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Behaviors of Flag-Shaped Dampers Using Combination of Magnetic Friction and Rubber Springs

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Background & Objective

- Dampers are used to dissipate input energy and reduce vibration of a system.
- In civil engineering, they are mainly applied in the protection of bridges and building from seismic attacks.
- In addition, they are used to control the vibration of structures induced by vehicles, human-being, or environmental loadings.
- Therefore, several type of dampers are developed, including fluid dampers, frictional dampers, metallic dampers, and SMA dampers.

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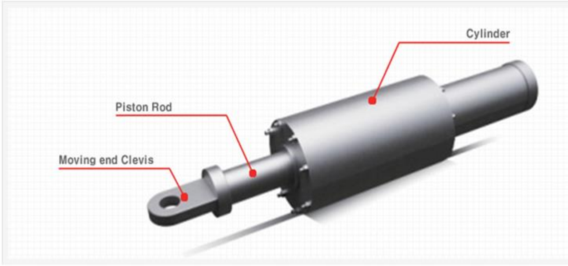
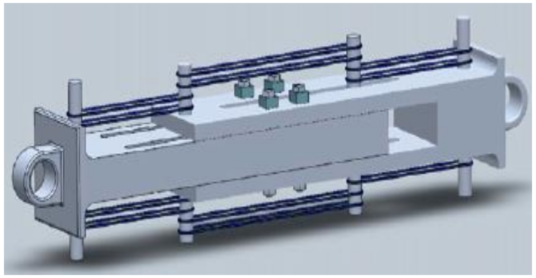
Background & Objective

- Several type of dampers
  - Viscosity(fluid) damper → Long time usage of liquid based damper creates high possibilities of liquid leaks
  - Damper using memory alloy(SMA damper) → New materials have a problem of being uneconomical.
  - Frictional damper(Using bolt tension) → Slight variation of bolt-tension or the surface-condition of frictional material may reduce frictional force.



<Viscosity damper>



<SMA damper>

<frictional damper>

➢ Proposed a new concept of a smart damper using magnet and rubber spring.

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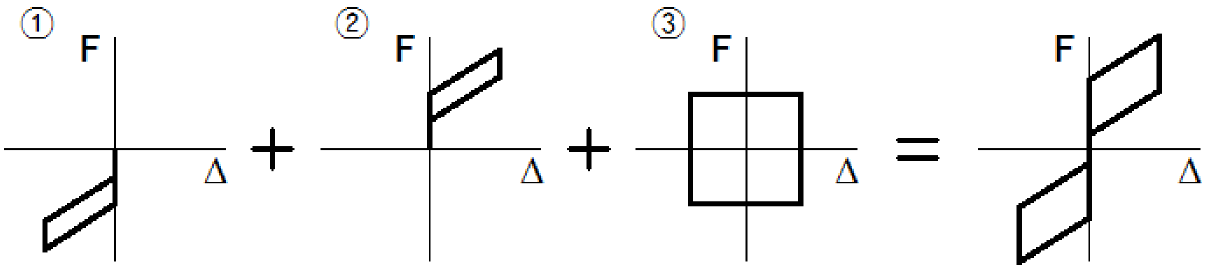
Background & Objective

- Concept of smart damper



  - A new concept of smart damper will be proposed that using the friction of permanent magnets and pre-compressed rubber spring.
  - The magnetic friction provides energy dissipation capacity.
  - The pre-compressed rubber springs provides self-centering capacity.
  - The combination of magnetic friction and pre-compressed rubber springs generates 'flag-shaped' behavior for a smart damper.

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Dynamic tests of magnetic friction damper

- Experiment Preparation

<Shape of the Magnet>

<Tensile test of the magnet>

➢ **The pulling force is 800N for each magnet.**

Identify the friction force and frictional coefficient by controlling the number of magnets and frequency of the UTM.

<Dynamic experiment preparation of magnetic damper >

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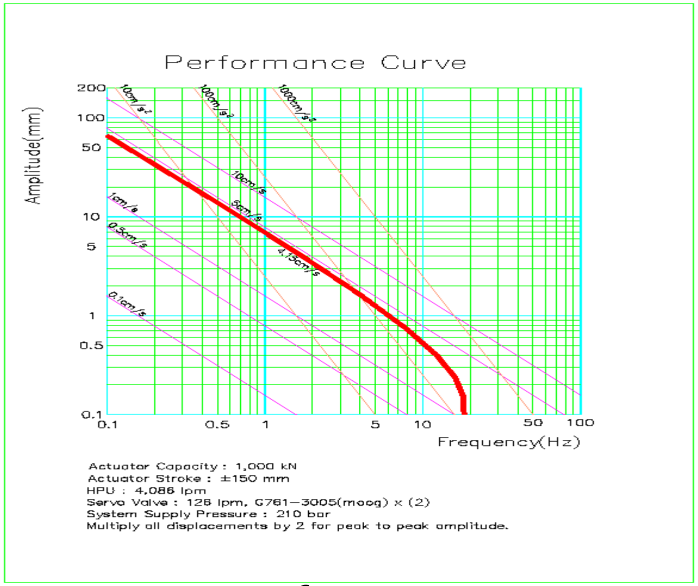
Dynamic tests of magnetic friction damper

- Experiment procedure
  - The experiment is proceeded by changing the number of magnets in the order of 2, 4, 6, 8, 10, 12 magnets each.
  - The experiment is proceeded by controlling the frequency of UTM in the order of 0.1, 0.25, 0.5, 0.75, 1, 2 Hz.
  - Stroke is controlled in consideration of the Performance curve of the UTM.



<UTM Perfomance curve>

No. of frequency	Stroke
0.10 Hz	± 10 mm
0.20 Hz	± 10 mm
0.50 Hz	± 10 mm
0.75 Hz	± 5 mm
1.00 Hz	± 5 mm
2.00 Hz	± 2 mm

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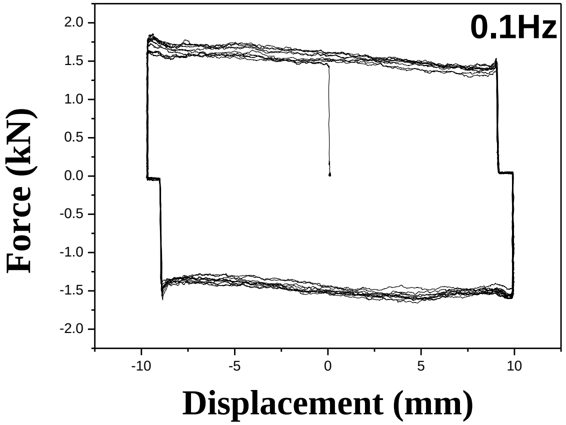
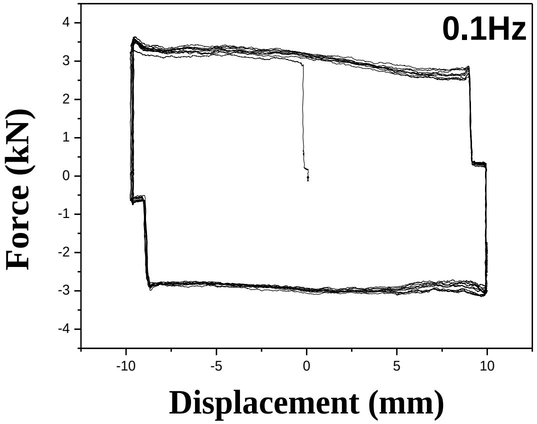
Dynamic tests of magnetic friction damper

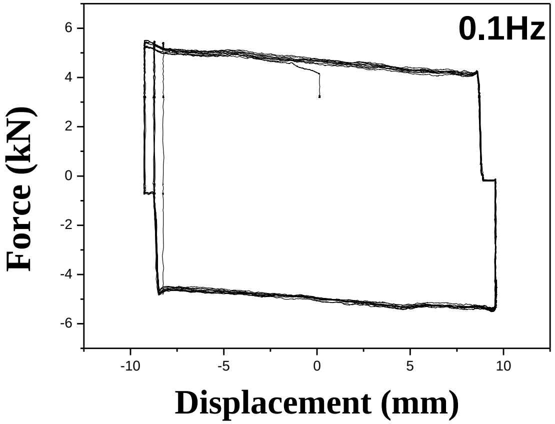
- Result of magnets adhered



<4 magnets adhered>



<8 magnets adhered>



<12 magnets adhered>

Magnets	0.1 Hz	0.25 Hz	0.5 Hz	0.75 Hz	1 Hz	2 Hz
4 magnets	1.51	1.58	1.64	1.68	1.73	1.82
8 magnets	3.05	3.35	3.44	3.35	3.45	3.5
12 magnets	4.75	4.86	5.1	4.95	5.05	4.92

(kN)

<Friction forces along with magnets number>

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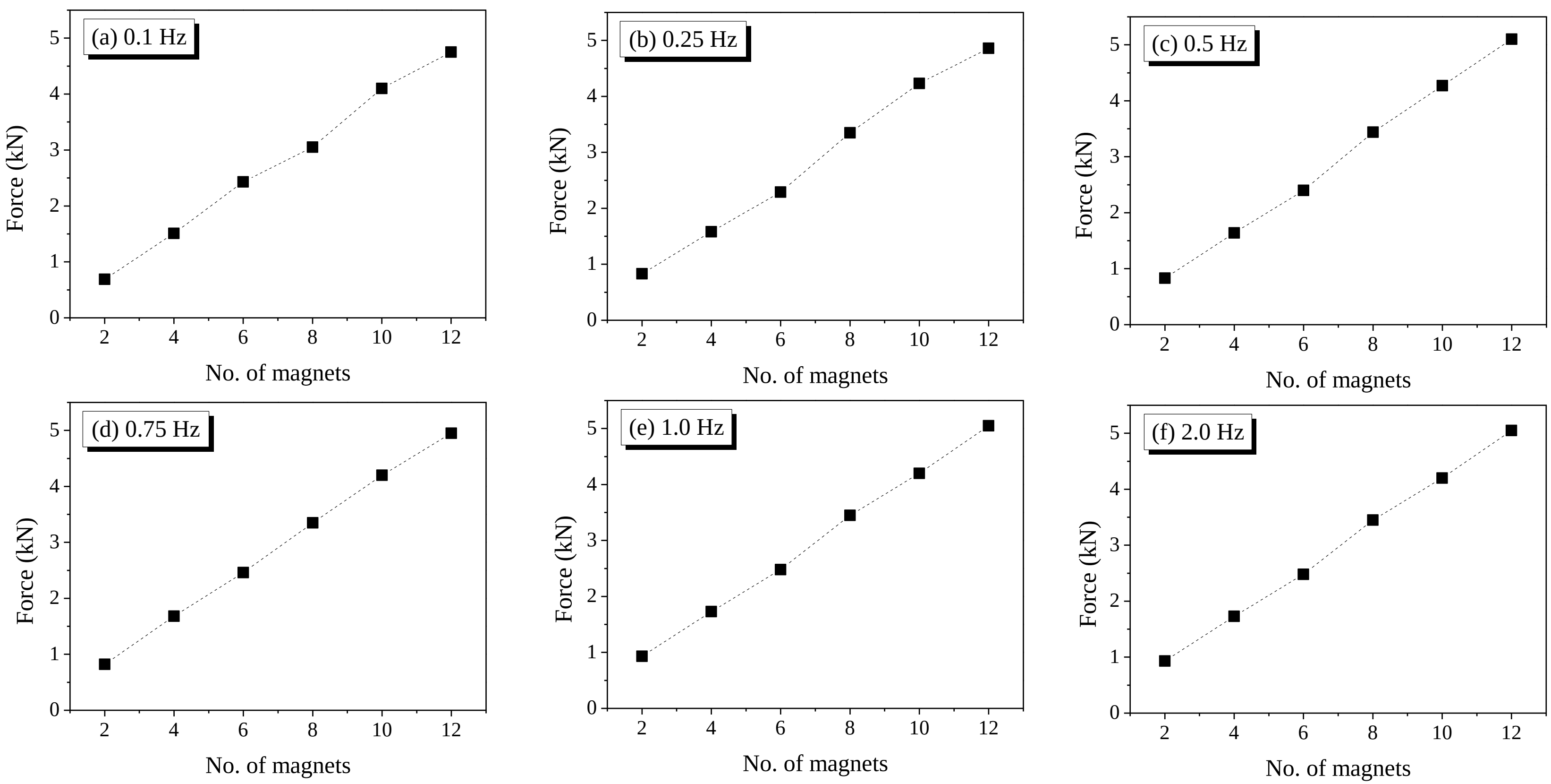
Dynamic tests of magnetic friction damper

- Estimation of friction force



  - The friction force depending on in number of magnets was a linear increase.

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Dynamic tests of magnetic friction damper

- Estimation of frictional coefficient.

$$F = \mu N \quad F = kn$$

$$N = 0.8n \quad \mu = \frac{k}{0.8}$$

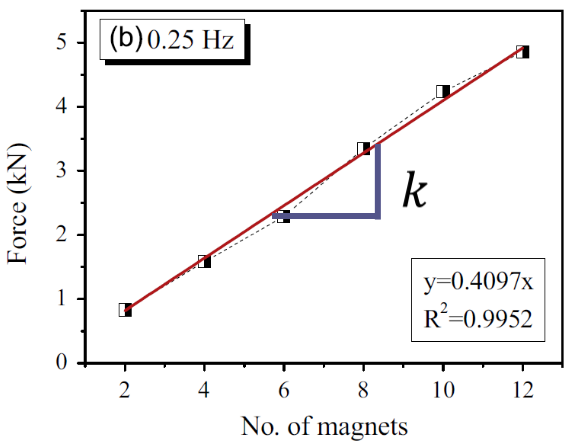
F : Frictional force

μ : Frictional coefficient

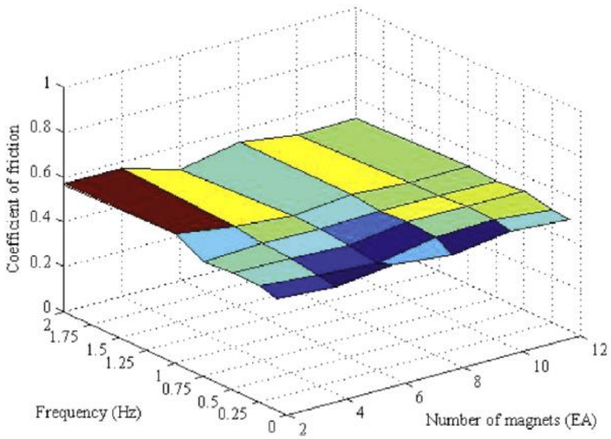
N : Normal force induced by magnetic force

k : Slope of the regression line

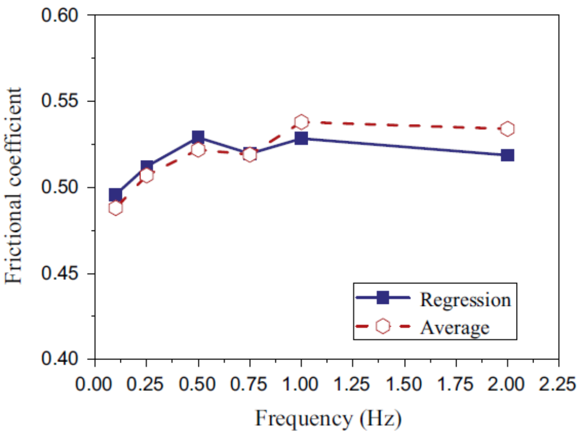
n : Number of magnet



Frictional force as a function of number of magnet (and regression line)



Frictional coefficient of the damper in a 3D graph



Frictional coefficient of average and regression

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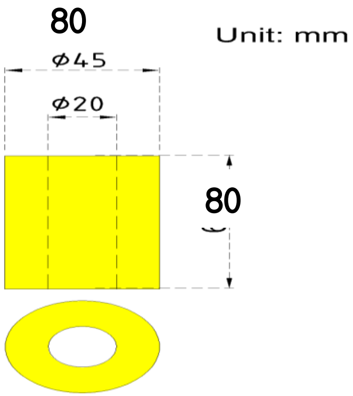
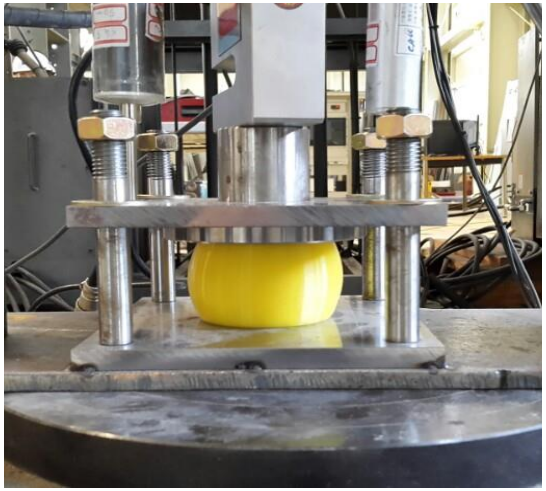
Pre-compressed rubber springs test

- Purpose of experiment
  - In order to develop the rubber spring + magnetic-frictional damper system, we made experimental rubber spring model.
  - Experimental test identify the behavior of the rubber spring and performing dynamic test. And the control frequency is 0.1-2Hz
- Preparation of Experiment



<Shape of the rubber spring>



<Test for dynamic tests>

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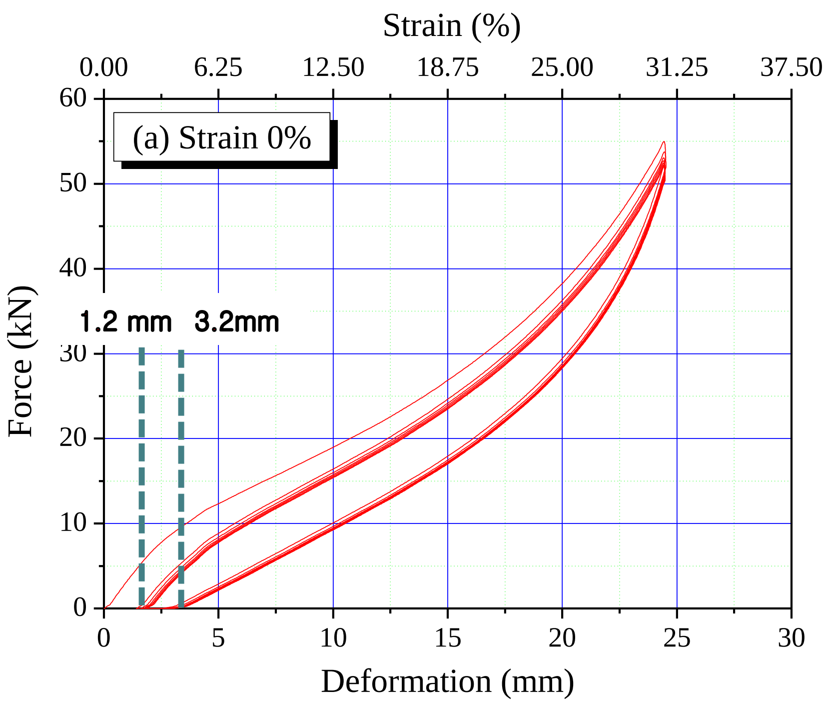
Pre-compressed rubber springs test

- Rubber spring’s behavior



- Compression until 25 mm (31.25 % strain)
- Residual deformation : 3.2 mm (4.0% strain)
- Recovery deformation : 2 mm (2.5% strain)
- Remained deformation : 1.2 mm (1.5% strain)

- The rubber spring should be initially compressed by at least 4.0% strain to prevent a slack behavior during vibrational cycles.

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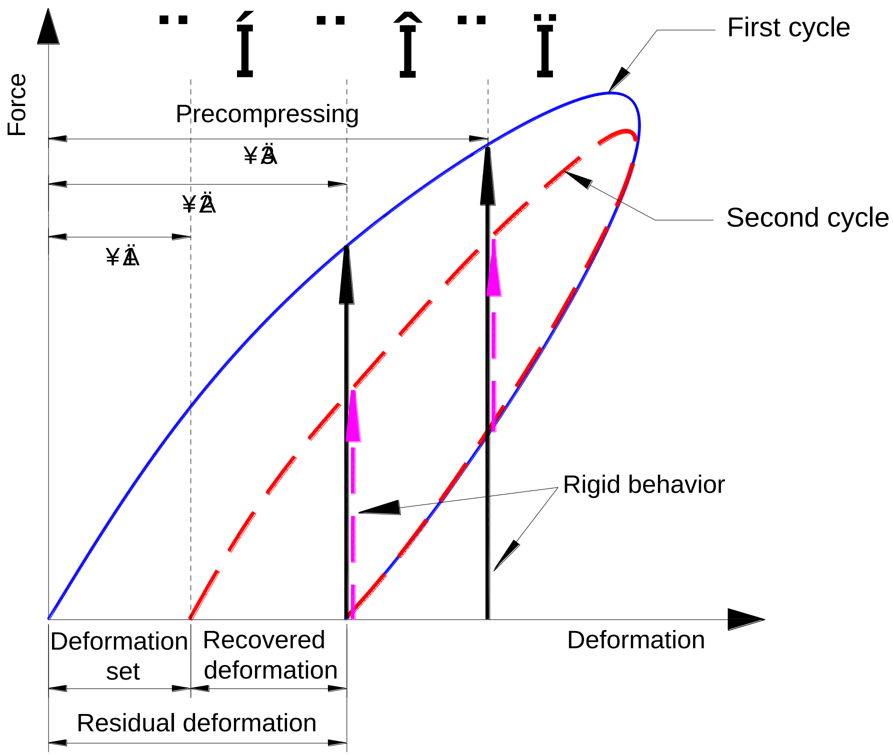
Pre-compressed rubber springs test

- Effect of pre-compression



- **Pre-compression < Δ1**

The second cycle begins with a gap.

- **Δ1 < Pre-compression < Δ2**

The deformation set is removed by the pre-compression. But, the recovered deformation remains.

- **Δ2 < pre-compression**

The behavior shows a rigid behavior up to the first loading path hen the unloading stops with remaining force and the curve goes up to the second loading path rigidly.

<Effect of precompression in the rubber spring>

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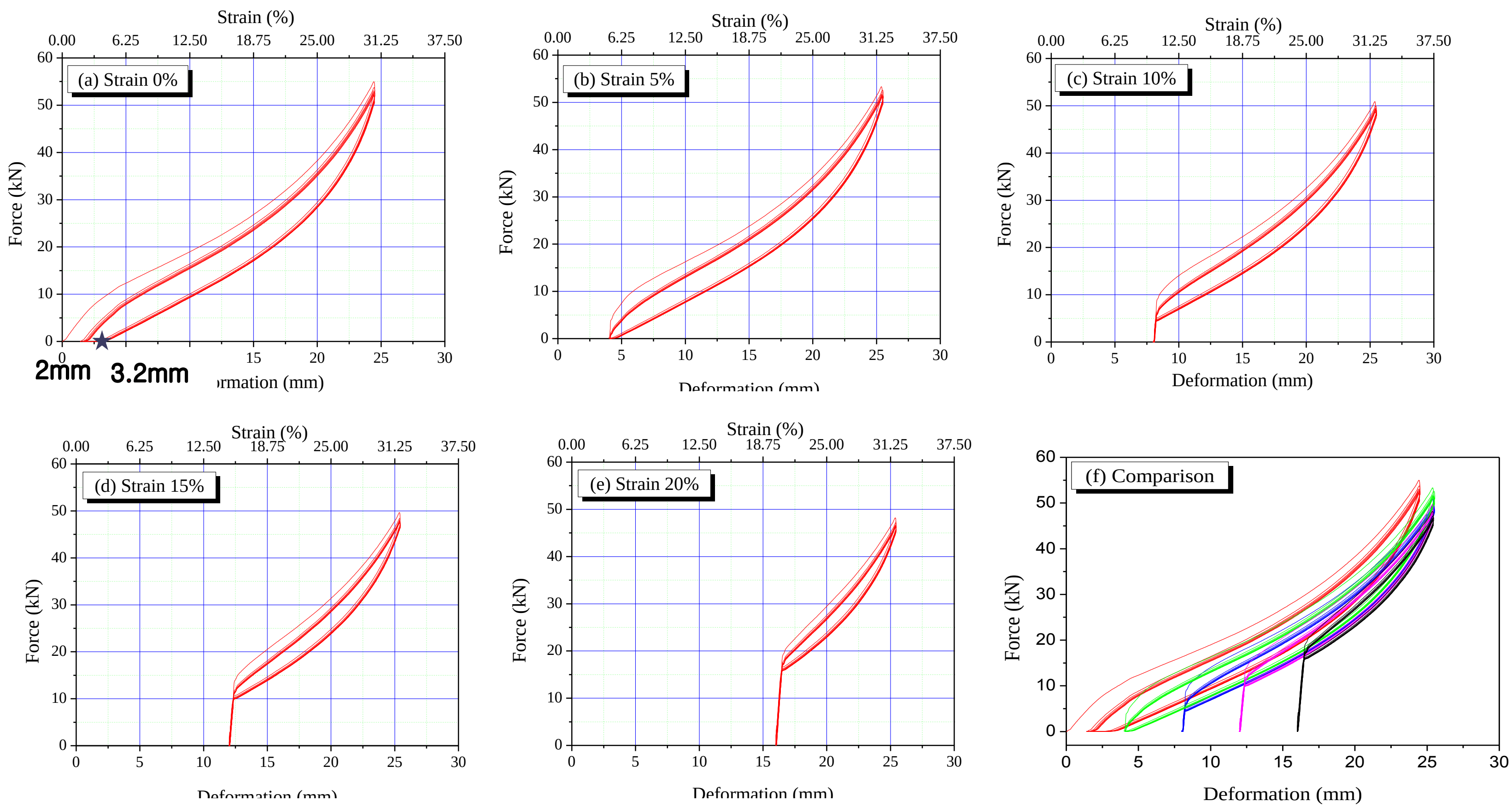
Pre-compressed rubber springs test

- Rubber spring's behavior along with pre-compression



< Force-deformation curves of the rubber springs >

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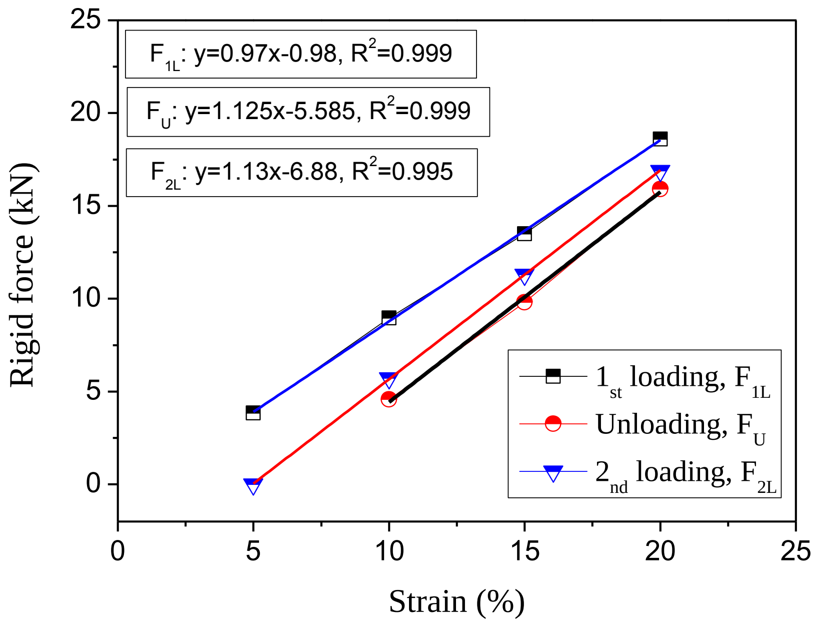
Pre-compressed rubber springs test

- Determination of pre-compression strain



$$y = 1.1254x - 5.585$$

- Frictional force for 8 magnets is 4.2 kN.
- From the equation, we obtained the corresponding strain (8.69%)
- In this study, use 10% (8.0 mm deformation) pre-compression strain

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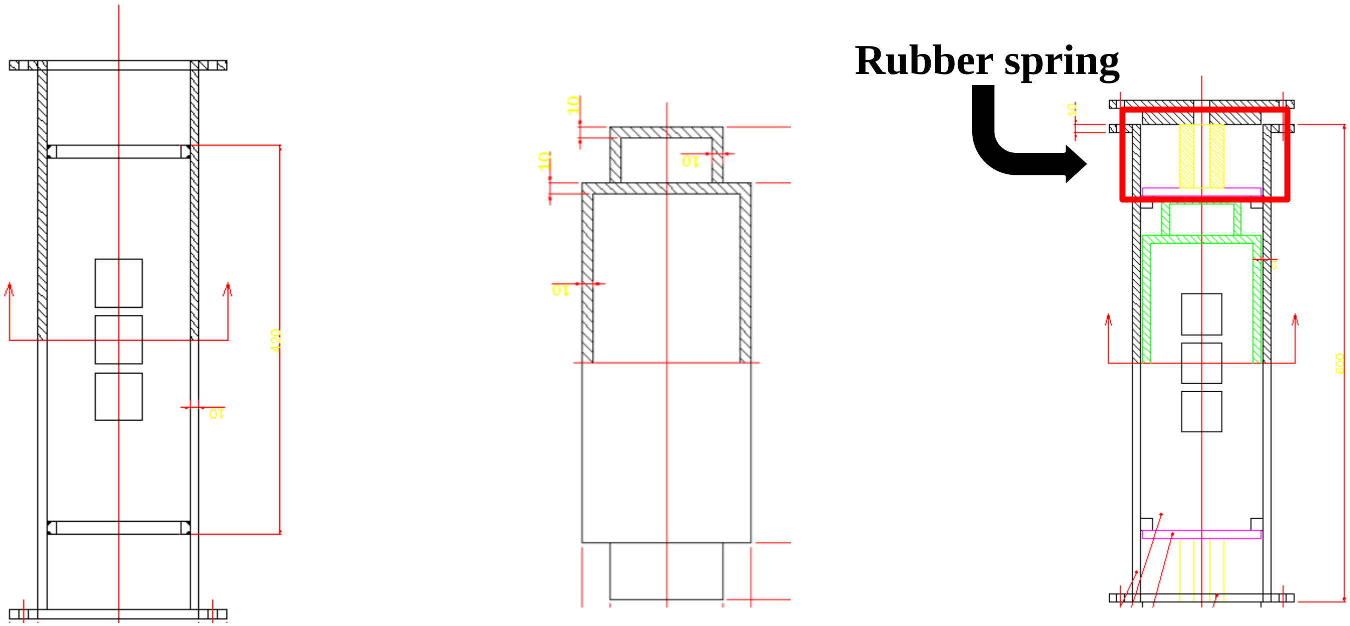
Smart damper dynamic test

- Shape of the smart damper



(a) Drawing of outer cylinder (b) Drawing of inner piston (c) Drawing of damper

<Drawing of smart damper>

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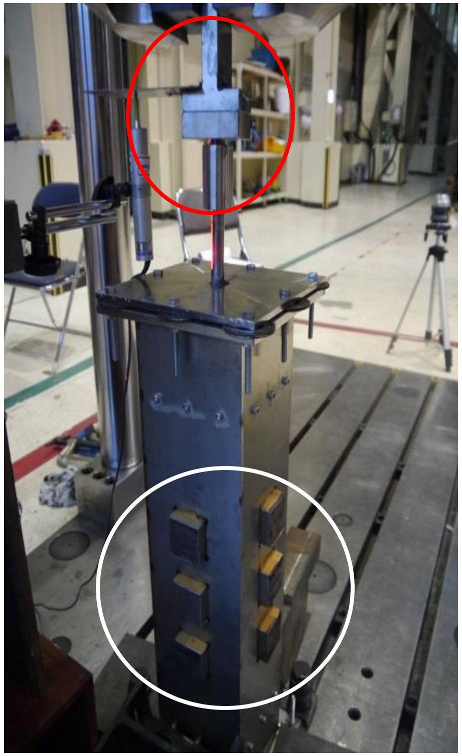
Smart damper dynamic test

- Experiment preparation

(a) Before pre-compression

(b) Pre-compression



(c) Dynamic test

<Experiment preparation>

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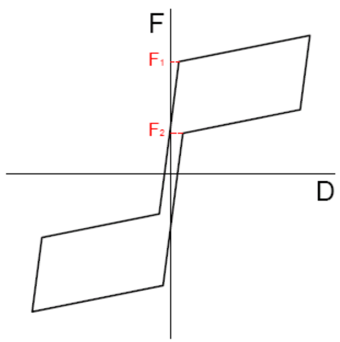
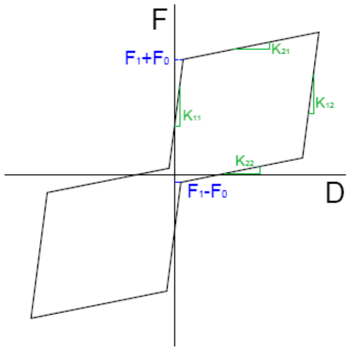
Smart damper dynamic test

- Determination of pre-compression strain



- Rigid force for self-centering > Frictional force
  - Return to the origin position



- Rigid force for self-centering < Frictional force
  - Remain residual displacement

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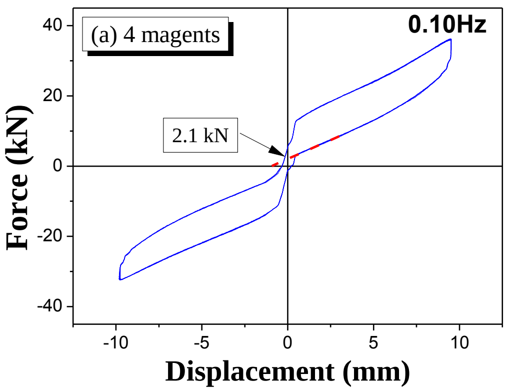
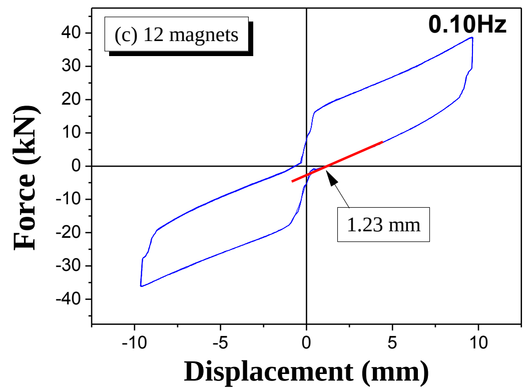
Smart damper dynamic test

- Determination of pre-compression strain



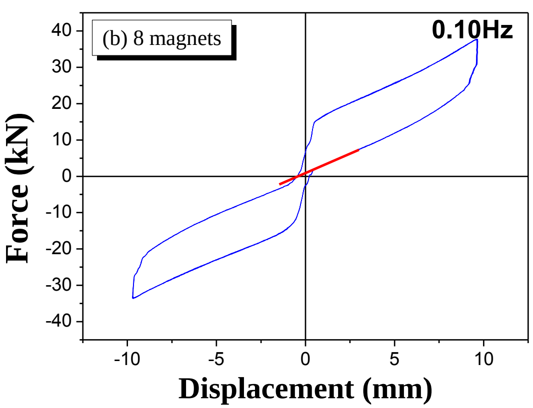
- 4 magnets

Remained rigid force
(2.1 KN)



- 12 magnets

Residual displacement
(1.23 mm)



- 8 magnets
  - Return to the origin position
  - The unloading rigid force of the pre-compressed rubber spring should be greater than the magnetic friction.

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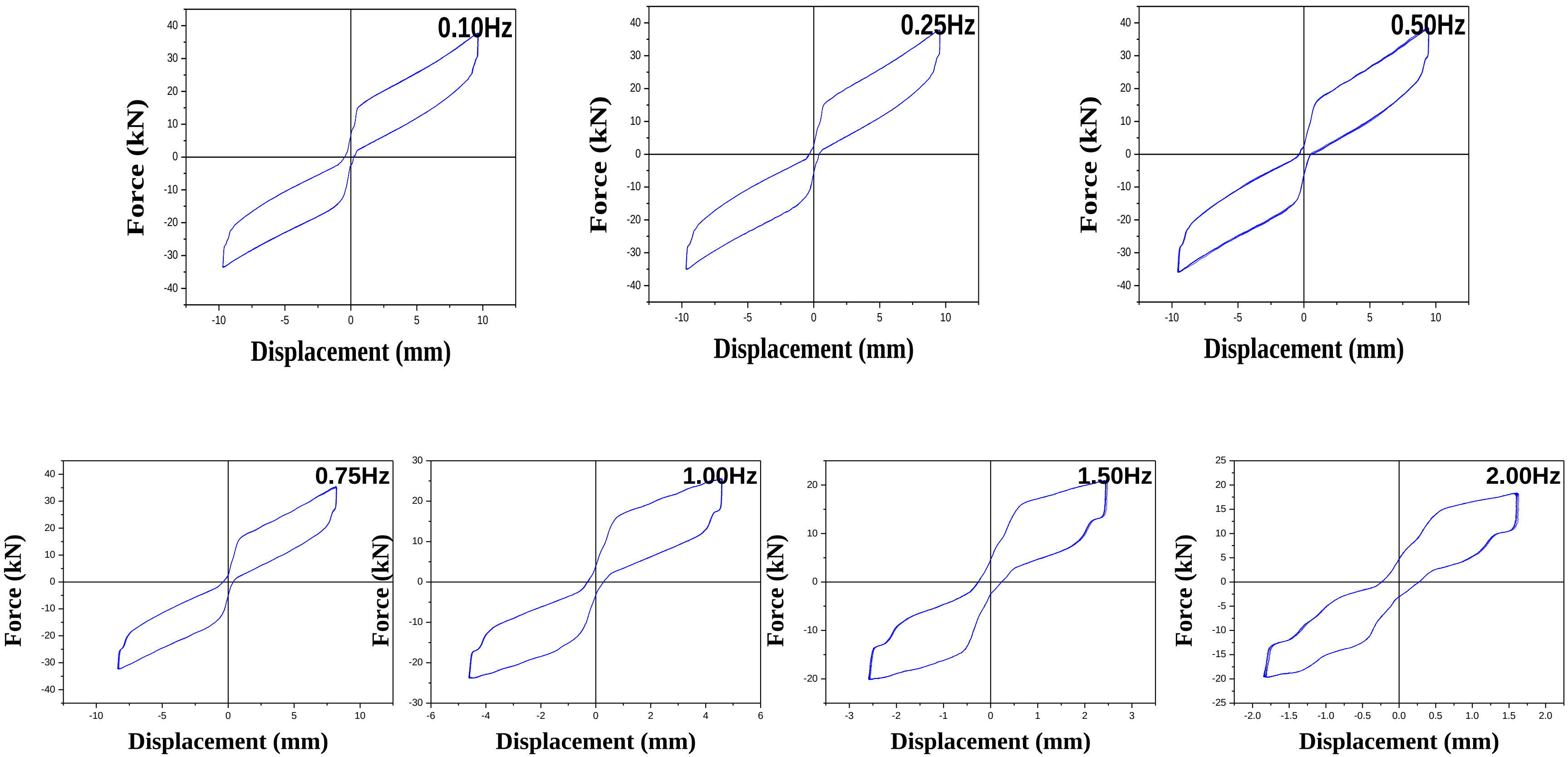
Smart damper dynamic test

- Results of vibration tests (8 magnets)



<Graph of symmetric behavior along with frequency>

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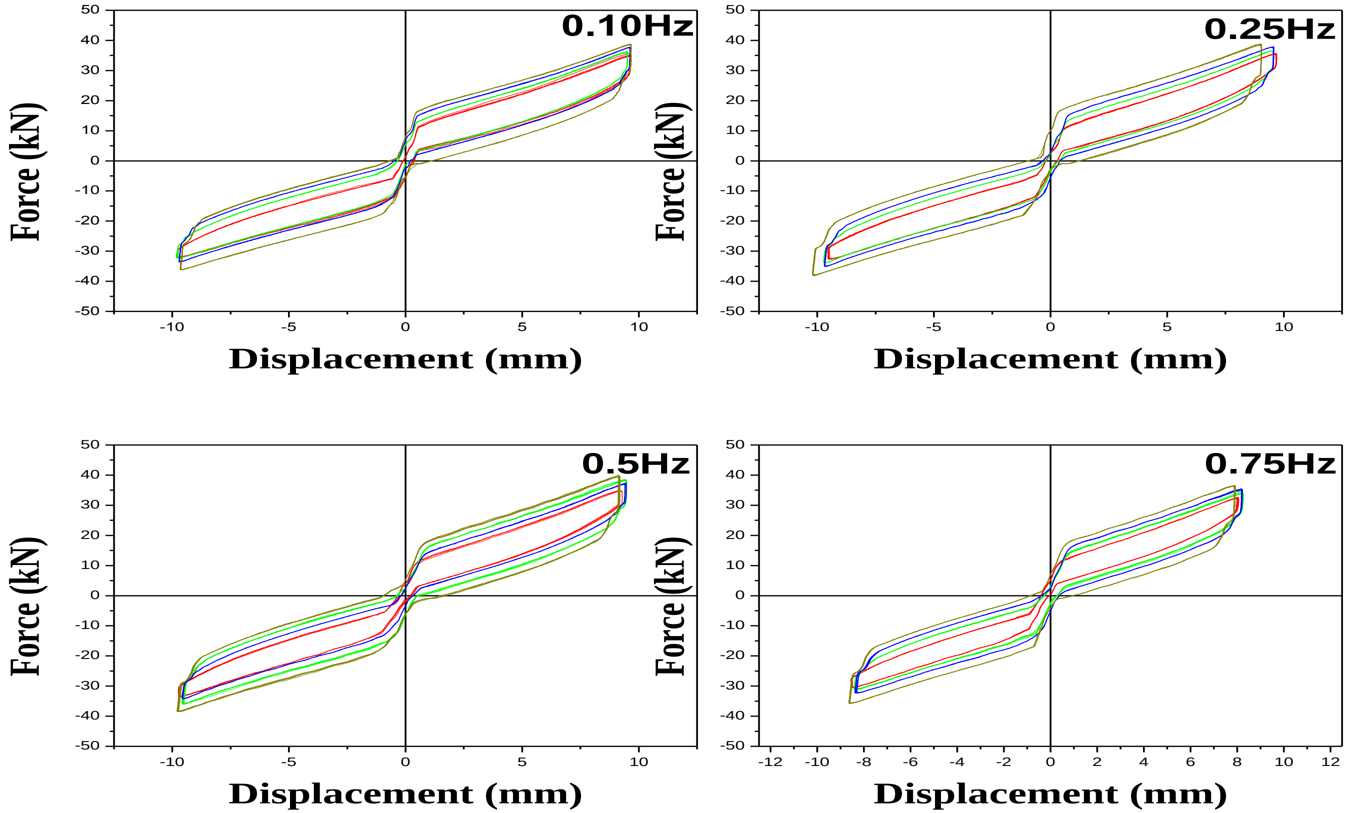
Smart damper dynamic test

- Symmetric behavior of the smart damper



<Comparison with symmetric behavior>

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Smart damper dynamic test

- Damping ratios of the hysteretic curves

Frequency (Hz)	No. of magnets			
	0	4	8	12
0.1	3.19	4.04	5.32	6.55
0.25	2.51	3.93	5.21	6.91
0.5	2.90	4.06	5.40	7.21
0.75	2.51	4.16	6.16	7.81
Average	**2.78**	**4.05**	**5.52**	**7.12**
1.0	3.28	4.96	6.85	8.76
1.5	3.63	6.16	9.02	11.62
2.0	3.53	6.32	10.24	13.41

< Damping ratio according to frequency and No. of magnets (%) >

$$\xi = \frac{E_d}{4\pi E_{so}}$$

- Damping ratios seemed not to increase with increasing loading frequency.
- Damping ratio increased almost linearly with an increasing number of magnets.

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Smart damper dynamic test

- Asymmetric behavior of the smart damper

  (the proposed smart damper can easily produce asymmetric behavior with the removal one rubber spring)

  - The damper will provide only friction in one direction and friction plus rubber spring force in the opposite direction.
  - Asymmetric damper would be useful for structures or systems that have resisting capacities that vary according to direction.
  - For a bridge, abutments generally have strong resisting capacity in passive action (pushing) but relatively small resistance in active action (pulling).

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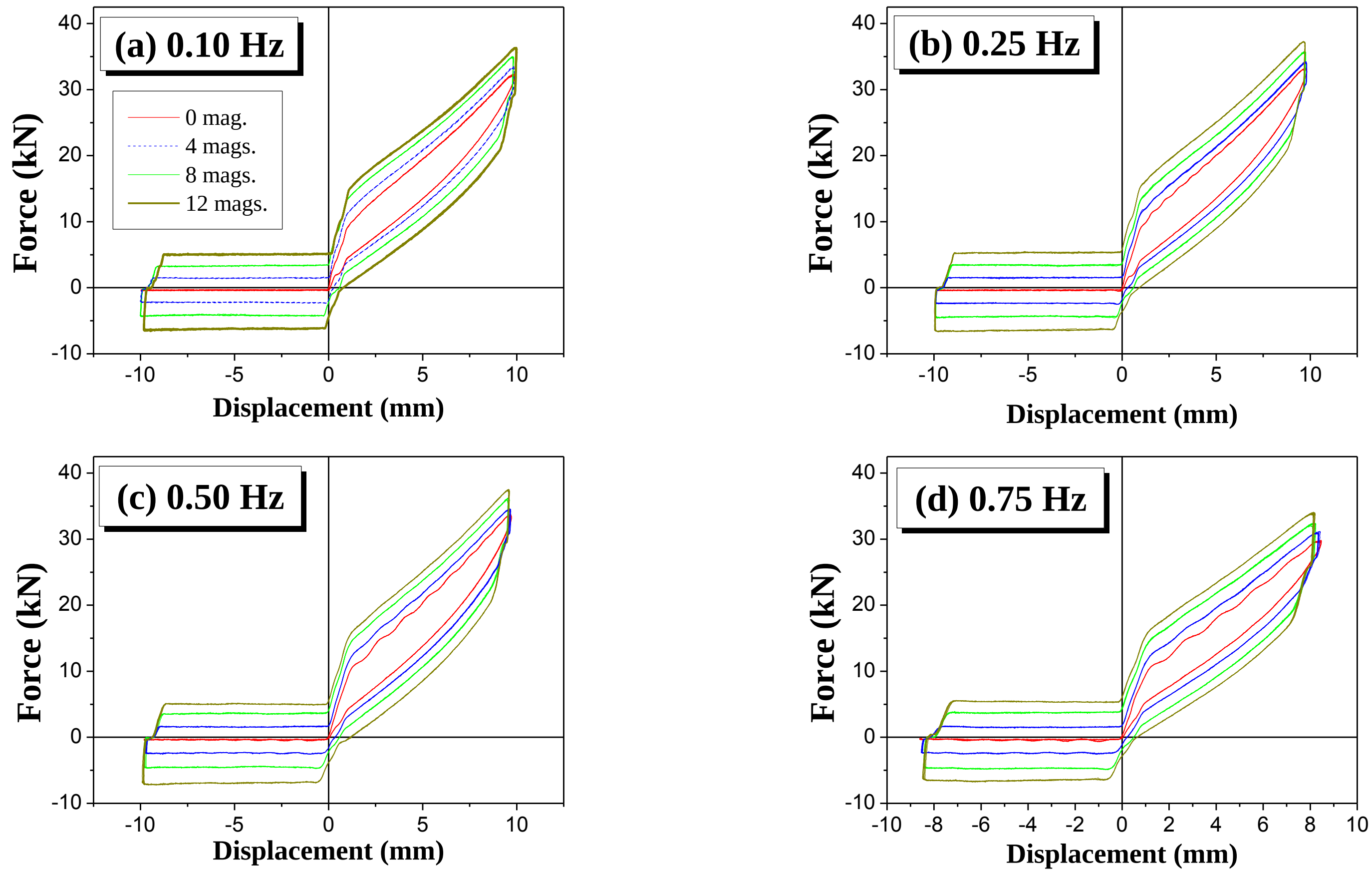
Smart damper dynamic test

- Asymmetric behavior of the smart damper



<Asymmetric behavior of the smart damper>

Conclusion

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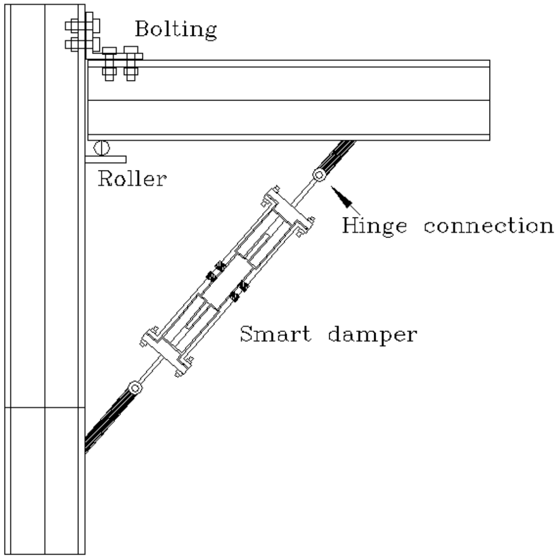
- This study proposed a new concept of a smart damper using pre-compressed rubber springs and magnetic friction. The performance of the magnets and pre-compressed rubber springs was verified through the dynamic.
- The damper with only rubber springs of 8% strain pre-compression excluding magnetic friction showed flag-shaped behavior; thus, the damper provided self-centering capacity and energy dissipation with a damping ratio of 2.7%.
- Additionally, the proposed damper can be used to support or control vibration of pipes in power plants and also it may be applied to structural parts such as beam-column-connections and bracing in moment frames because inexpensive materials is used, its mechanism is relatively simple, and prove that it provide self-centering and energy dissipation.



Thank you for your attention

Acknowledgement

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