

***Vibration Control  
for Flexible Structures  
Arranged in Parallel  
Like Solar Panels***

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# Outline

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- 2 . Purpose**
- 3 . Control Object**
- 4 . Making of Control Model**
- 5 . Control System Design**
- 6 . Simulations**
- 7 . Experiments**
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# Background(1)

## Cause of Vibration

- Thermal stress
- Collisions of space-debris
- Human activity

## Problem of Vibration

- Reduced efficiency of Solar array panels
- Communication error
- Damage in Solar array panels

In the Space, there are less natural damping

# Vibration Control

# Background(2)

## Control Object

Space station → Rotor

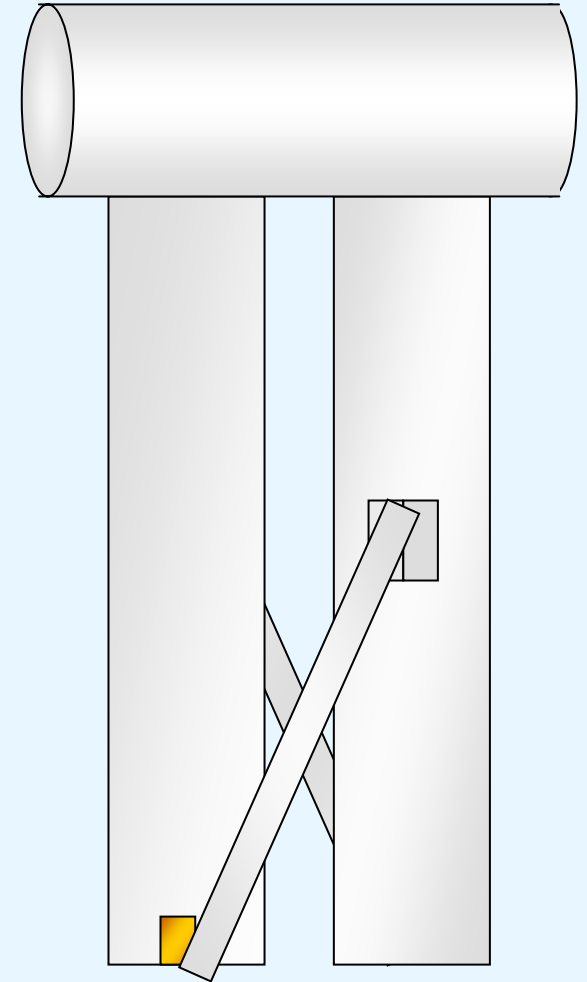
Solar array panels

→ Two flexible plates in parallel

## Control Method

Using interactive force

→ Cross arm actuators

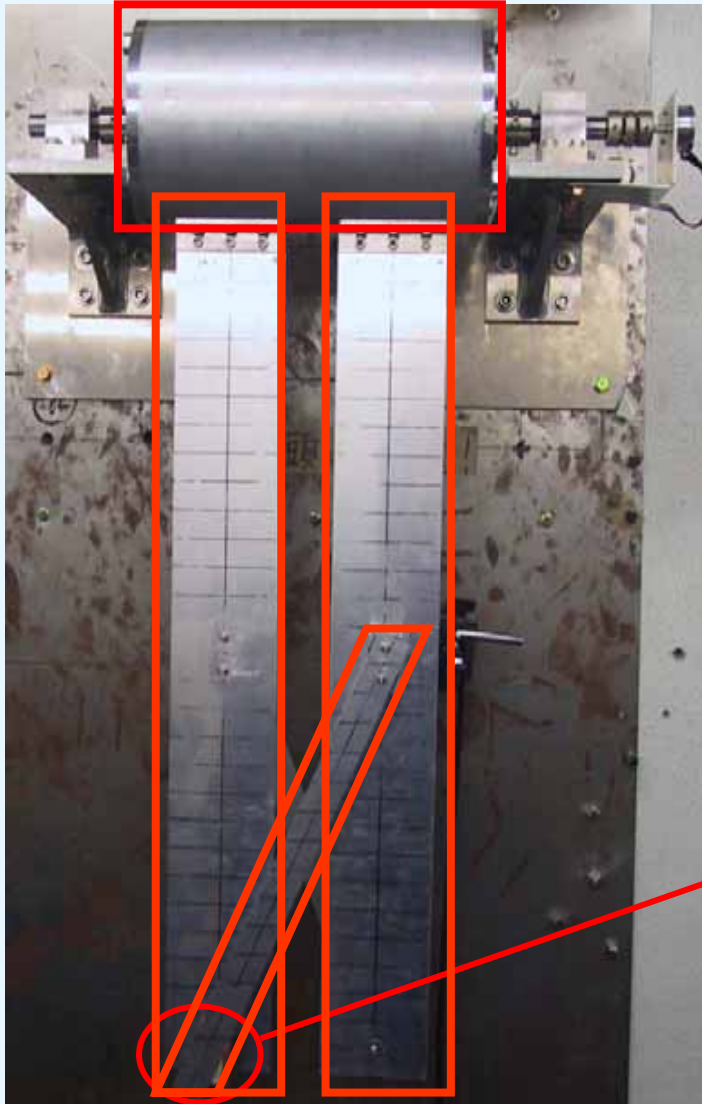


# Purpose

Proposal of the modeling method for flexible structures with the rotor

Verification of effects on the control method using interactive force

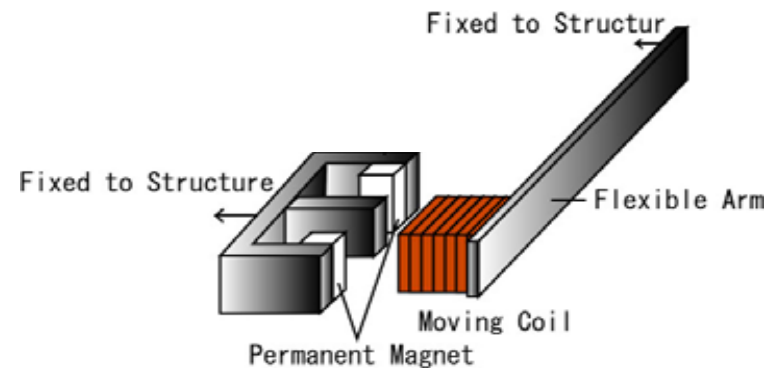
# Control Object



Rotor :  $180 \times 300$   $t=20$ [mm]

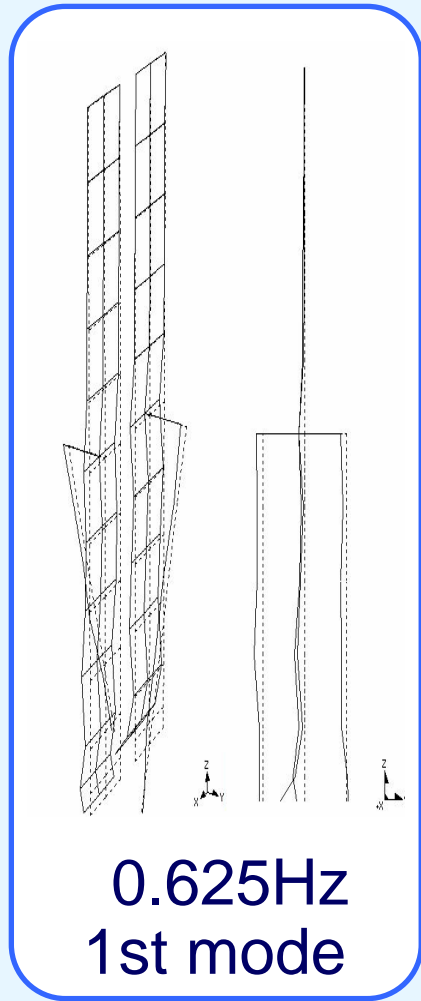
Flexible plates :  $750 \times 100 \times 2$ [mm]

Cross arm actuator :  $350 \times 30 \times 2$ [mm]

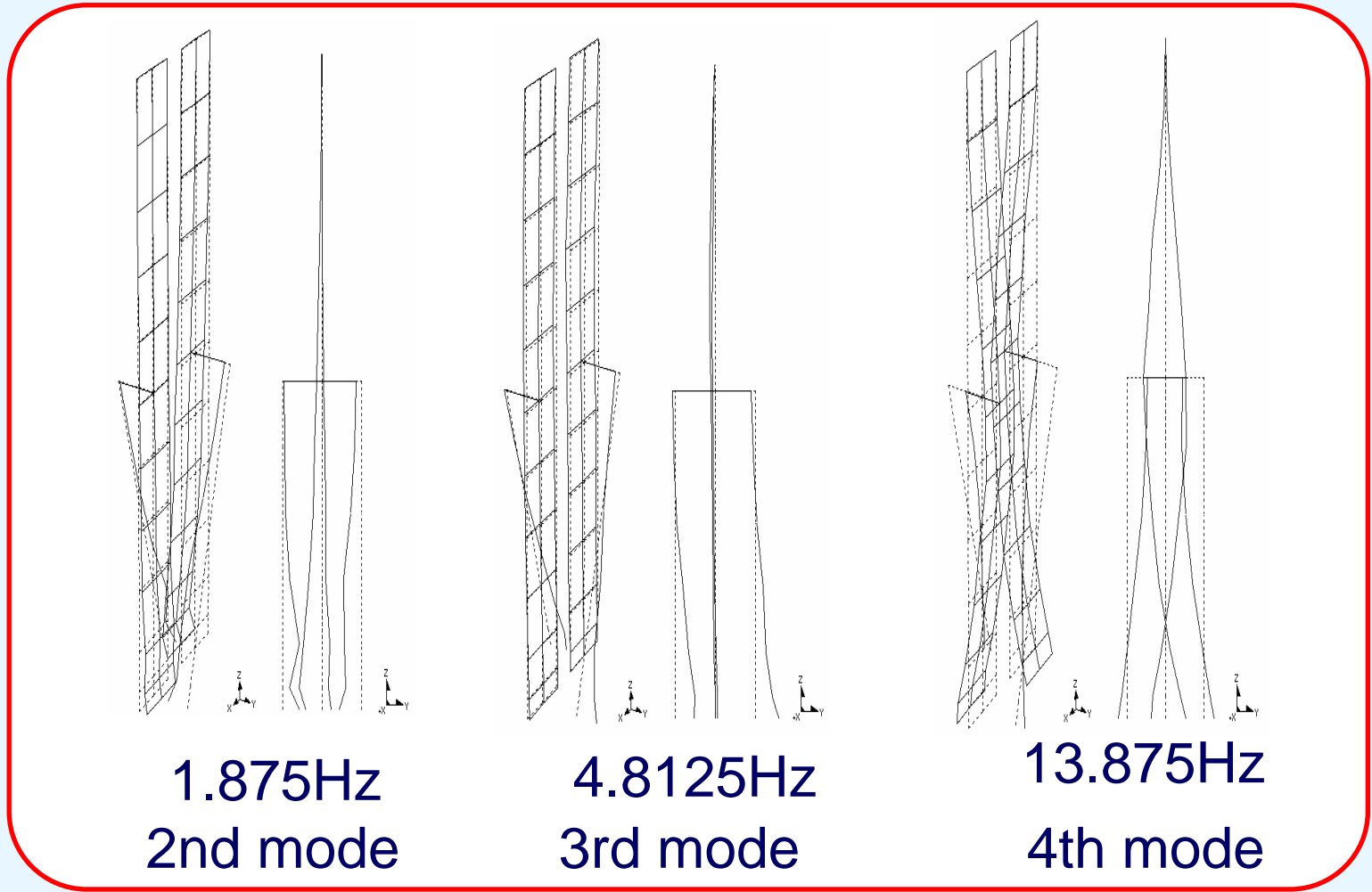


Electromagnetic  
actuator(0.165N/V)

# Experimental Modal Analysis

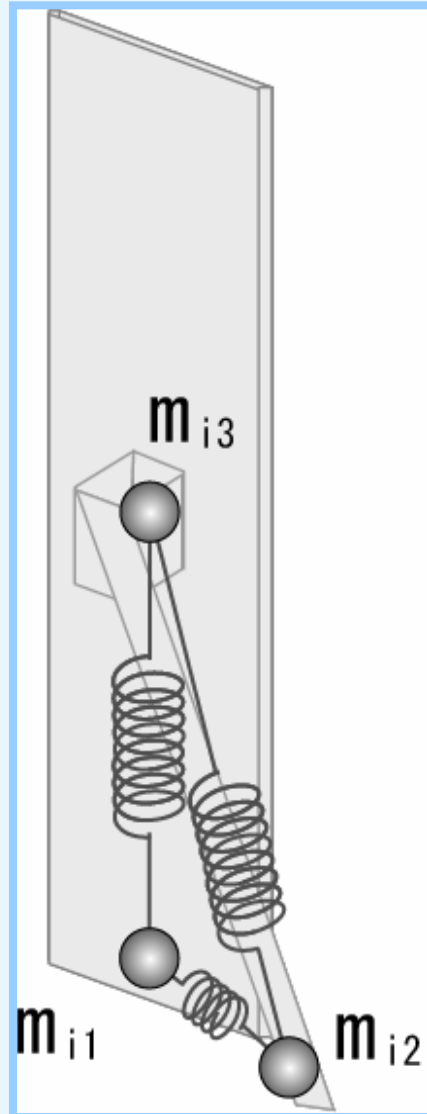


Rigid body mode



Flexible body mode

# Modeling points



# Making Control Model

## Control Model

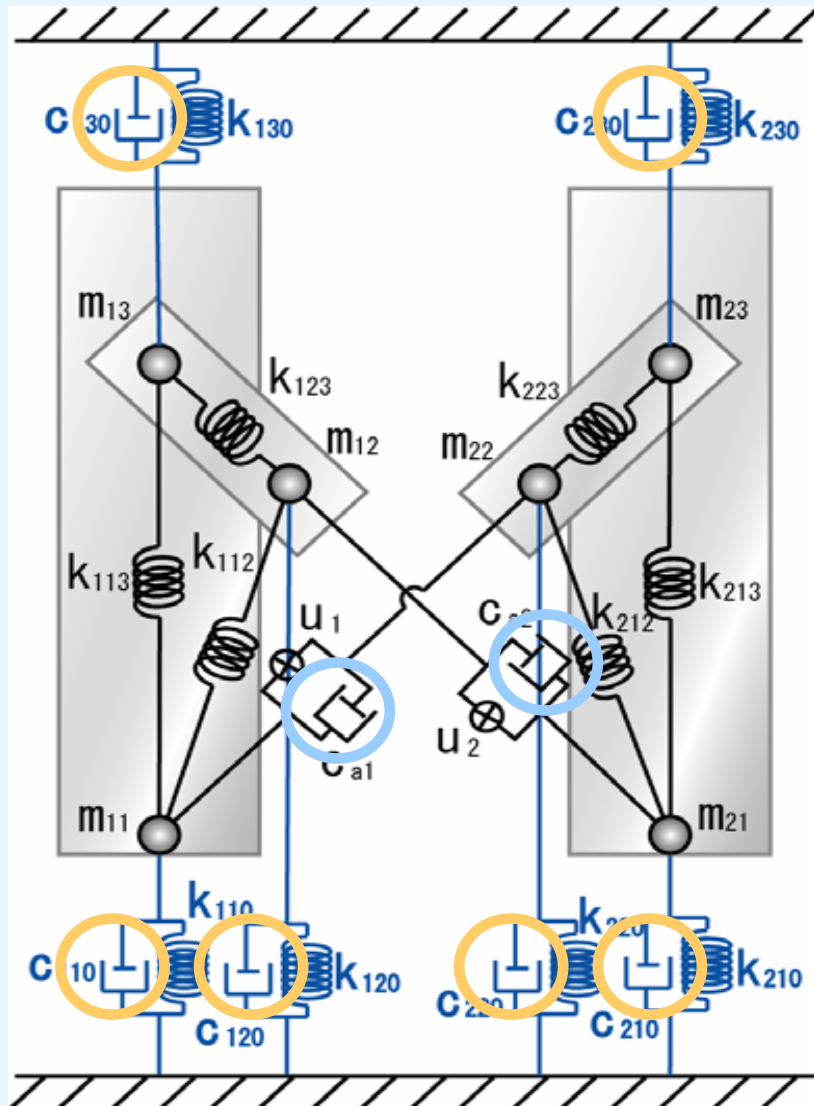
**Rigid body model**

**Rotational motion**

**Flexible body model**

**Vibration**

# Flexible Body Model



## Physical Parameters

$$m_{i1}=0.1764[\text{kg}] \quad m_{i2}=0.0648[\text{kg}] \quad m_{i3}=0.308[\text{kg}]$$

$$K_{i12}=9.855[\text{N/m}] \quad K_{i13}=5.365 \times 10^2[\text{N/m}]$$

$$K_{i23}=1.223 \times 10^2[\text{N/m}] \quad K_{i10}=-3.067 \times 10^2[\text{N/m}]$$

$$K_{i20}=-9.056 \times 10[\text{N/m}] \quad K_{i30}=1.393 \times 10^3[\text{N/m}]$$

$$C_{i10}=0.0053[\text{Ns/m}] \quad C_{i20}=0.0023[\text{Ns/m}]$$

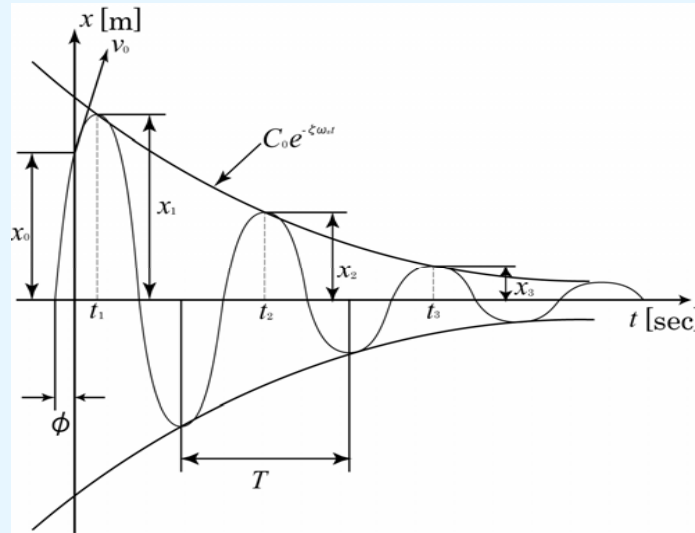
$$C_{i30}=0.0216[\text{Ns/m}] \quad C_{ai}=0.198[\text{Ns/m}]$$

i:Structure Number(1,2)

Internal damping of structures

Magnetic damping of actuators

# Rigid Body Model

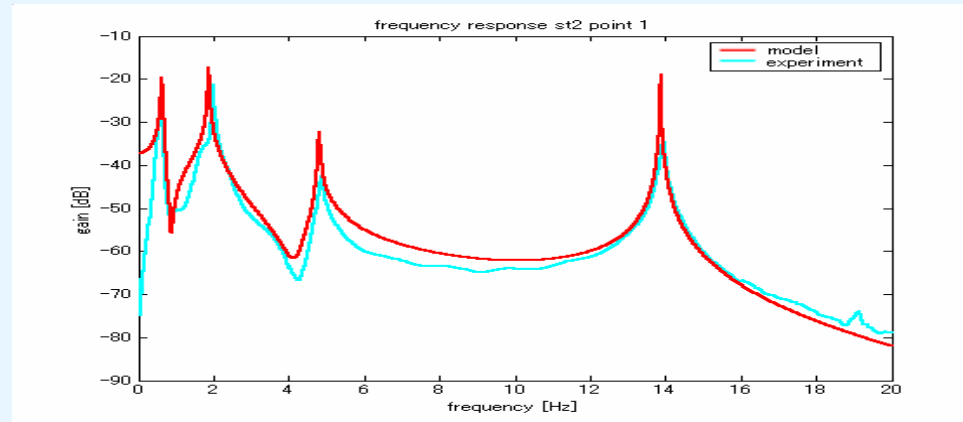


Time response of the rotor

$$J\ddot{\theta} + Ct\dot{\theta} + Kt\theta = M$$

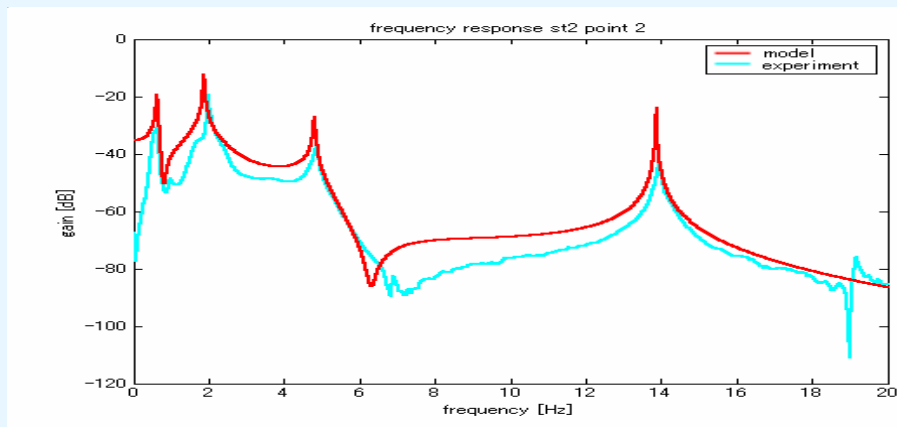
[	Moment of inertia :	$J = 3.4875 \text{ [kgm}^2\text{]}$
	Torsion spring coefficient :	$K_t = 53.778 \text{ [Nm / rad]}$
	Torsion attenuation coefficient :	$C_t = 0.1090 \text{ [Nms / rad]}$

# Verification of Control Model

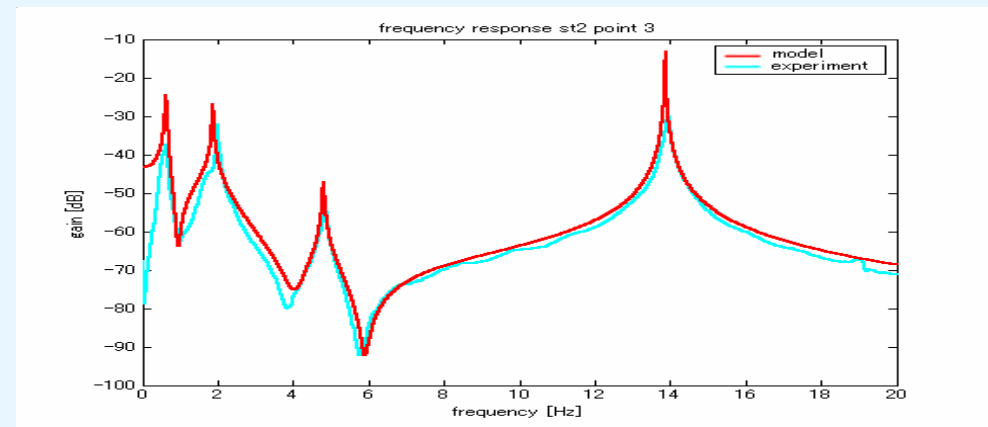


— Model  
— Experiment

Excited at mass point 21



Excited at mass point 22

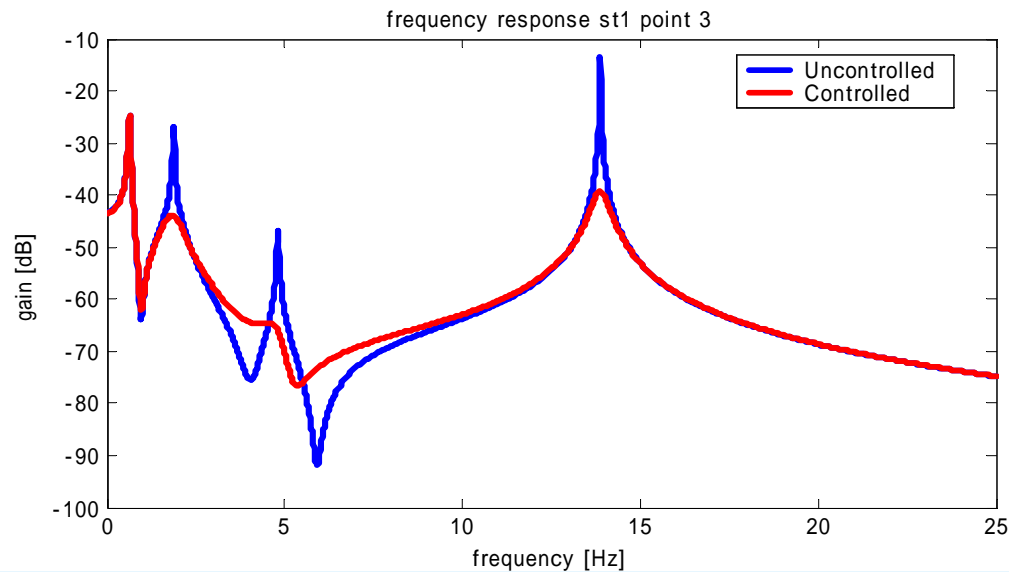


Excited at mass point 23

## Frequency Response

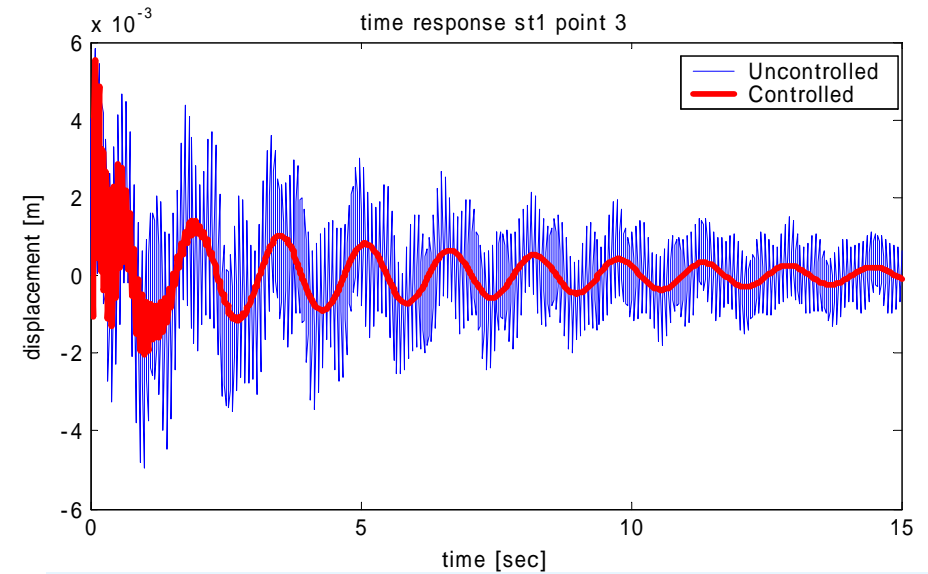
Excited at each mass point, Observed at mass point 23

# Simulation Results



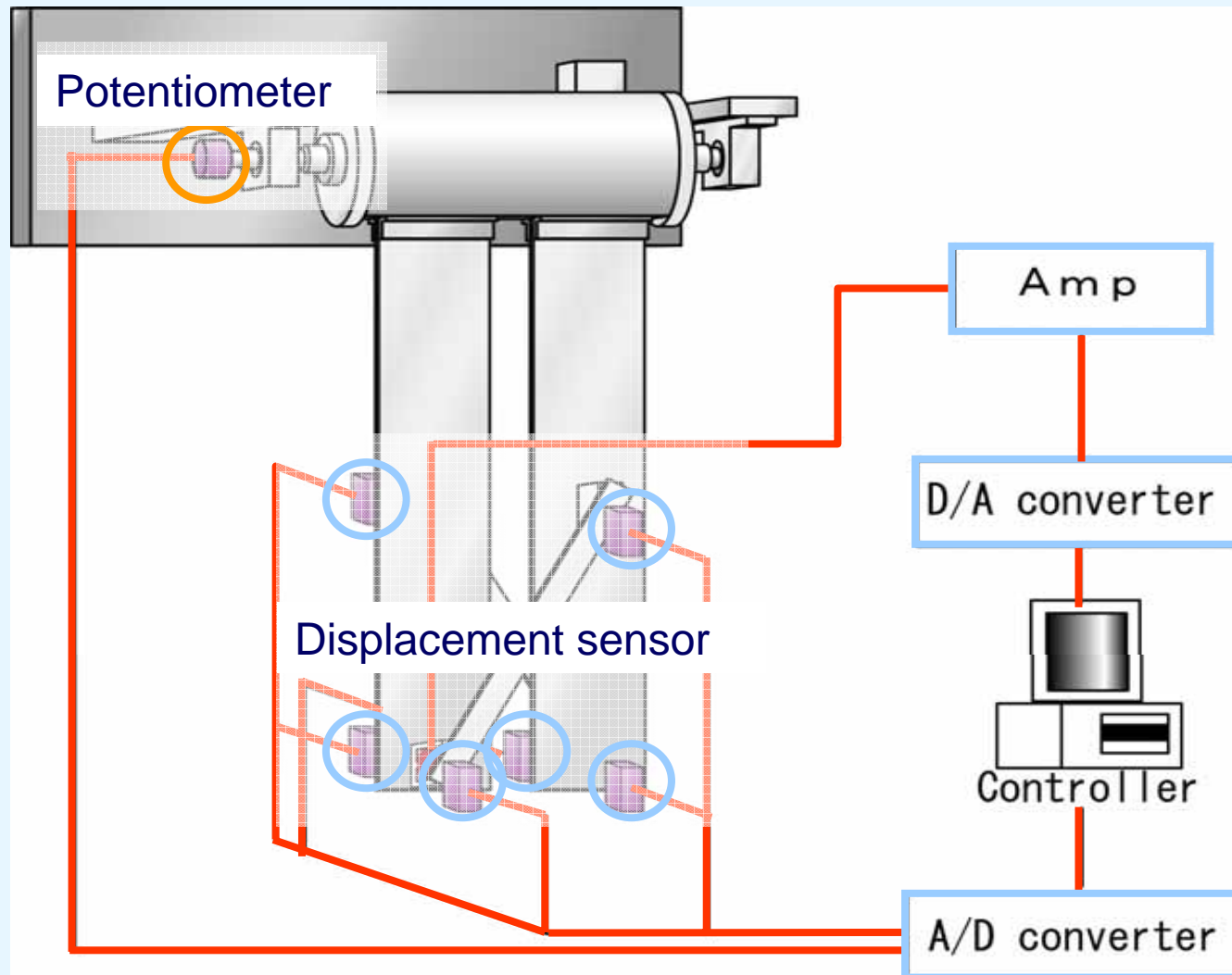
## Frequency response

Excited at mass point 13  
Observed at mass point 13

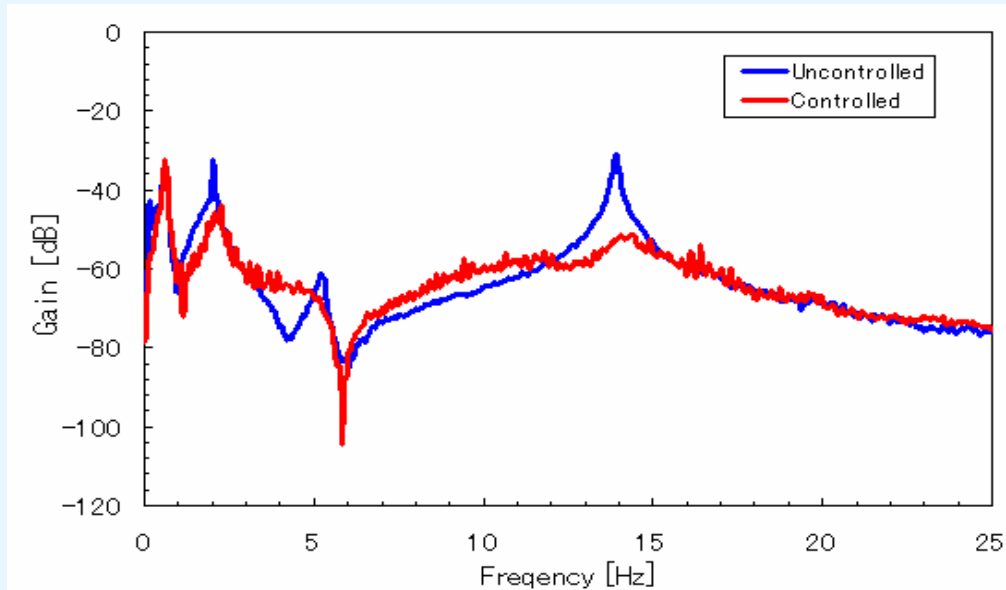


## Time response

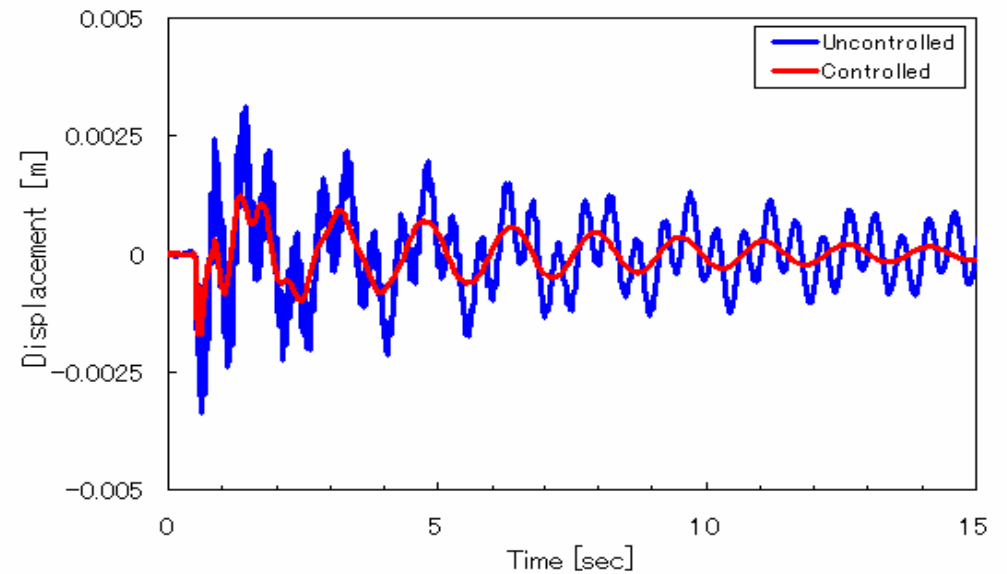
# Experimental Equipment



# Experimental Results



Frequency response



Time response

Excited at mass point 13  
Observed at mass point 13

# Conclusions

Proposed modeling method was able to make the effective control model

Effectiveness of the control method using the interactive force was verified

Usefulness of cross arm actuators to control parallel structures was confirmed

*Thank you !*

If you have questions, Please ask slowly.

Nihon Univ. Seto&Watanabe Lab.

# Reduced Order Physical Model ( 1 )

Measure mode shapes of the control object



make the temporary modal matrix



correct this modal matrix  $\Phi$



Mass matrix  $M$ , Stiffness matrix  $K$

$$M = (\Phi \Phi^T)^{-1}$$
$$K = (\Phi^T)^{-1} \Omega^2 \Phi^{-1}$$

# Reduced Order Physical Model ( 2 )

adjust the Damping factors  $c$  and make Damping matrix  $C$



$M, K, C$



**the Reduced Order Physical Model**

- Visually easy to be realize
- Conserve the mode shape