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# *Control of the Magnetic Suspension and Balance System for Dynamic Wind-Tunnel Testing*

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## *Introduction*

### *Background*

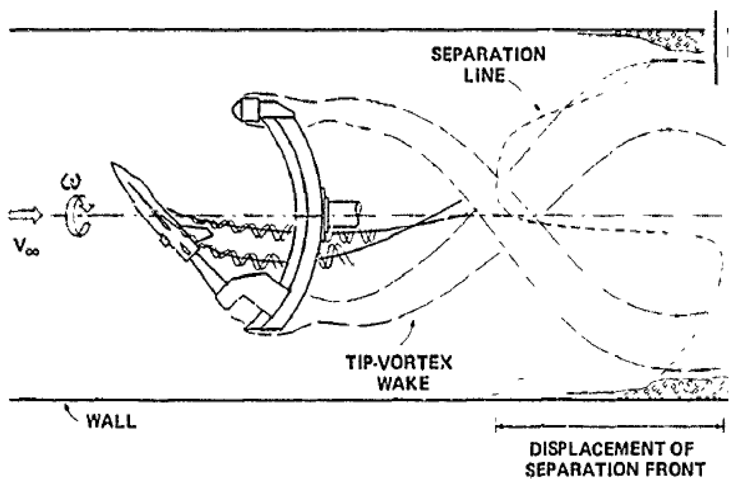
**Dynamic Wind-Tunnel Testing (DWT)**

- In order to understand nonlinear aerodynamic behavior of aircraft, it is necessary to clarify unsteady phenomena.
- In general, aircraft model is oscillated or rotated by using robotic manipulator.

DWT using a robot manipulator
(DLR, MPM)

**Support interference effects**

- The interference of support and airflow makes measurement accuracy lower.
  - ✓ Asymmetry of rolling moment (M. E. Beyers/ L. E. Ericsson, 1993)
  - ✓ Effect on the vortex breakdown (G. S. Taylor/I. Gursul, 2005)
  - ✓ Promotion of boundary-layer separation (L. E. Ericsson, 1990)

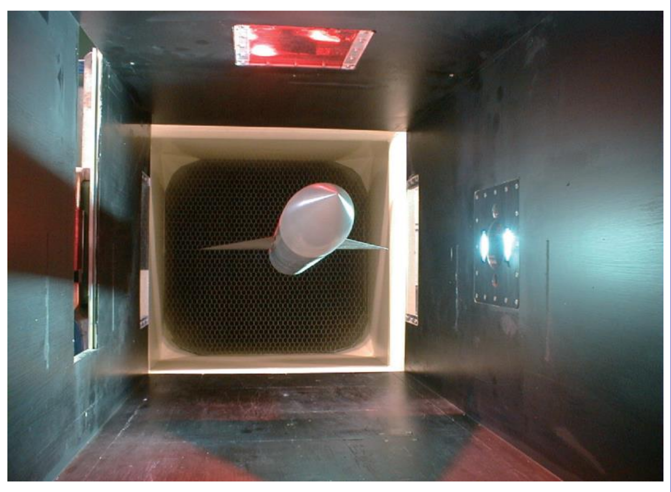



M. E. Beyers (1992)

**Magnetic Suspension and Balance System (MSBS)**

■ **Characteristics**

- Levitated by magnetic force
- Wind tunnel test without support interference
- Multi-axis control
- Measuring aerodynamic forces



AGARD-B model
(JAXA)

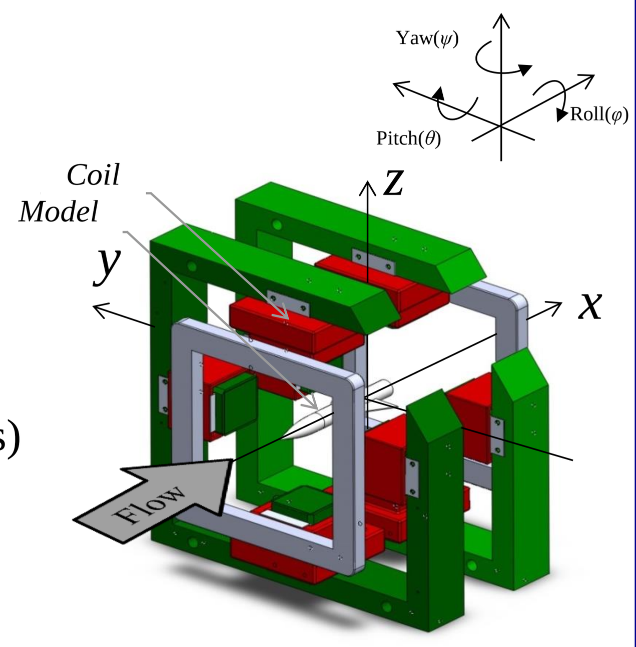
### *Objective*

**To develop control system of MSBS for dynamic wind-tunnel testing.**

## *0.3m MSBS*

**Hardware Configurations**

| | |
|---|---|
| **Model** | (Neodymium magnet is inserted) |
| **Coils** | (Forming magnetic field) |
| **Sensor system** | (Detecting model position) |
| **Control system** | (Control of model position) |
| **Power Supply** | (The current flows through the coils) |



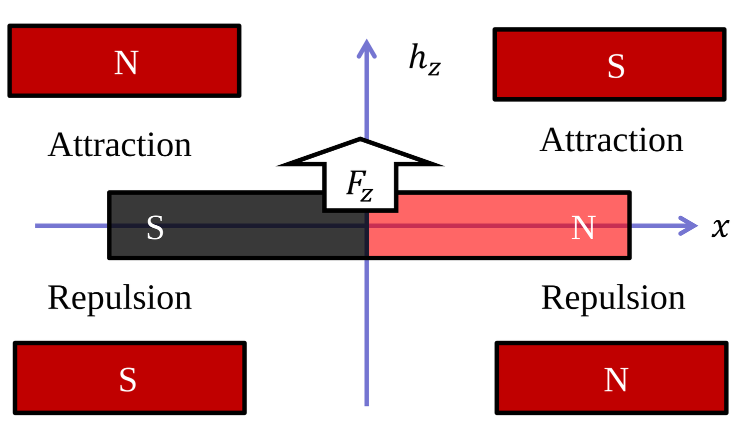

0.3m-MSBS coil system

**The magnetic suspending system**

- Magnetic forces

$$\begin{cases} F = \int_V (M \cdot \nabla) H dv & \text{(Translational force)} \\ N = \int_V M \times H dv & \text{(Torque)} \end{cases}$$

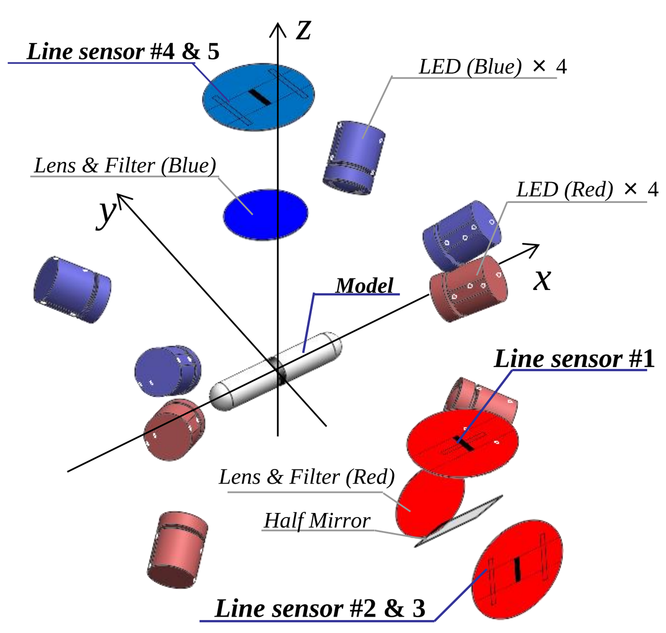
$M$ : Magnetic moment (Wb・m)
$H$ : Magnetic field intensity (AT/m)




- ✓ To balance Magnetic forces with Gravitational force
- ✓ To control Magnetic forces by current value

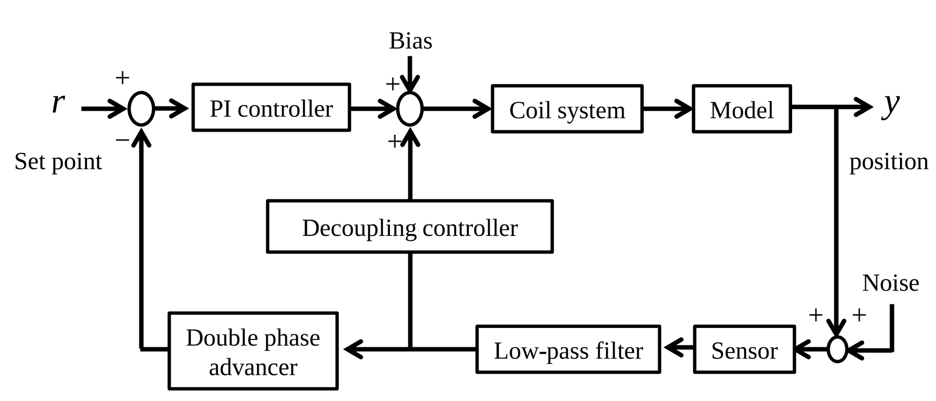
**The position sensing system**

- The sensor system using CCD line sensor cameras
  - ✓ Detecting model edge and marker
  - ✓ The position is measured from two directions
  - ✓ The model is illuminated by red and blue LEDs with different wavelengthsn




**The position control system**

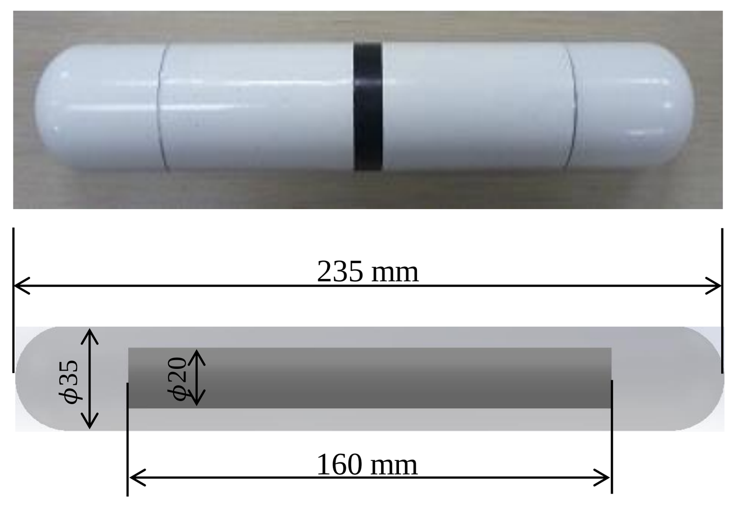
- Model position control by PI control
  - ✓ Phase-lag compensation by Double phase advancer
  - ✓ Stabilizing by adjustment of proportional gain and amount of phase advance




## *Experiments*

**Test model**

- Shape : Cylinder
- Model size : $\phi$35 mm × 235 mm
- Magnet : Neodymium magnet
- Magnet size : $\phi$20 mm × 160 mm
- Mass : 578.5 g

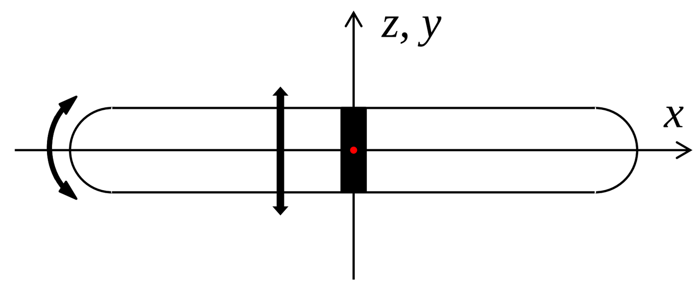



Test model

**Test conditions**

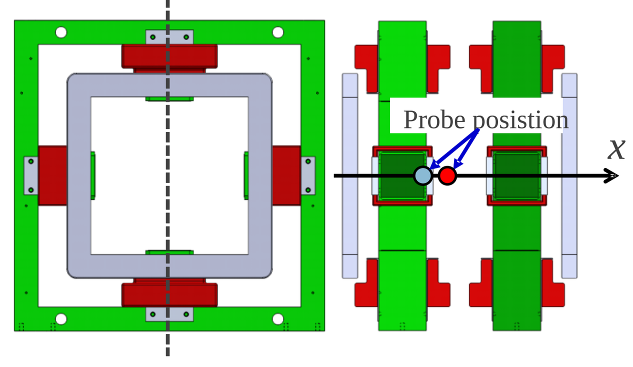
- 1 DoF motion test

| Axis | Amplitude (mm or deg) | Frequency (Hz) |
|---|---|---|
| $y, z, \theta, \psi$ | 1 | 0.6, 0.8, 1.0, 2.0 …, 9, 10 |
| | 2 | |



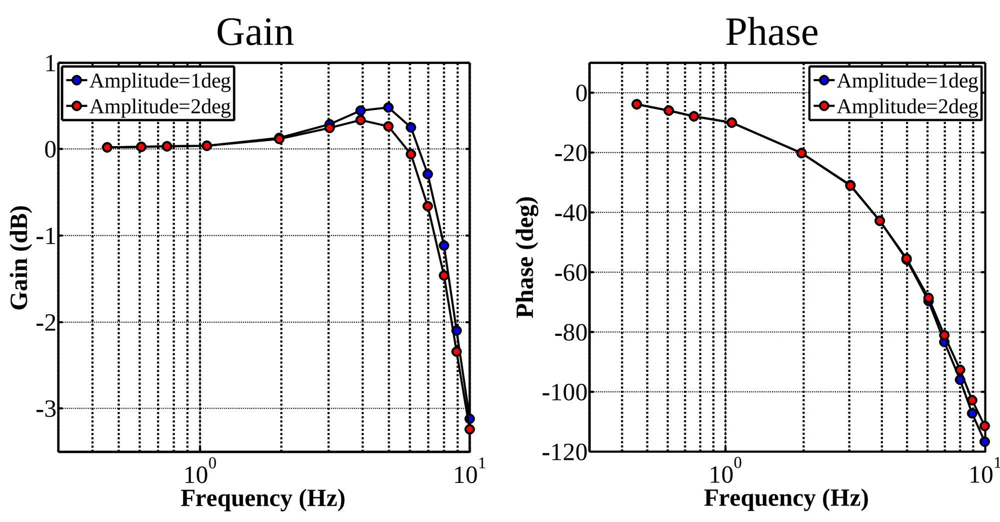

- Unsteady magnetic field measurement

| Axis | Position of probe (mm) | Amplitude (A) | Frequency (Hz) |
|---|---|---|---|
| $y, z, \theta, \psi$ | -40, -80 | 6 | 0.8, …, 20 |



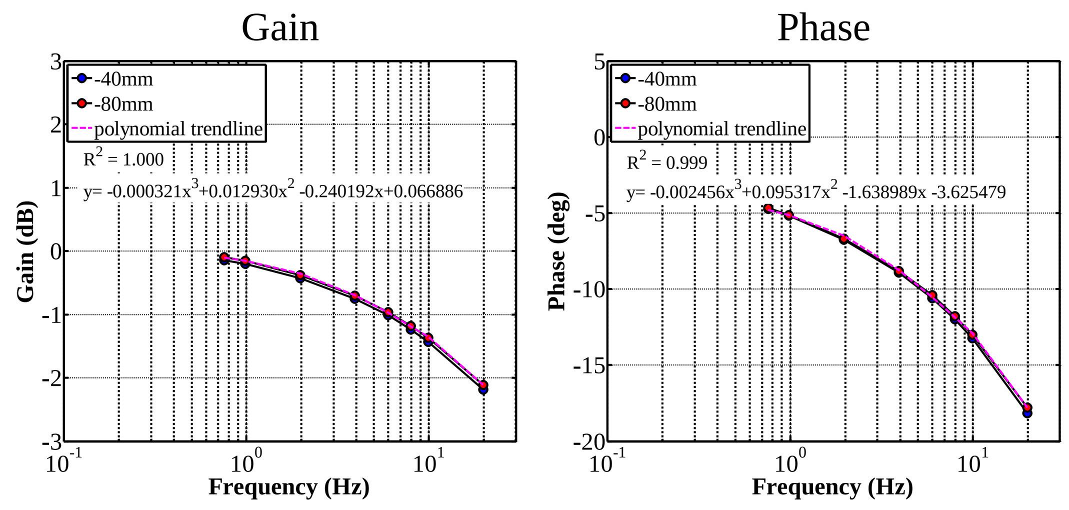

## *Results and discussion*

**Model motion test (Pitching direction)**



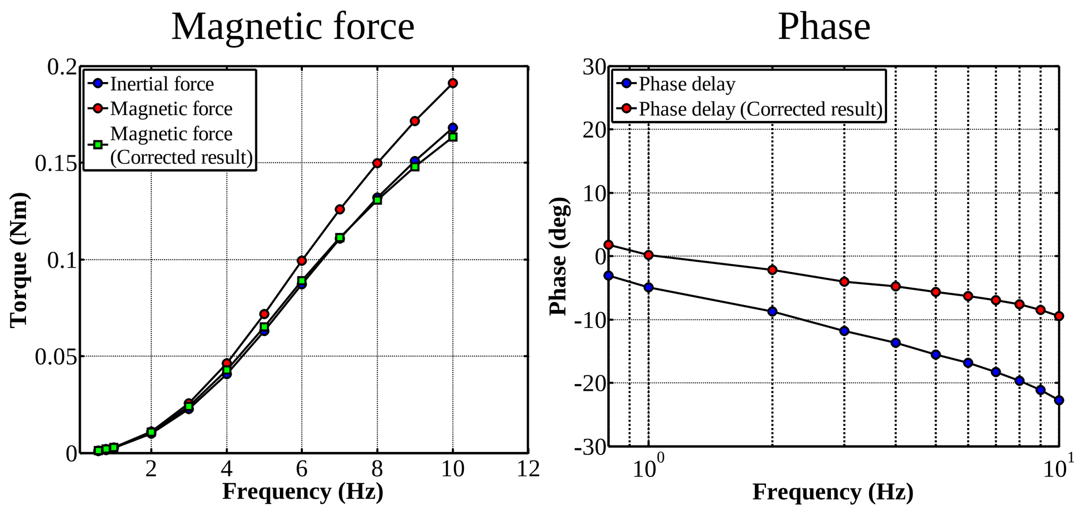

- When the input amplitude become big, gain is decreasing.
- The influence of the input amplitude is almost not seen.

**Unsteady magnetic field measurement (Pitching)**




- The big difference by the position of measurement is not seen.
- The gain decrease and the phase is delayed when frequency become high.

**Correction of magnetic force and Phase**




- Comparison of the inertial force and magnetic force
  - ✓ There are few difference from inertial by correction of magnetic force.
- The delay of inertial force to magnetic force
  - ✓ The phase difference becomes small by correction.

## *Conclusions*

- Model motion test was performed and frequency characteristics were measured.
- The measurement of unsteady magnetic field was conducted and the correction of magnetic force and phase were performed.
- It was found that large energy decrement and phase delay occur in formation of magnetic field.
- The magnetic force approaches inertial force and phase delay becomes small by correction.

## *Future works*

- To improve measurement accuracy of unsteady aerodynamic force, quantitative analysis about the error of the parameter identification method, effect of small aerodynamic force and electromagnetic induction will be performed.
- To evaluate unsteady aerodynamic phenomenon, visualization method will be developed.