Seismic Response Control for Parallel Building Structures Using MR Damper

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Background (1/2)

Buildings are getting higher.

Natural frequencies are getting lower.

Disturbance such as winds, earthquakes, etc

Structural vibrations become a serious problem.

Reduction of the vibrations is required.

Shinjyuku, Tokyo

Great Hanshin-Awaji Earthquake

Background (2/2)

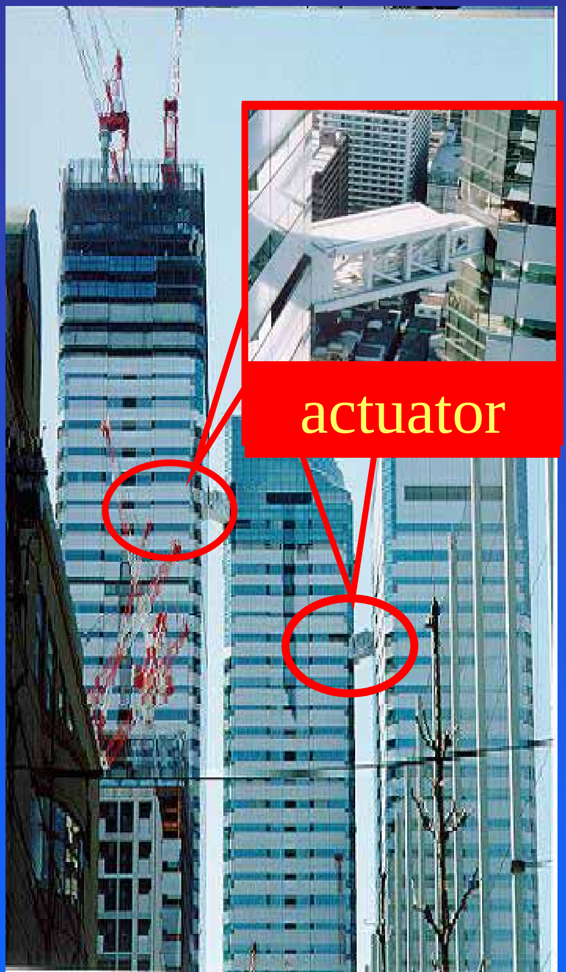
・Connected buildings control method is available for vibration control of multiple buildings, and obtain large control force at low frequency.

・Semi-active control systems have large control force with lower energy than energy required in active control system, and inherent stability.

・ Recently, a MR damper is introduced as a semi-active device.

・They can be controllable for large vibrations like earthquakes.

Connected Buildings Control (CBC) Method



Triton tower

A vibration control mechanism using the interaction of the multiple buildings by installing the control equipment between parallel buildings.

merit

- A large control force can be obtained at low frequency vibrations
- No need for additional mass like a TMD.
- Reduce a number of vibration control devices.
- Useful space inside the control equipment used as a passageway to connect buildings.

Purpose

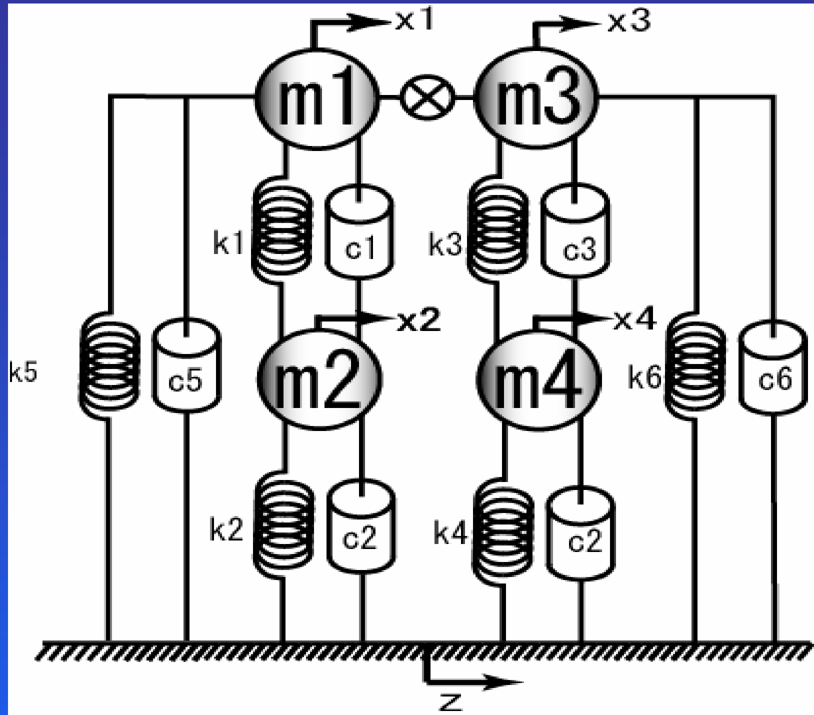
To propose a design method of a semi-active control system with a suitable MR damper

- To verify the effectiveness of semi-active vibration control for buildings connected with the MR damper by the simulation and experiment.

- To propose a design method of a feedback gain using a genetic algorithm for MR damper characterized by non-linearity.

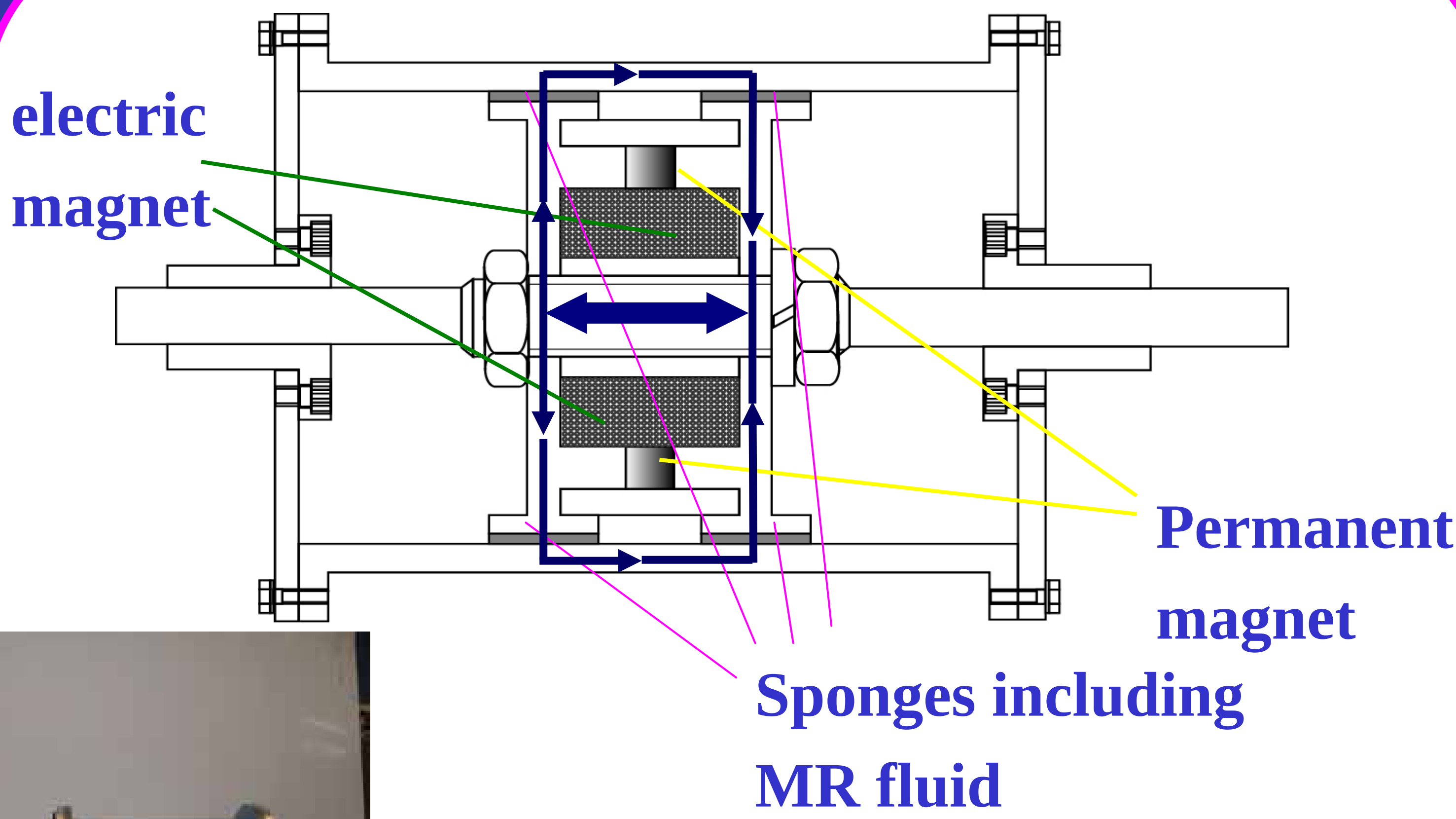
Controlled Objects and Model

Natutal freqency	1st mode	2nd mode
Structure1	5.55	16.69
structure2	7.96	23.9



Mass[kg]	Stiffnes[N/m]	Damping[Ns/m]
m1=35.58	$k1=1.89\times10^5$	c1=10
m2=43.61	$k2=2.81\times10^5$	c2=47
	$k11=-5.62\times10^4$	c11=4
m3=27.61	$K3=3.08\times10^5$	c3=6
m4=34.75	$k4=3.53\times10^5$	c4=60
	$k22=-6.91\times10^4$	c22=10

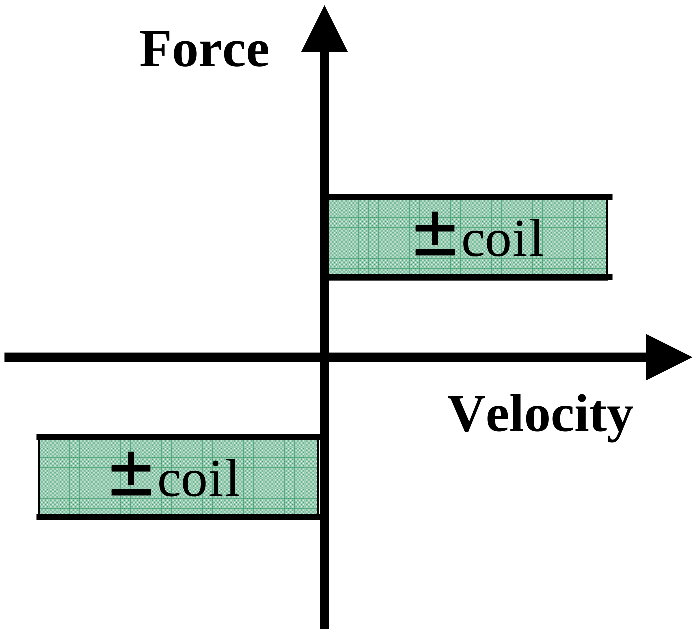
Sponge type Hybrid MR damper



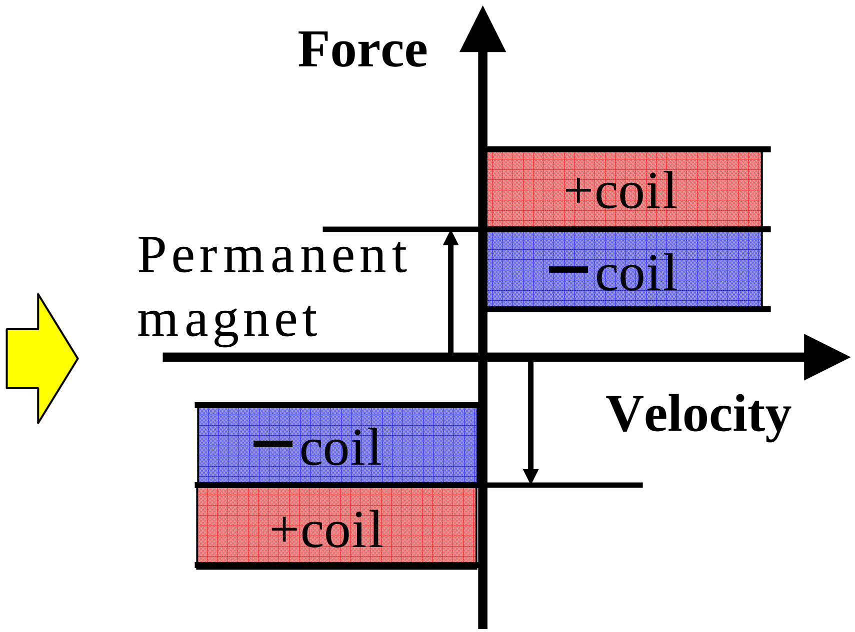
→ Magnetic pass

Range of Variable Damping Force

Compare the range of variable damping force

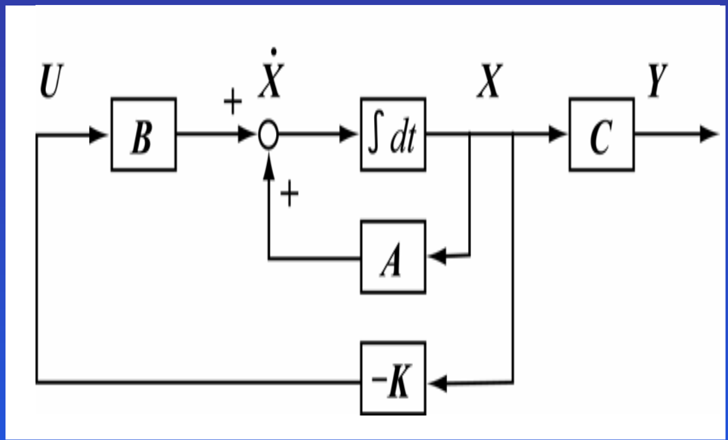


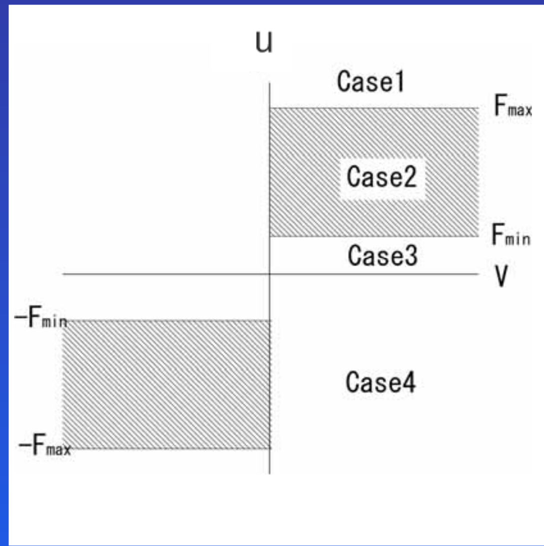
Only a electric magnet

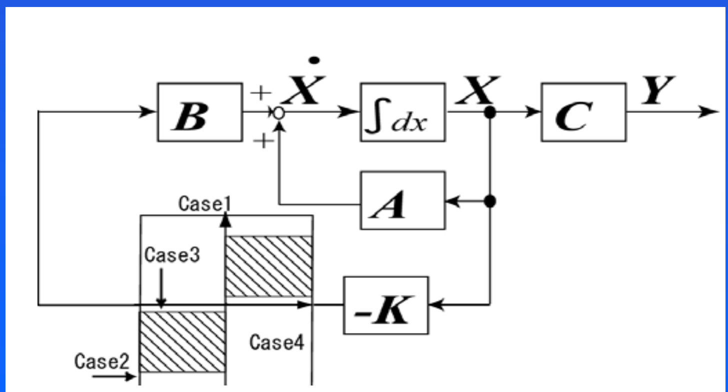


Combine electric and permanent magnets

Semi-active Control



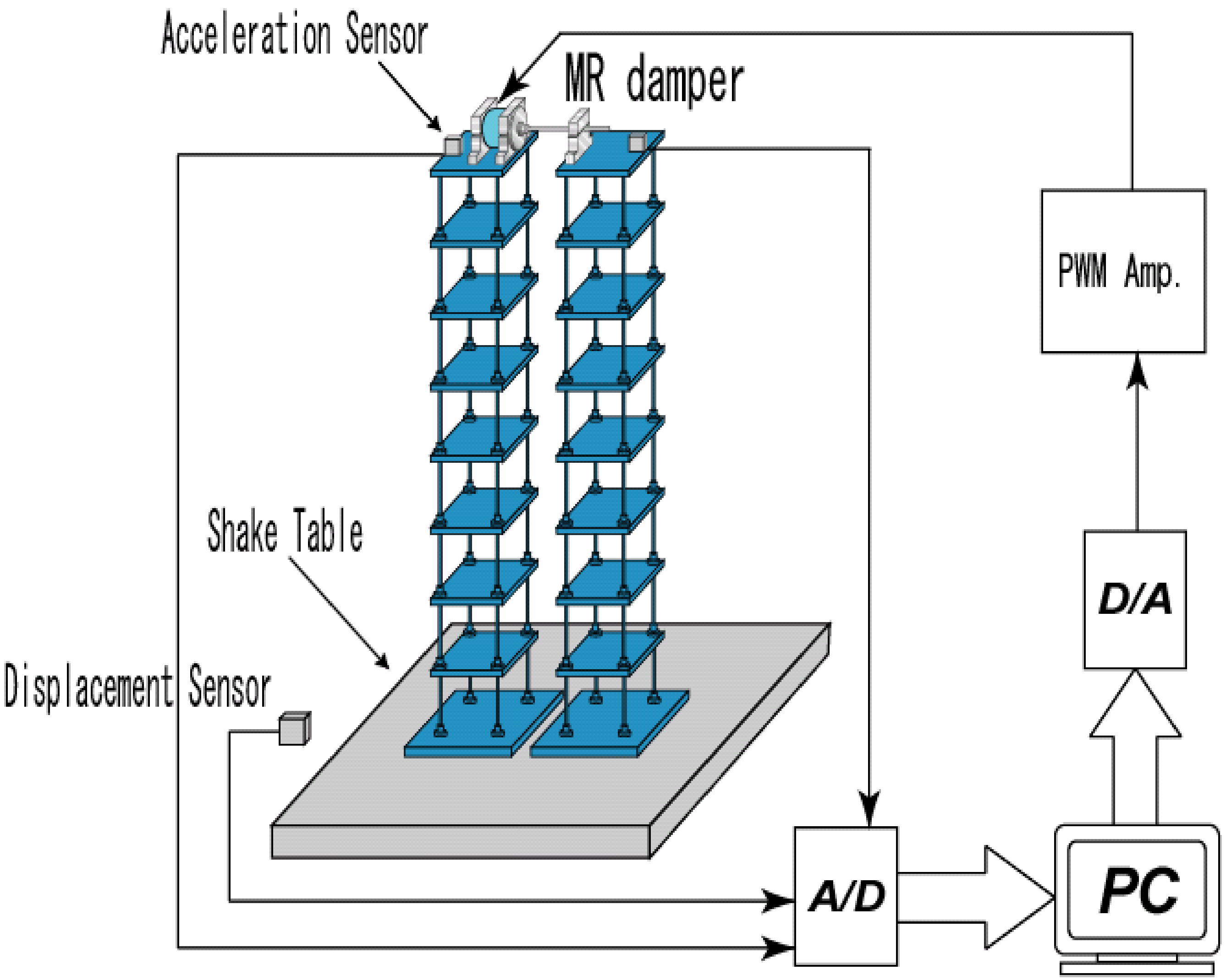




Dividing output for
semi-active control

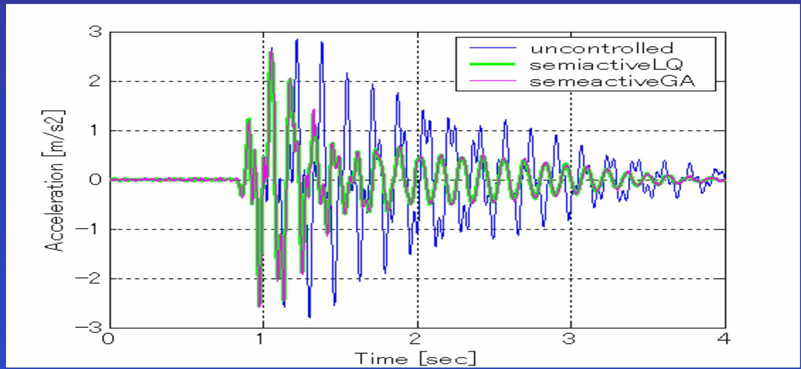
$$F_S = \begin{cases} F_{max} & (u \times v > 0\ ,\ |F_{max}| < u) & \cdots Case1 \\ u & (u \times v > 0\ ,\ |F_{min}| < u < |F_{max}| & \cdots Case2 \\ F_{min} & (u \times v > 0\ ,\ |F_{min}| > u) & \cdots Case3 \\ F_{min} & (u \times v \leq 0) & \cdots Case4 \end{cases}$$

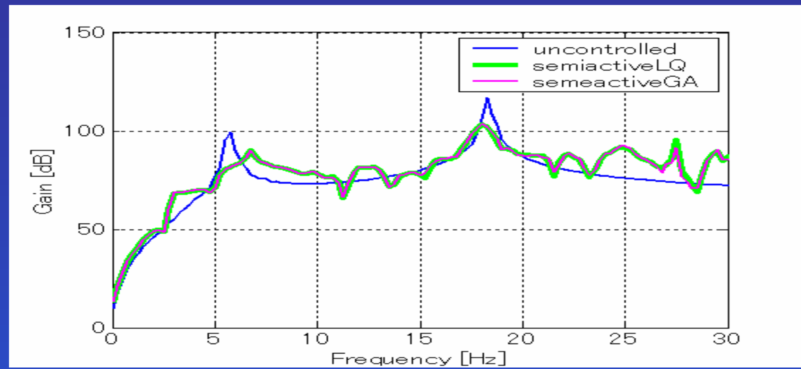
Experimental Setup



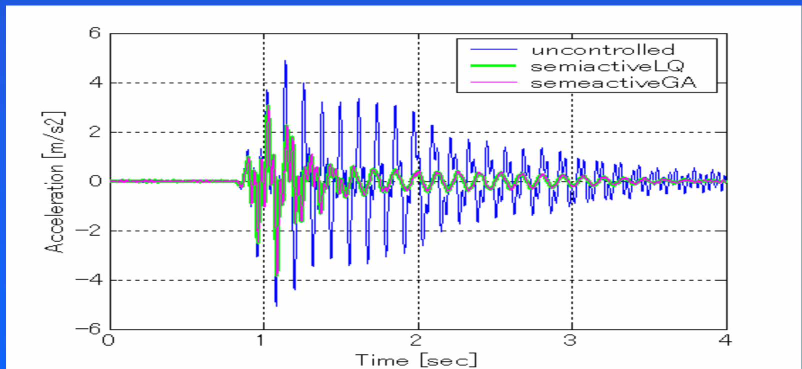
Simulation Results

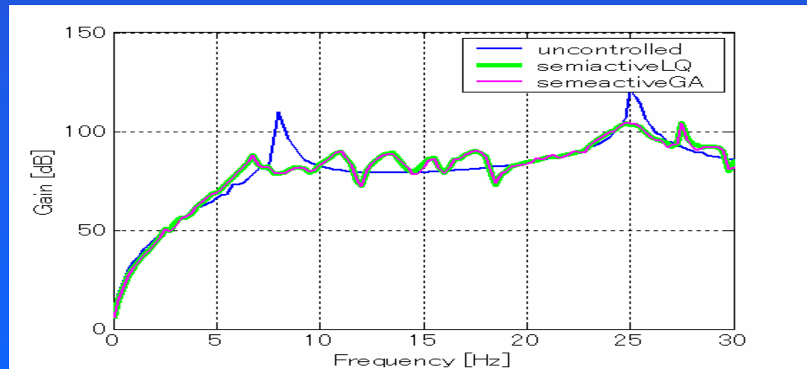
Top of structure 1





Top of structure 2



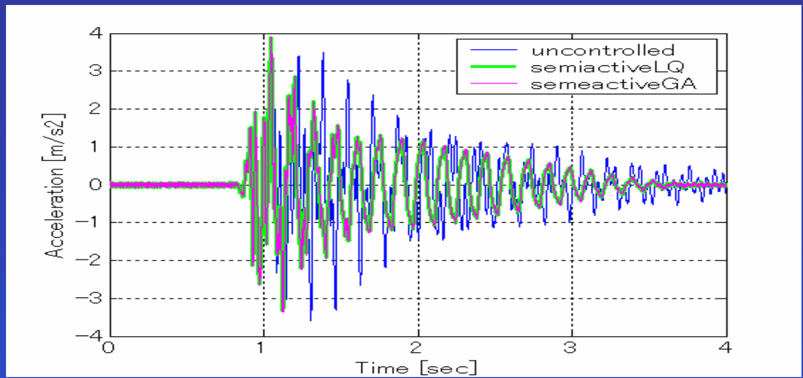


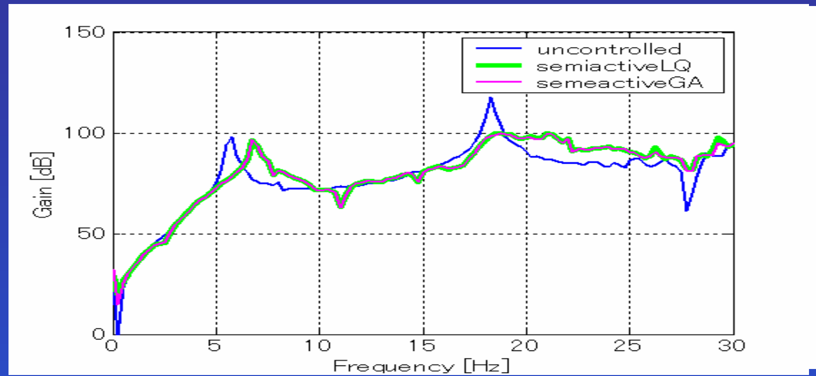
Acceleration time responses

Frequency responses

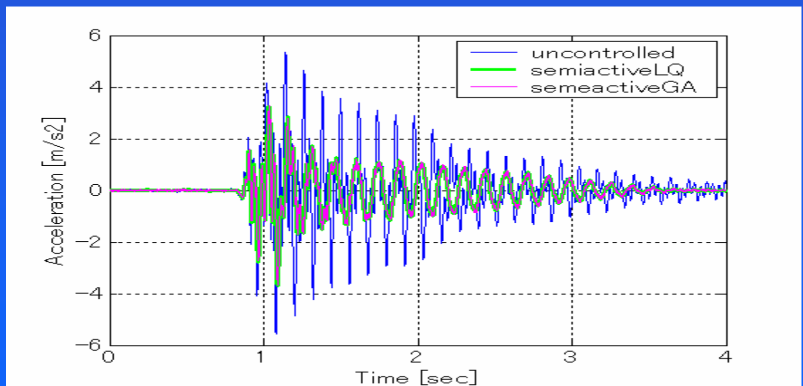
Experimental Results

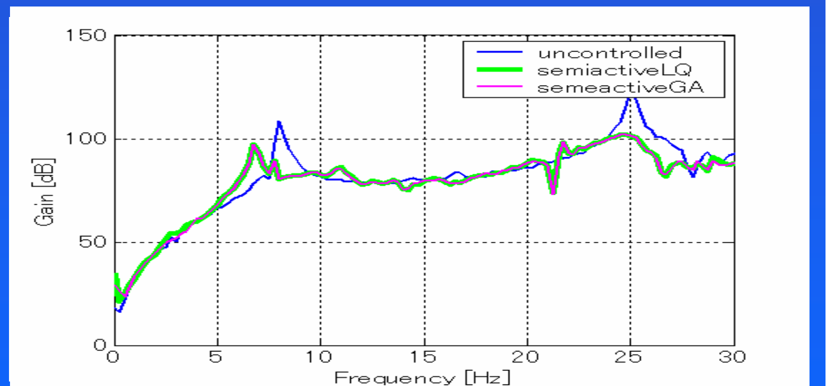
Top of structure 1





Top of structure 2

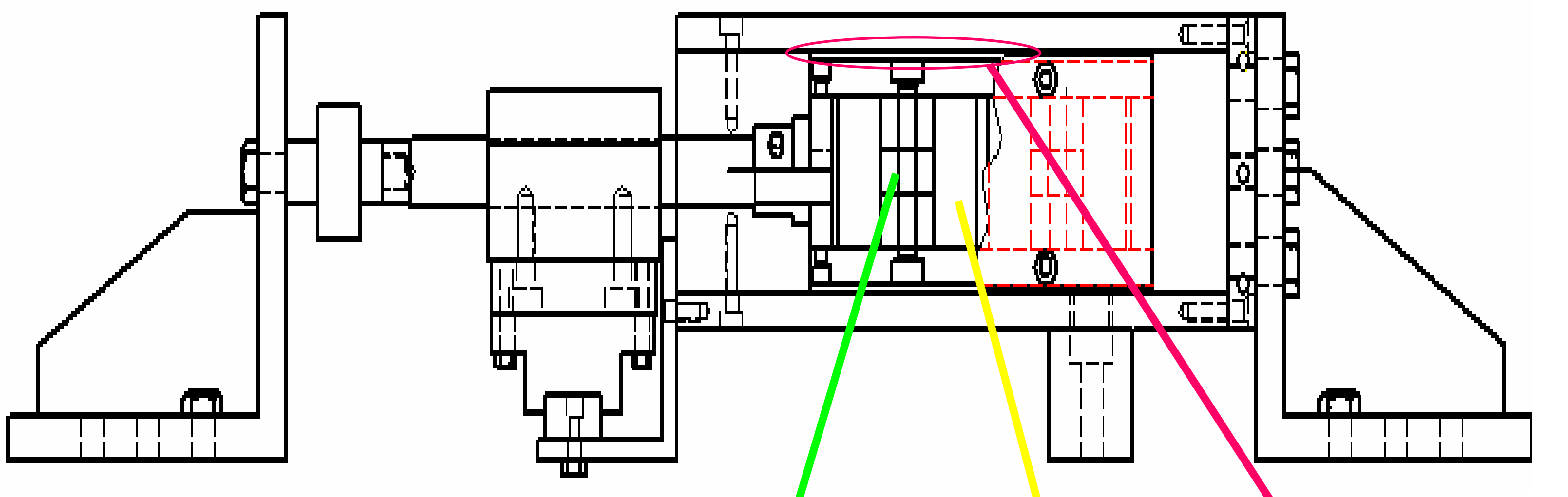


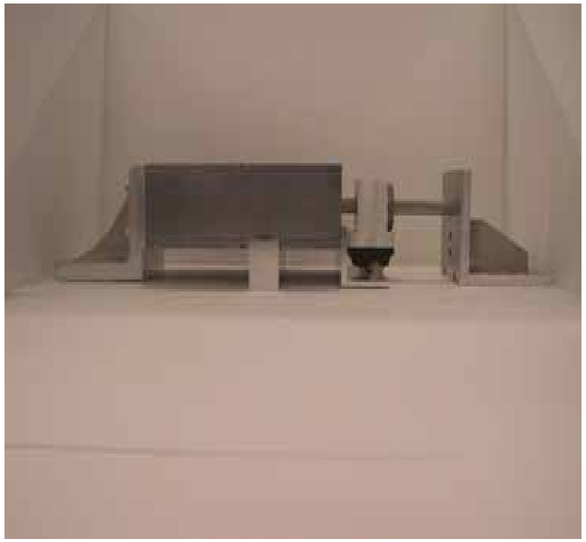


Acceleration time responses

Frequency responses

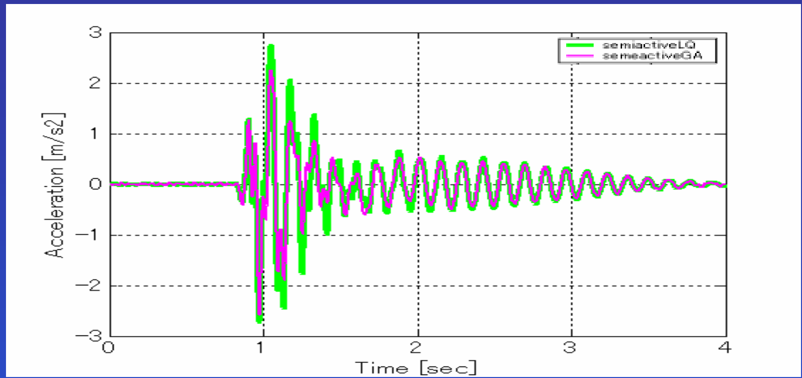
Upgrade MR damper

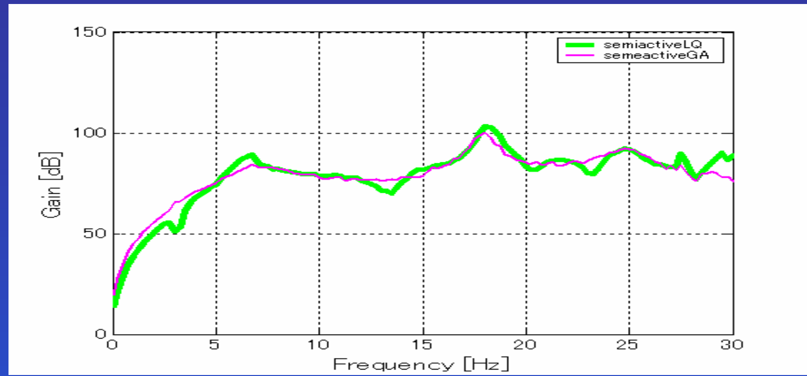




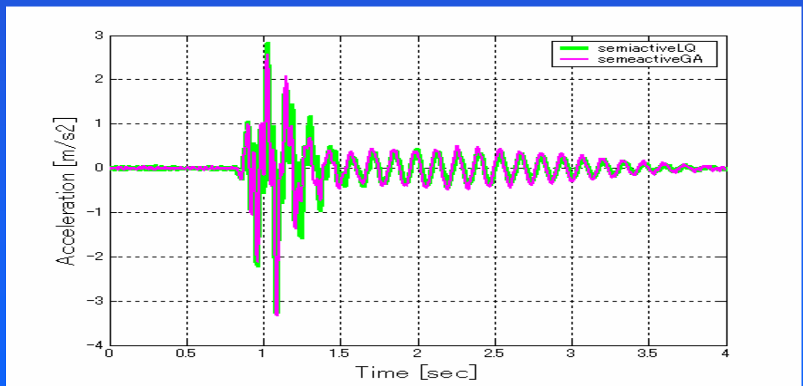
Simulation Results With Upgrade Damper

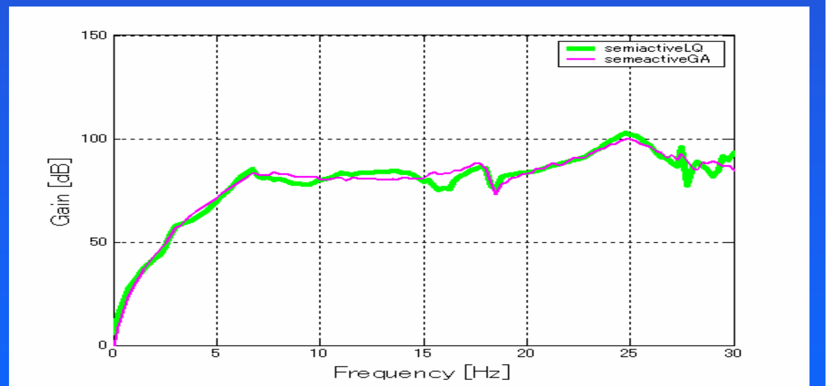
Top of structure 1





Top of structure 2





Acceleration time responses

Frequency responses

Conclusions

1. A new sponge type MR damper mechanism was presented, and its capability was confirmed through experiments.
2. **The method using GA was effective for the nonlinear semi-active system better than using LQ theory.**
3. The control algorithm for semi-active system suppressed two vibration modes by one actuator.


Thank you
for your attention

Damping Devices

Passive Systems

- Not adjusted from outside
- No energy is required

Active Control Systems

- Controllable
- Large energy is required

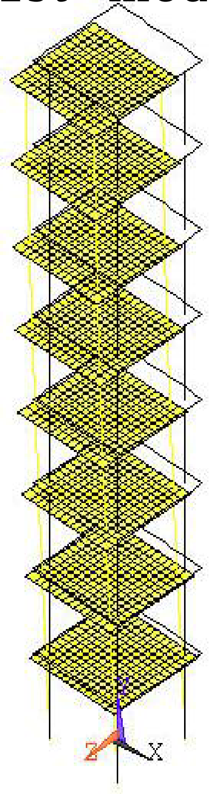
Semi-active Systems

- Controllable
- Little energy is required

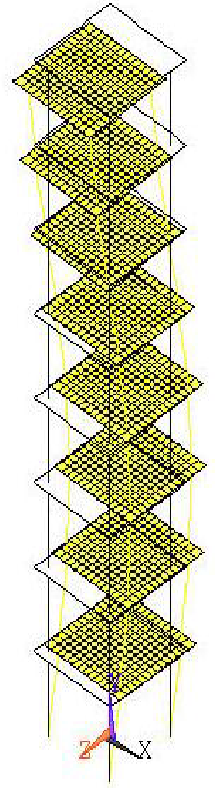
A sponge type hybrid MR damper is used

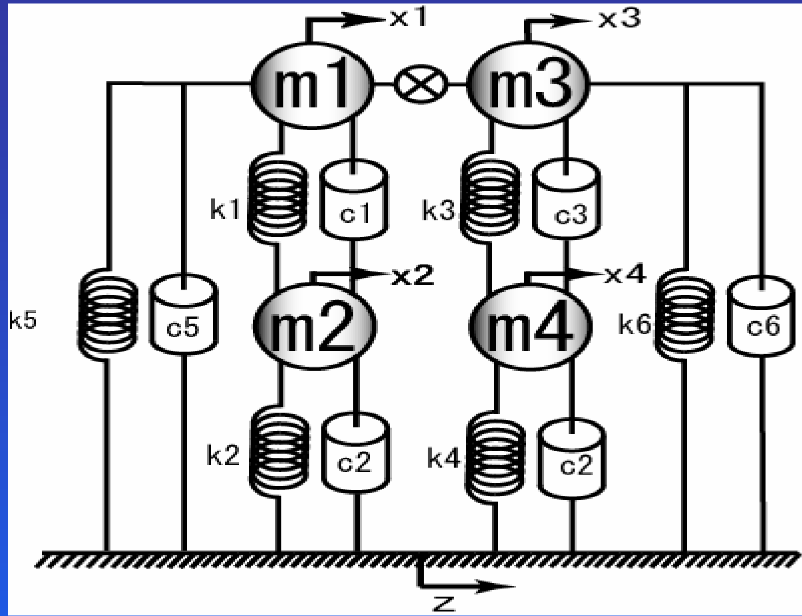
Vibration Mode Shapes and Controlled Model

1st mode



2nd mode





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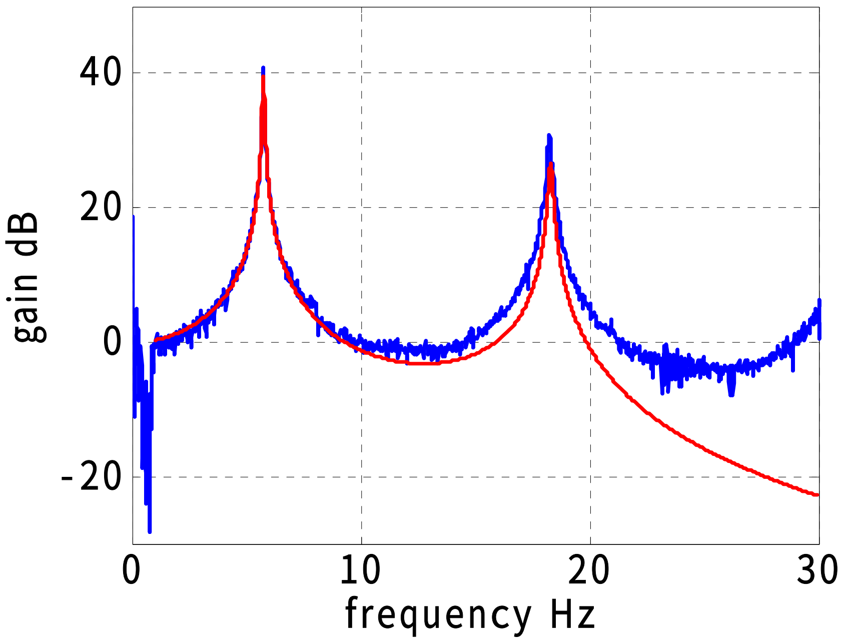
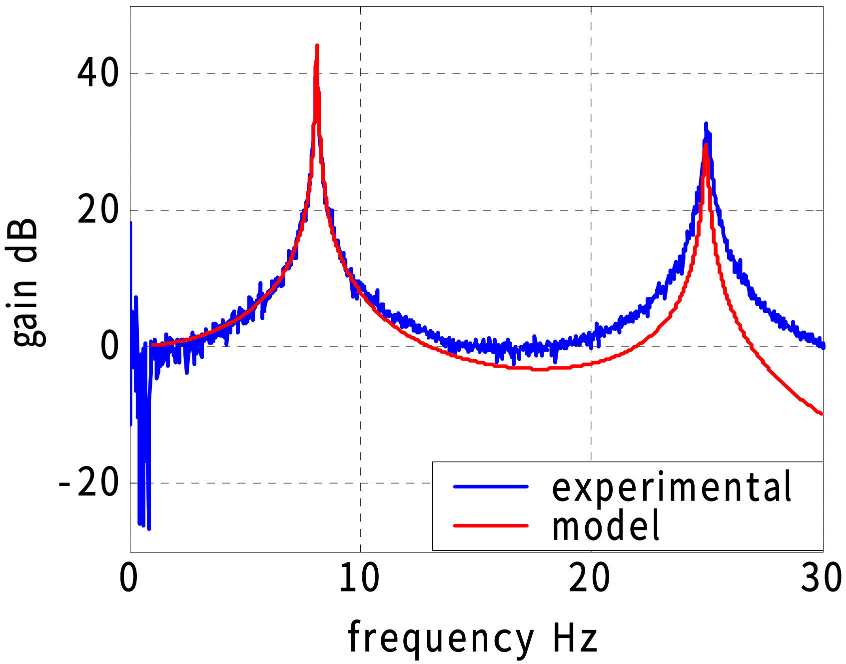
Verification of the Model



Top of Structure 1



Top of Structure 2

MR Fluid

MR fluid（Magneto-Rheological Fluid）

･･･：The fluid suspending magnetic particles in oil

In magnetic field, The magnetic particles form clusters.

These clusters become the flow resistance and increase the apparent viscosity of MR fluid.

This fluid can be controlled electrically using electric magnet.

by Lord co.

Genetic Algorithm (GA)

GA emulates Darwin's theory of evolution, and is the algorithm to search a broader region and to find an optimal solution.

- Semi-active control guarantees the stability,because its device is a kind of passive device.

→ The system is stable, even if the feedback control is used.

- The optimal solution may be in an instable area which is not able to be searched with LQ theory.

→ GA can search both stable and instable area.

- A semi-active system design method has not been established yet.

Feedback gain K is designed by GA.

State Equation

$$\dot{\boldsymbol{X}} = \boldsymbol{A}\boldsymbol{X} + \boldsymbol{B}\boldsymbol{U} + \boldsymbol{E}\boldsymbol{W}$$

$$\boldsymbol{X} = \begin{bmatrix} \dot{x}_1 & \dot{x}_2 & \dot{x}_3 & \dot{x}_4 & x_1 & x_2 & x_3 & x_4 \end{bmatrix}^T$$

$$\boldsymbol{E} = \begin{bmatrix} \frac{c_{11}}{m_1} & \frac{c_2}{m_2} & \frac{c_{22}}{m_3} & \frac{c_4}{m_4} & 0 & 0 & 0 & 0 \\ \frac{k_{11}}{m_1} & \frac{k_2}{m_2} & \frac{k_{22}}{m_3} & \frac{k_4}{m_4} & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

$$\boldsymbol{A} = \begin{bmatrix} -\frac{c_1+c_{11}}{m_1} & \frac{c_1}{m_1} & 0 & 0 & -\frac{k_1+k_{11}}{m_1} & \frac{k_1}{m_1} & 0 & 0 \\ \frac{c_1}{m_2} & -\frac{c_1+c_2}{m_2} & 0 & 0 & \frac{k_1}{m_2} & -\frac{k_1+k_2}{m_2} & 0 & 0 \\ 0 & 0 & -\frac{c_3+c_{22}}{m_3} & \frac{c_3}{m_3} & 0 & 0 & -\frac{k_3+k_{22}}{m_3} & \frac{k_3}{m_3} \\ 0 & 0 & \frac{c_3}{m_4} & -\frac{c_3+c_4}{m_4} & 0 & 0 & \frac{k_3}{m_4} & -\frac{k_3+k_4}{m_4} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\boldsymbol{B} = \begin{bmatrix} -\frac{1}{m_1} & 0 & \frac{1}{m_3} & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

$$\boldsymbol{W} = \begin{bmatrix} \dot{w} & w \end{bmatrix}^T$$