the AlNiCo magnet and reversing its magnetization. Unlike general electromagnets, EPMs do not **require electrical energy** to maintain the attractive force.

The authors have proposed a **new wideband vibrational device** that can switch its degree of freedom (DOF) by connecting and separating the EPM. However, the pulse current required for the magnetization reversal of the AlNiCo magnet depends on an air gap variation between the main system and the EPM. Without control of magnetizing currents, **failed connection behavior** is often reported (**Kato et al., *IEEE Trans. Magn.*, 2023**).

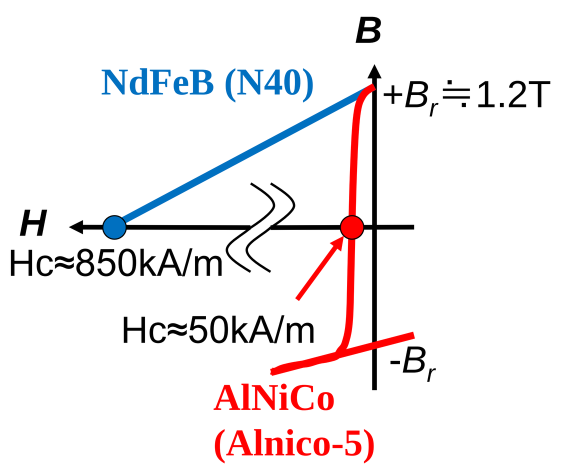
This study proposes a **sensorless** method for **estimating the state of connection** and separation of the EPM by using a periodic induced voltage. **Magnetization current control** is proposed to achieve stable EPM connection and separation to avoid unnecessary power consumption owing to failed operations.

Wideband Vibrational Device Using Electropermanent Magnet

Basic configuration

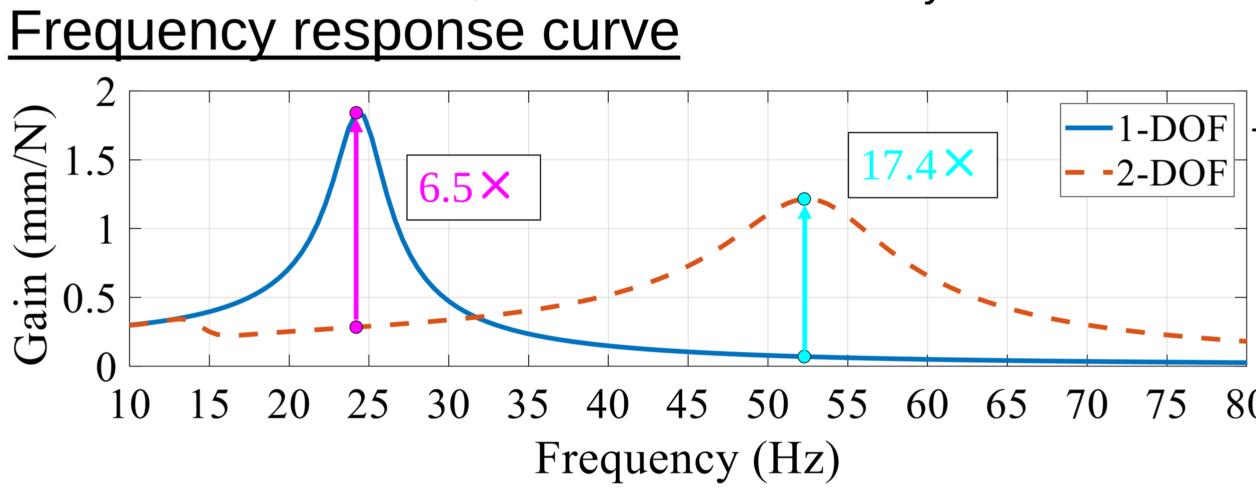


EPM uses both **low-** and **high-**coercivity magnets



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

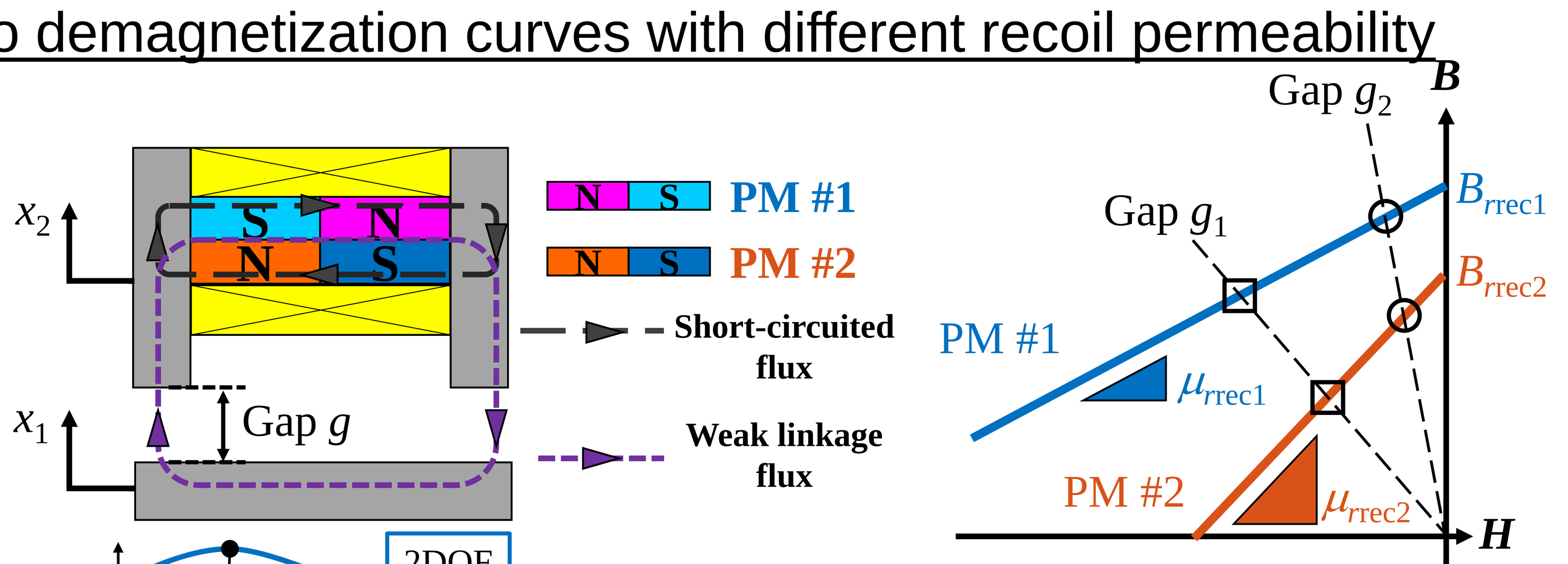
Frequency response curve

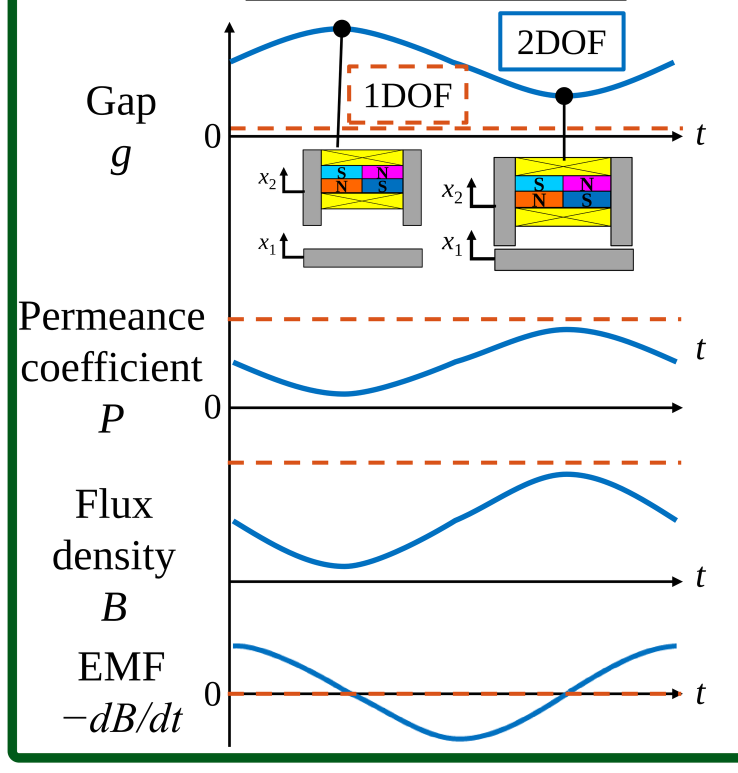


The proposed device achieves **wider operational range** by switching its DOF, involving only a slight copper loss during the switching.

Connection and Separation State Estimation Using Induced Voltage of EPM

Two demagnetization curves with different recoil permeability





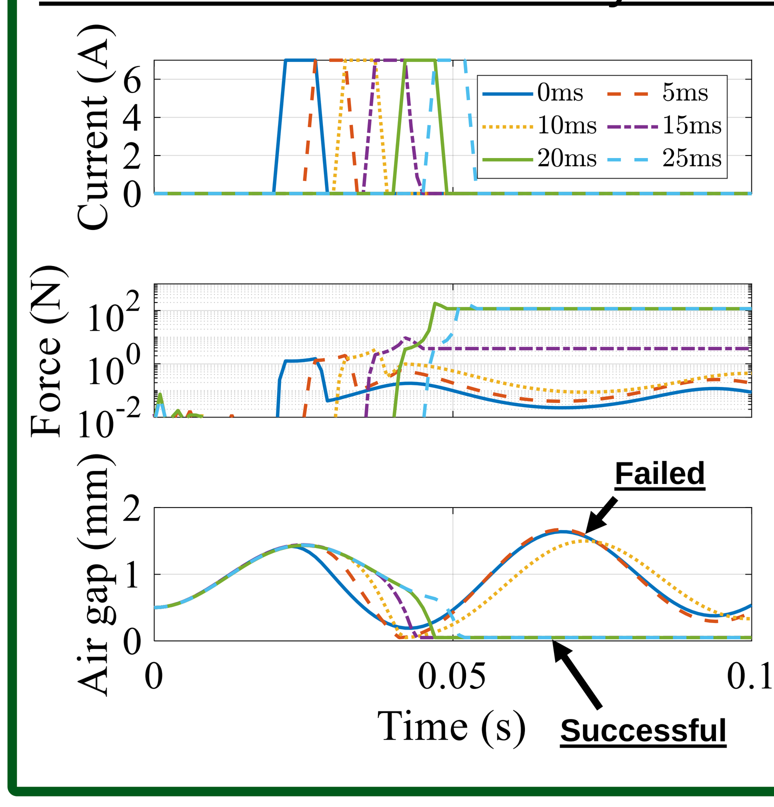
In the 2-DOF system, the air gap between the main system and the EPM g fluctuates periodically over time. The permeance coefficients of the NdFeB and AlNiCo magnets P also change and are synchronized with the air gap fluctuation. Consequently, the time-periodic magnetic flux through the coil induces **the back electromotive force** (**EMF**).

In the 1-DOF system, the back EMF **remains zero** because of the maintained connection state between the main system and the EPM (i.e. $P(t)$ **= const.**).

The DOF of the wideband vibrational device can be estimated accurately by detecting the back-EMF and processing it with a microcontroller.

Sensorless Current Phase Control for Stable Connection of EPM

3-D finite element analysis for connecting motion of EPM

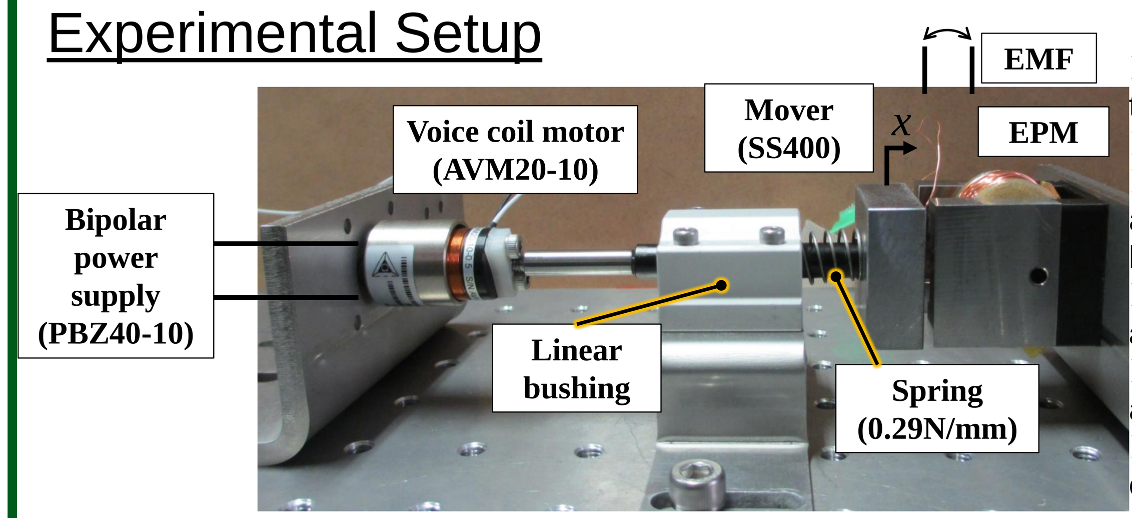


The air gap is minimized on the detection of the **positive-going zero crossing of the EMF.** In this case, **the AlNiCo magnet is magnetized effectively** because of the lowest magnetic resistance of the magnetic path flowing through the AlNiCo magnet, air gap, and iron core.

The left figure (FEA results) indicates
- Successful connection of the EPM requires **proper current phase control** (the phase information can be estimated by the EMF)
- This phase adjustment is **the reasonable way of mitigating the Joule loss** during the pulsed current

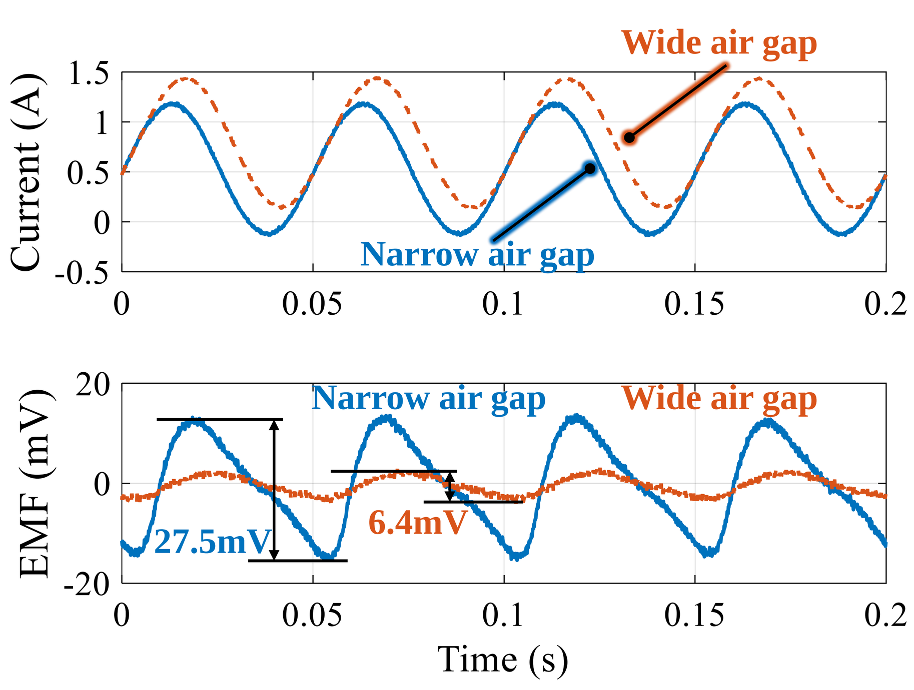
Experimental Verification

Experimental Setup

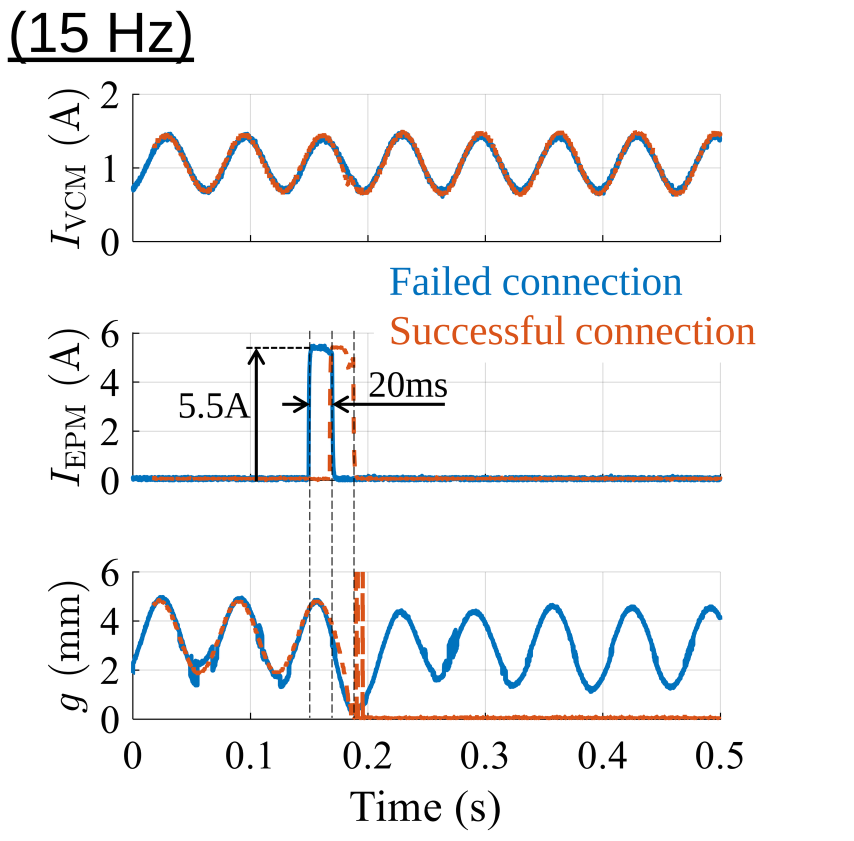


- The EPM is fixed on a base plate and the iron mover is oscillated forcibly by a VCM.
- DC+AC voltage is applied to the VCM.
- The DC current is used for changing the initial air gap because the restoring force of the spring balances the constant thrust exerted from the VCM.
- The measured EMF is amplified to the level of a few volts by an operational amplifier.
- The amplified EMF is converted to a trigger signal with a zero-crossing detection.
- processed as an interrupt command of the pulsed current inside the DSP (dSPACE).

Measured EMF (20 Hz)



Sensorless Current Phase Control (15 Hz)



- Measured EMF **is time-periodic and synchronized with the reciprocating motion** of the iron core.
- The sawtooth-like waveform is **qualitatively consistent with the computed one** (not shown in this poster)
- ✓ **This result proves the effectiveness of the proposed estimation method.**

- In the failed connection, the phase of the pulse current is approximately aligned with the maximum air gap. After the pulse current ends, the air gap decreases to approximately 0.2 mm and subsequently fluctuates periodically again **because of the insufficient attractive force**.
- By contrast, providing a phase delay of approximately 20 ms results in **persistent connection state**.
- **The measured results validate the effectiveness of the proposed current phase control method.**

Conclusion and Future Works

- This study proposed a **sensorless** method for **estimating the state of connection and separation** of an EPM by using a periodic induced voltage signal of the EPM's coil.
- ✓ The estimation principle was feasible because of the **different recoil permeability** between the two magnets (NdFeB: 1.05, AlNiCo: 3.6).
- A **magnetization current phase control** was proposed to achieve a stable EPM connection and **avoid useless power consumption** resulting from failed operations. The 3-D FEA and experiments revealed that the control could **ensure stable connection of the EPM.**

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