

**RISE#5**

# **Passenger ride comfort and Vibration control**

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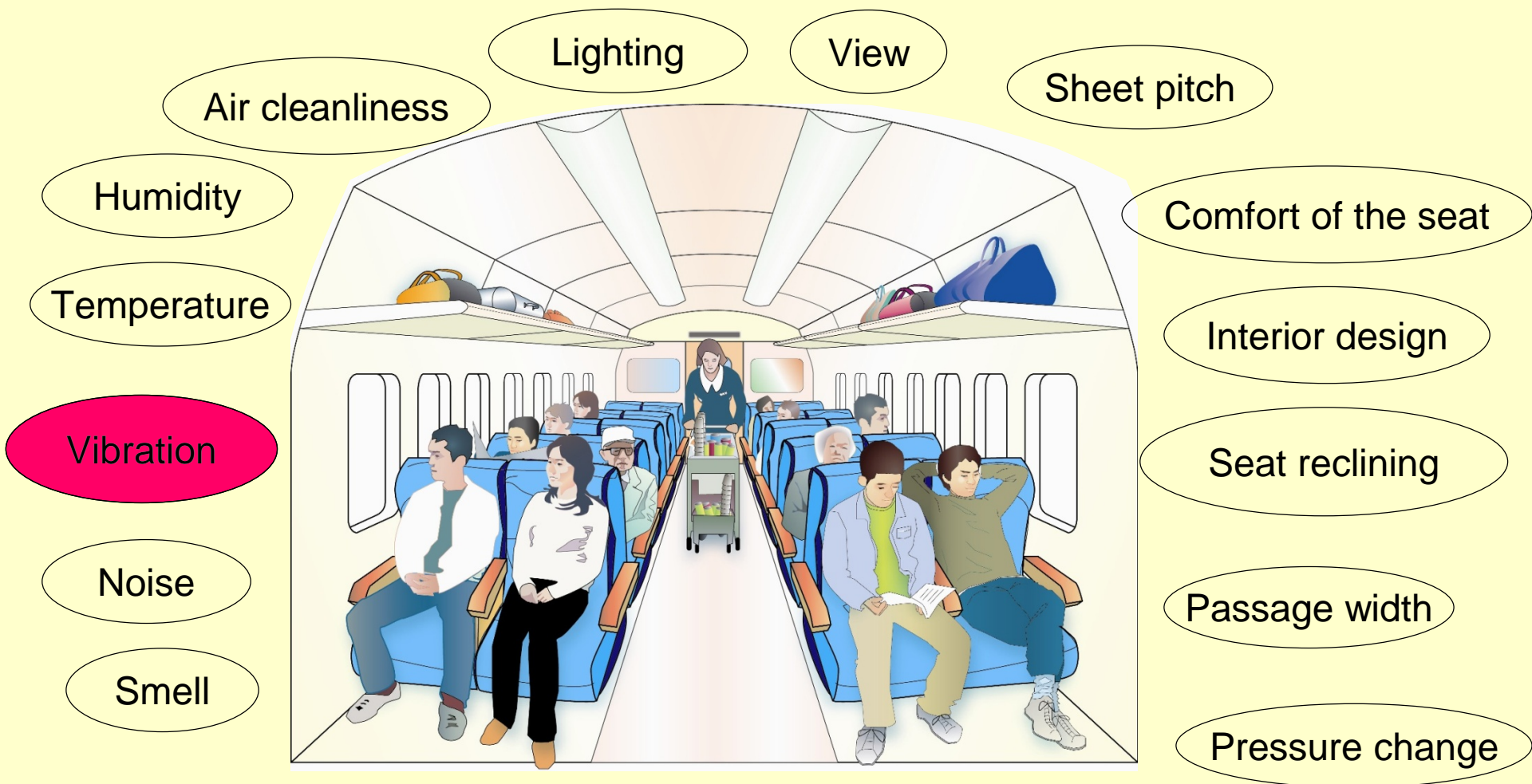


*Railway Technical Research Institute*

# Contents

- Ride comfort in a broad sense
- Vehicle vibration
- Vibration frequency disliked by human body
- How to measure Ride comfort
- How to analyze Ride comfort
- Vibration control

# Ride Comfort in a broad sense



# Contents

- Ride comfort in a broad sense

- **Vehicle vibration**

- Vibration frequency disliked by human body

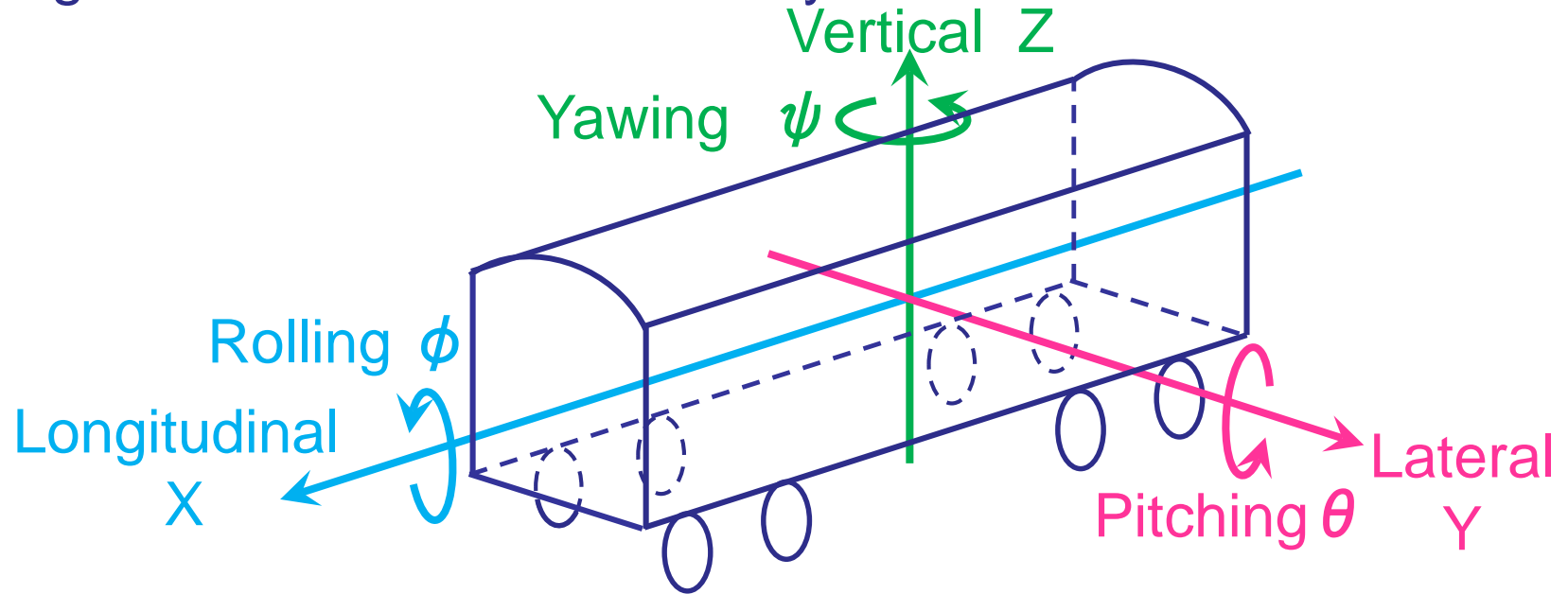
- How to measure Ride comfort

- How to analyze Ride comfort

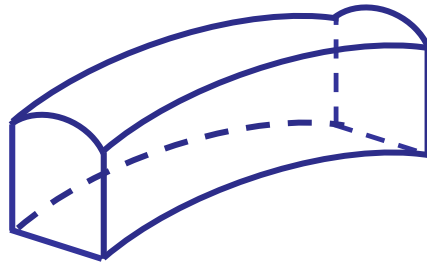
- Vibration control

# Vehicle Vibration

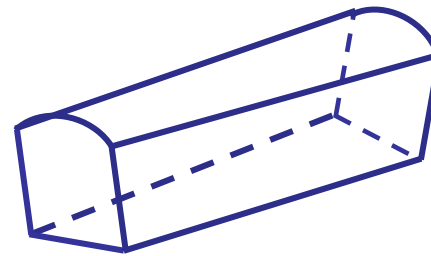
- 6 degree of freedom of vehicle dynamics



- Elastic vibration of car body in bending and twisting



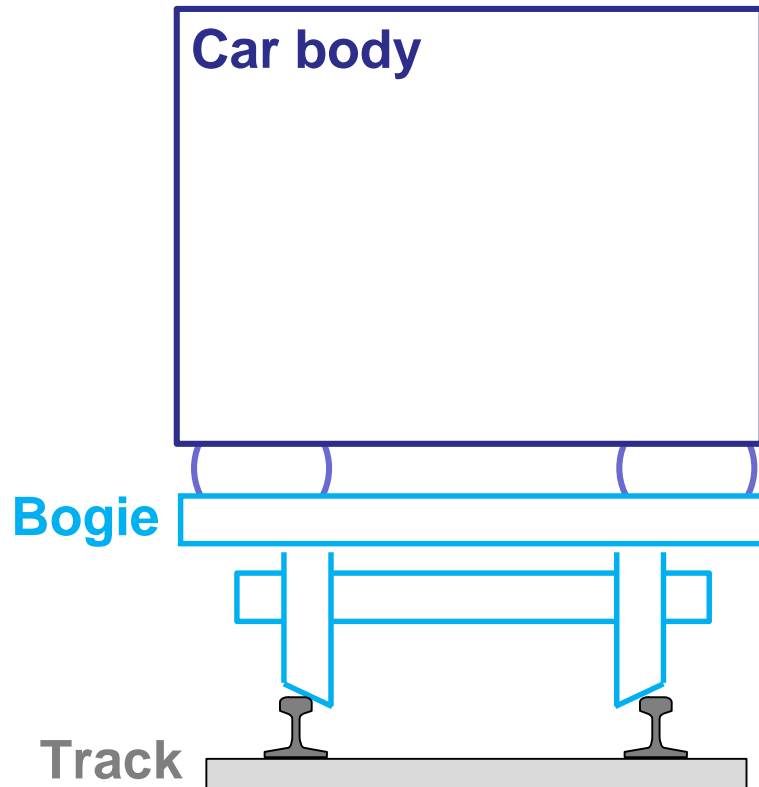
Bending



Twisting

# Vehicle Vibration

## Factors of Vehicle Vibration

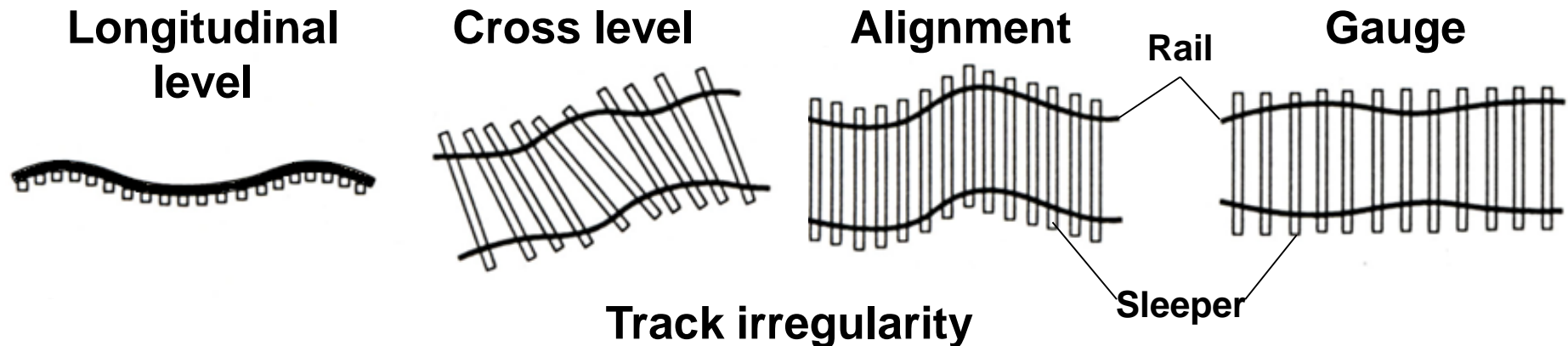


- Forced vibration by track irregularity
- Forced vibration by centrifugal forces at curved track
- Forced vibration by cross winds
- Forced vibration by unsteady aerodynamic forces in tunnel
- Self-excited vibration of the bogie (Hunting motion of the bogie)
- Vibration by wheel unbalance mass

# Vehicle Vibration

## Forced vibration by track irregularity

Track irregularity causes vehicle vibration and deterioration of the ride comfort



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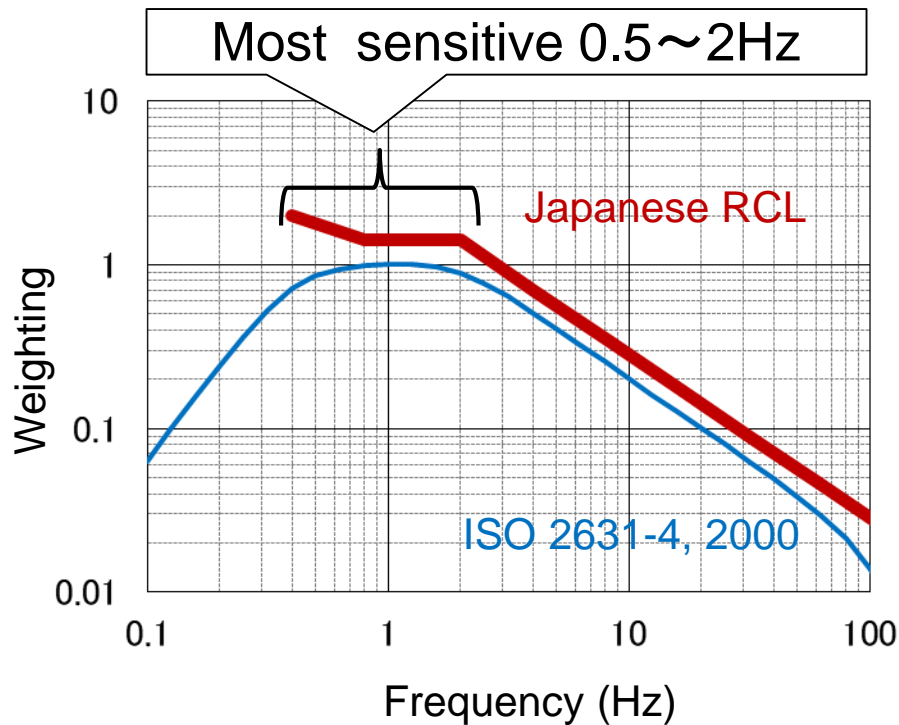


# Vibration frequency disliked by human body

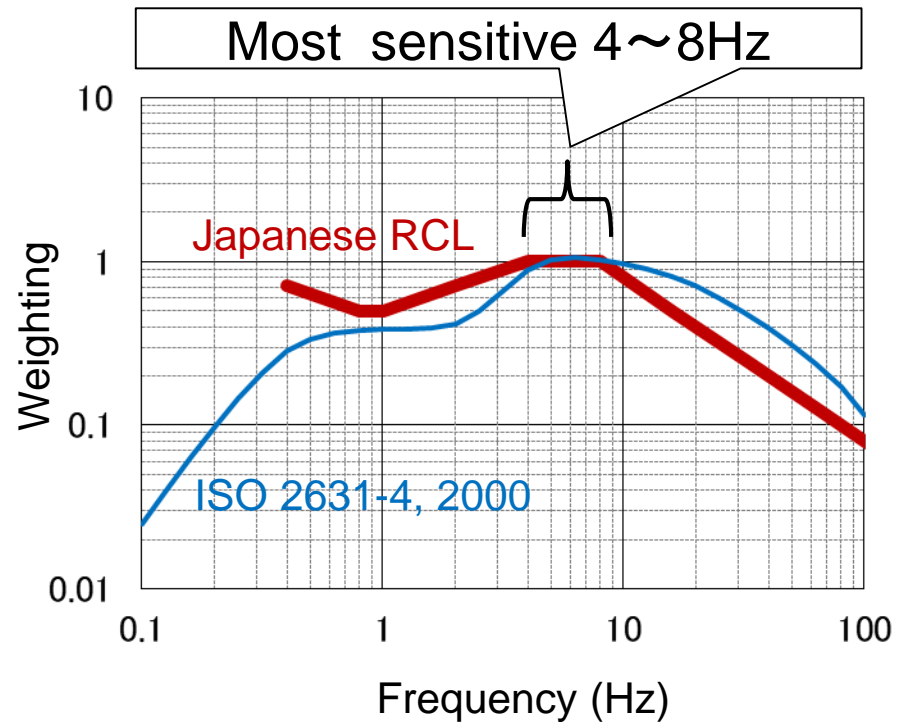
Japanese popular evaluation method :

**“Ride Comfort Level (RCL)”** proposed in 1981

## Frequency weighting curve



(a) for **Horizontal** vibration  
(Longitudinal and Lateral)



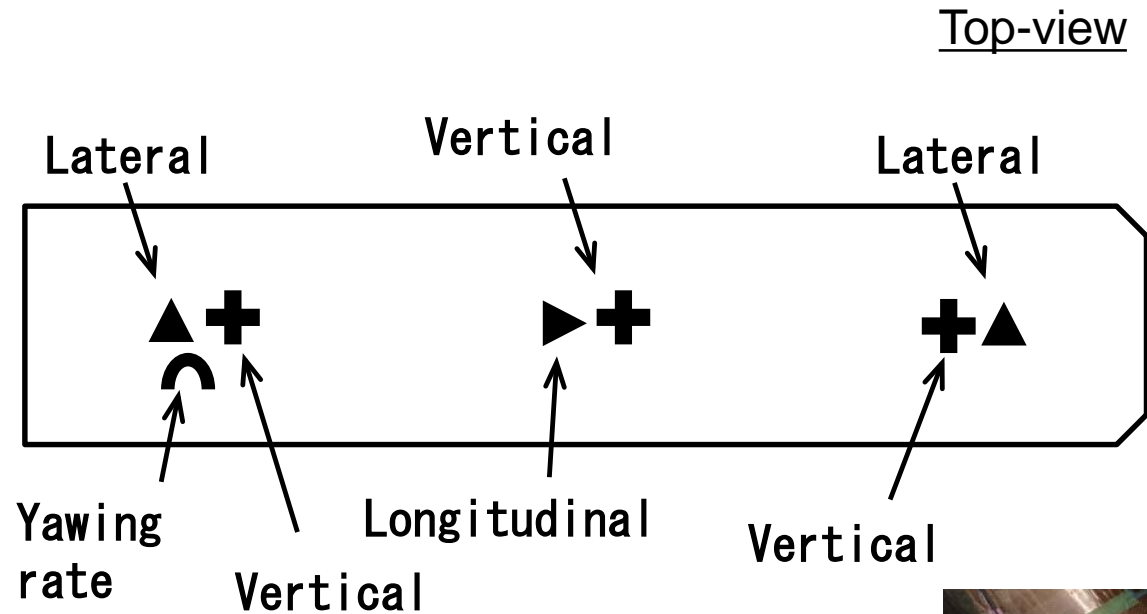
(b) for **Vertical** vibration

# Contents

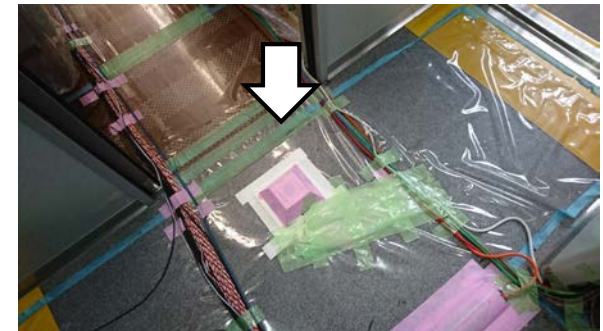
- Ride comfort in a broad sense
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# How to measure Ride comfort

## How to measure vibration



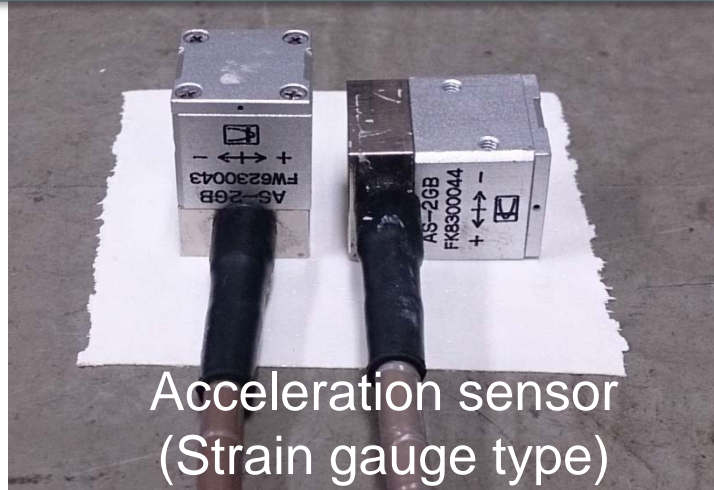
The floor of car body



# How to measure Ride comfort

## How to measure vibration

To measure **translational** motion



Acceleration sensor  
(Strain gauge type)

To measure **rotating** motion



Gyro sensor  
(Optical fiber type)

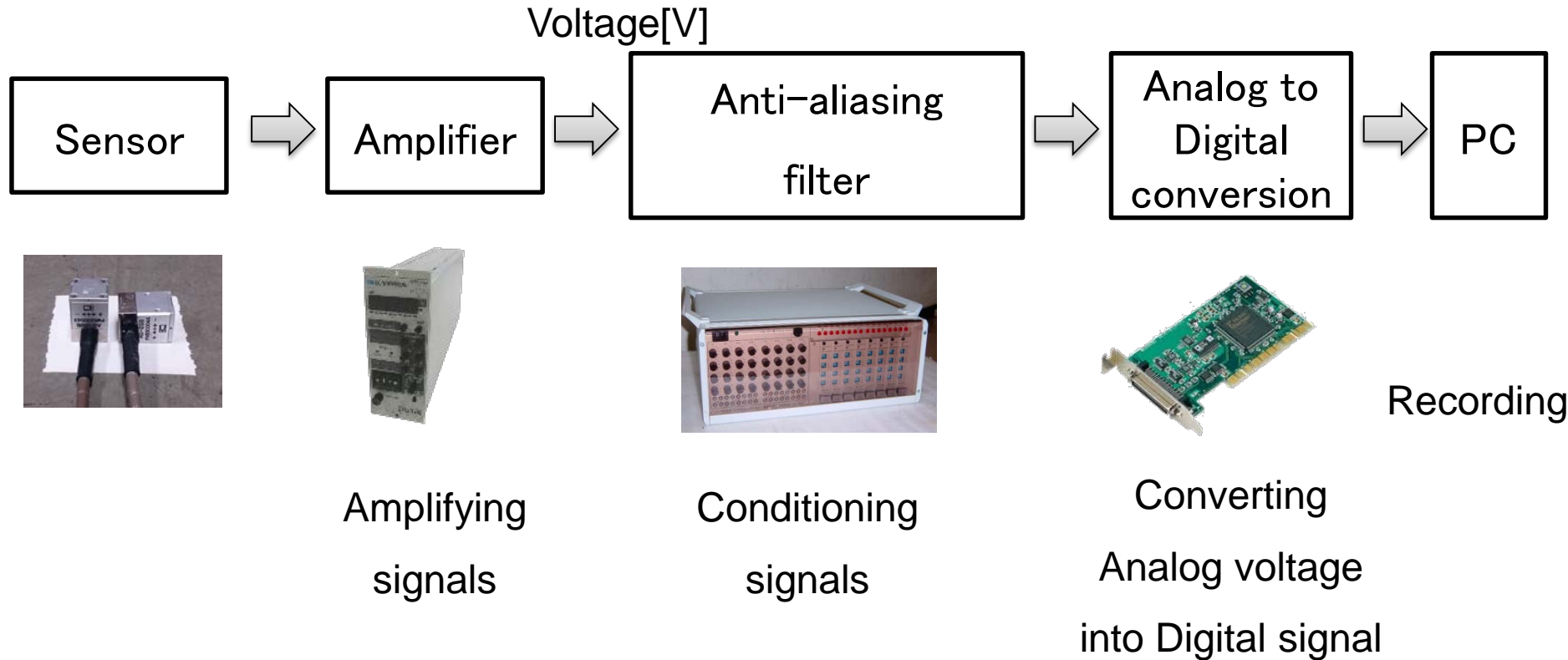


Gyro sensor  
(MEMS type)

(MEMS : Micro Electro Mechanical Systems)

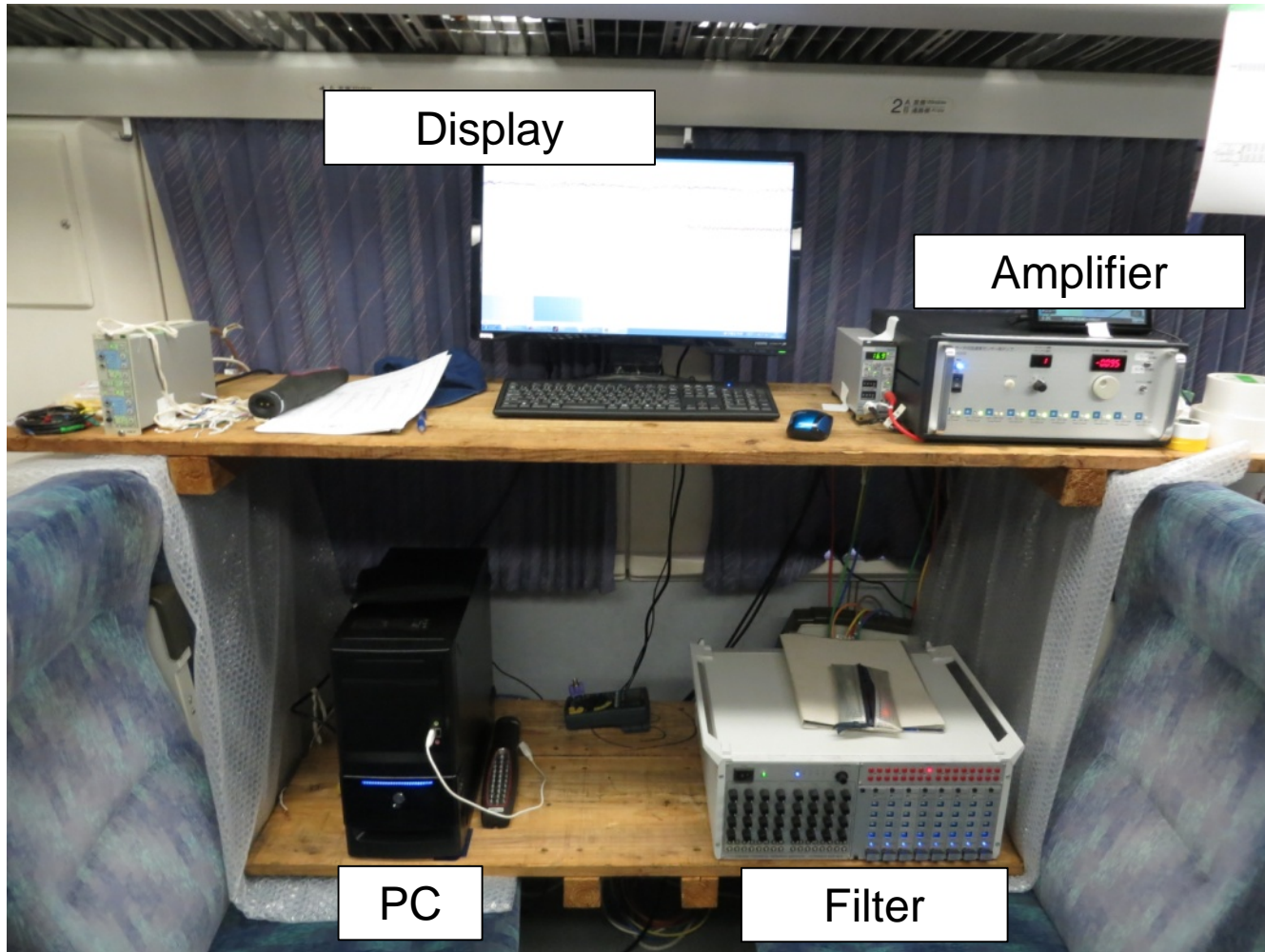
# How to measure Ride comfort

## How to measure vibration



# How to measure Ride comfort

## Measurement station



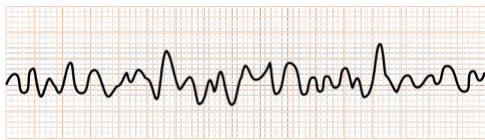
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# How to analyze Ride comfort

## How to calculate



Measured  
data



Software

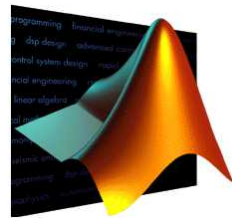


Calculating

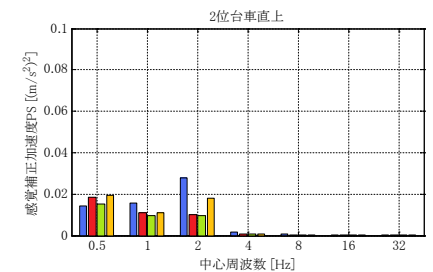
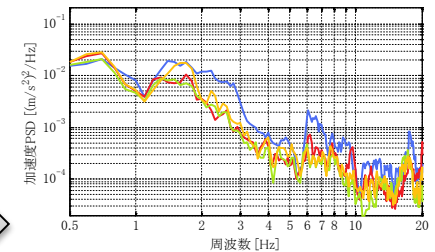


0.00	1.24	4.30	...
0.01	1.26	4.21	...
.	.	.	
.	.	.	

Digital data



**MATLAB**  
The Language of Technical Computing  
The MATH WORKS Inc.



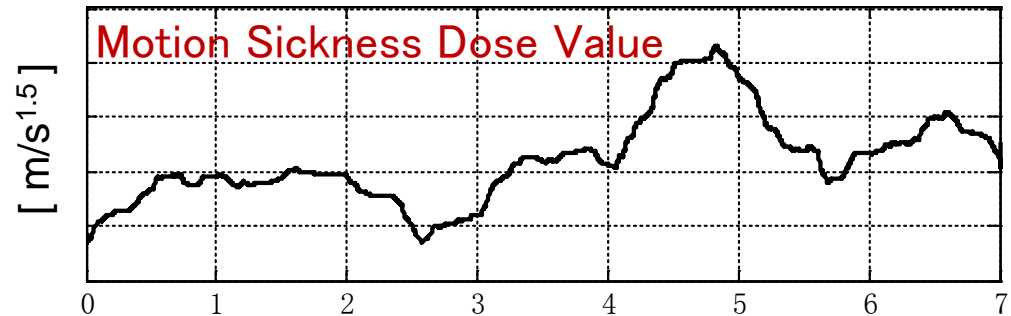
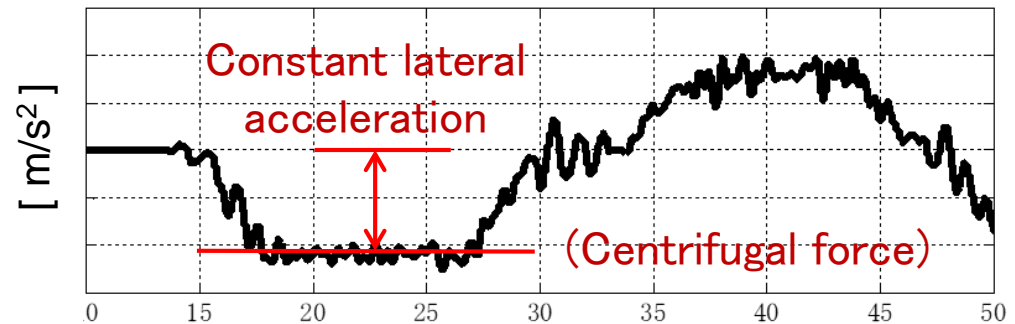
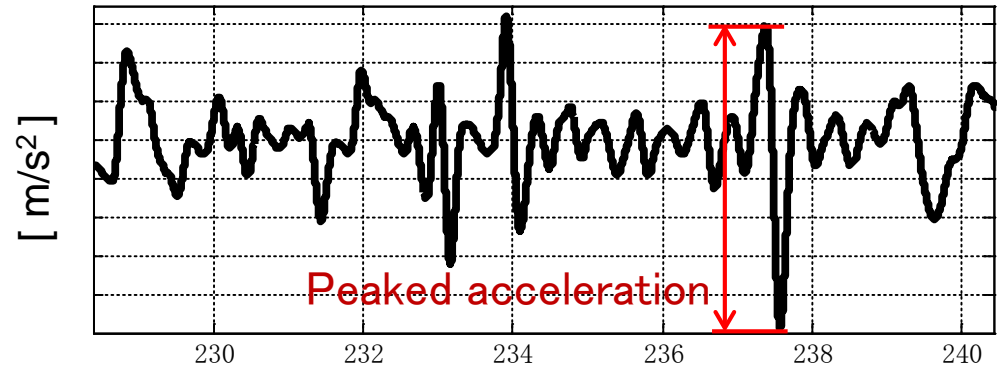
- Evaluation values
- Graphs



# How to analyze Ride comfort

## Evaluation indexes

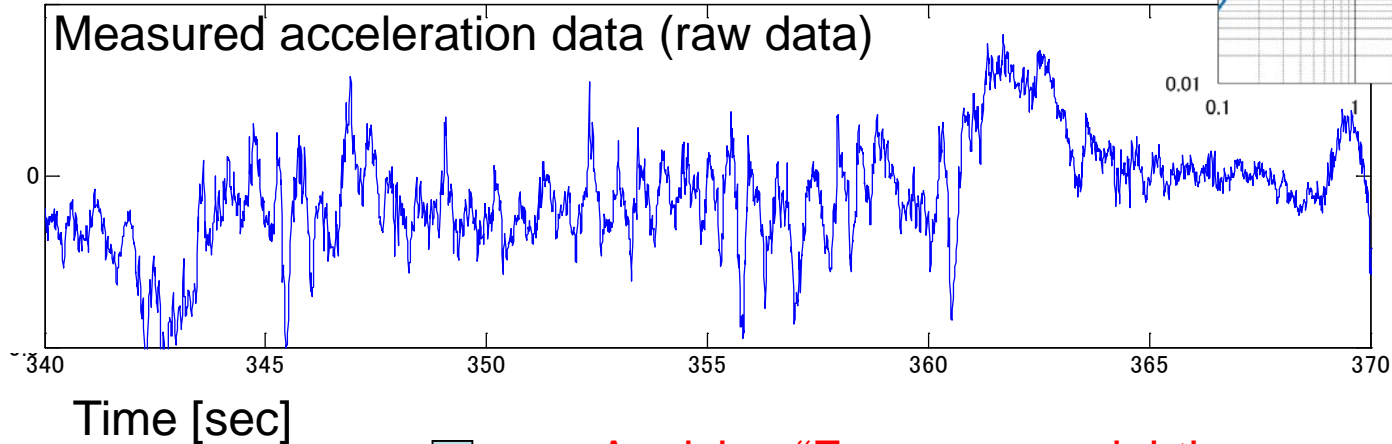
- Ride Comfort Level
- Peaked acceleration
- Constant lateral acceleration
- Motion Sickness Dose Value



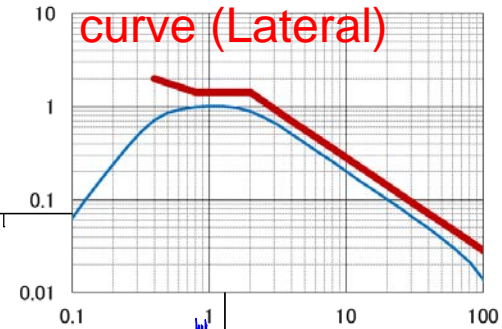
# How to analyze Ride comfort

## How to calc. Ride comfort level

Acceleration [ $\text{m/s}^2$ ]

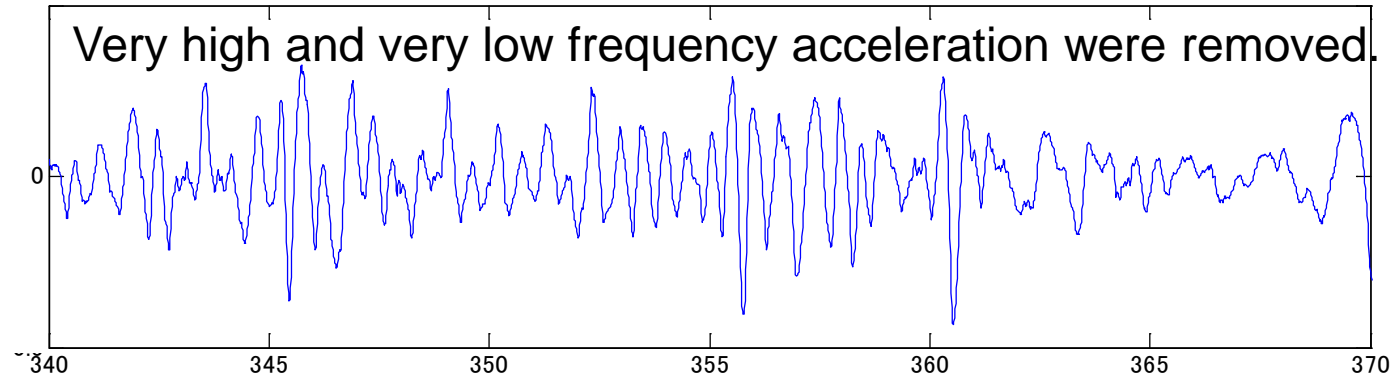


Frequency weighting curve (Lateral)



Applying “Frequency weighting curve (Lateral)”  
(Digital filtering, like a band-pass filter)

Acceleration [ $\text{m/s}^2$ ]



# How to analyze Ride comfort

## How to calc. Ride comfort level

Raw acceleration data



Filtering with filter coefficient of the frequency weighting curve

Extracted data with sensitive frequency



Calculating Power spectral density (PSD) (Frequency analysis)

PSD of the data



Integrating PSD values all frequency (0.5 - 80Hz)  
Converting into logarithm indication 
$$L_T = 20 \log_{10} \frac{\bar{a}_w}{a_{ref}}$$

Ride quality level [dB]

$L_T$  : Ride quality level (dB)

$a_{ref}$  :  $10^{-5}$  (m/s<sup>2</sup>)

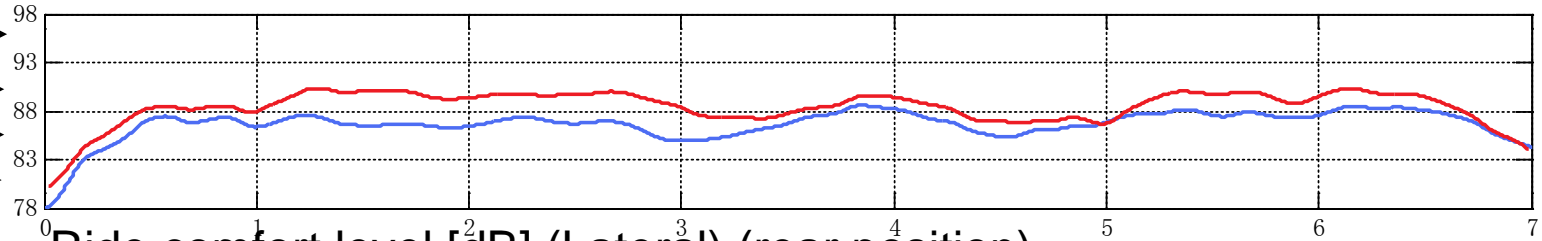


Scale

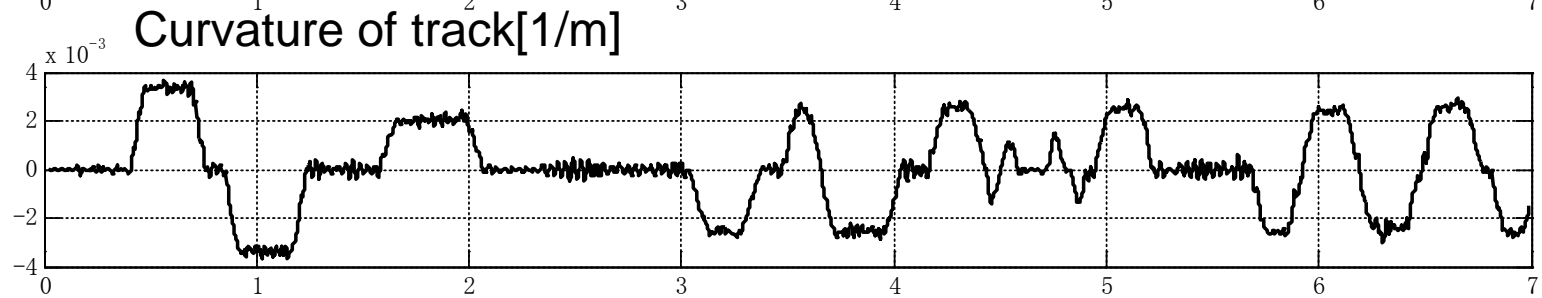
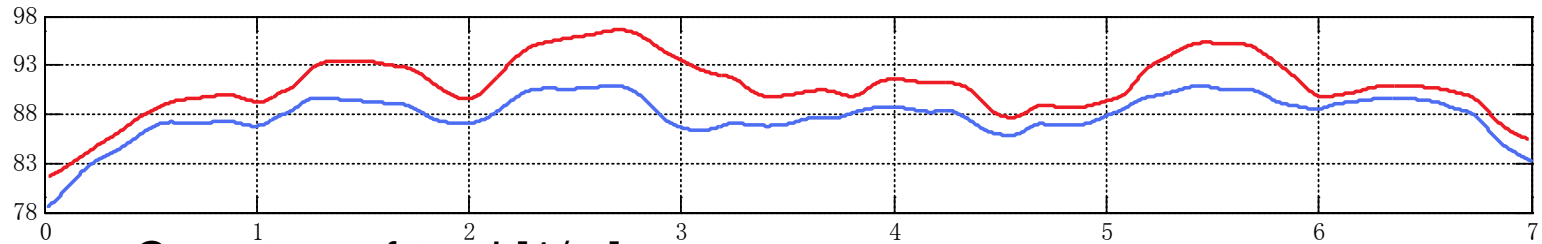
⑤ →  
④ →  
③ →  
② →  
① →

Ride comfort level [dB] (Lateral) (front position)

— Type1 — Type2



Ride comfort level [dB] (Lateral) (rear position)



Running position [km]

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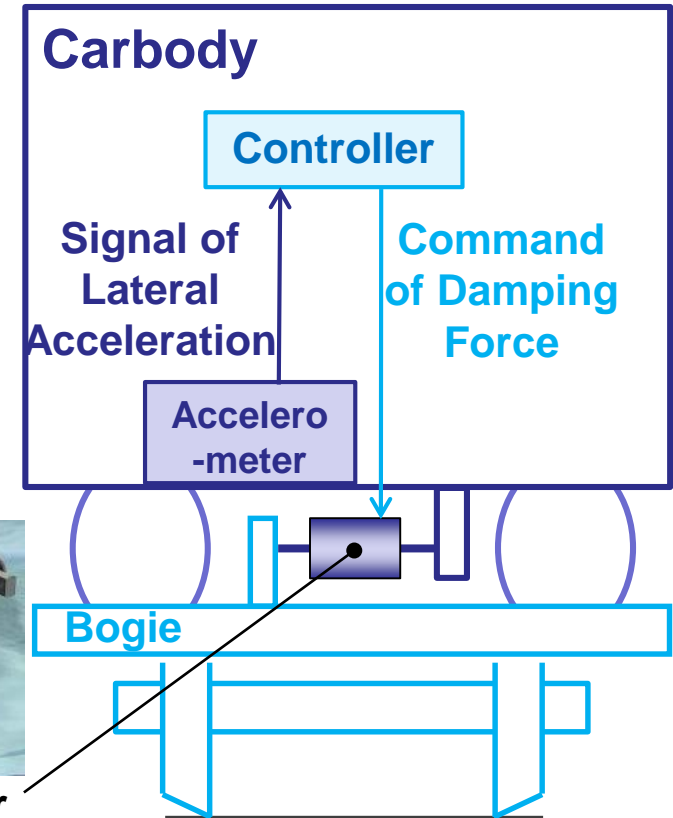
# Vibration control

## ◆ Semi-active suspension system

Changing damping coefficient of lateral damper to optimum value for restraint momentary vibration by control



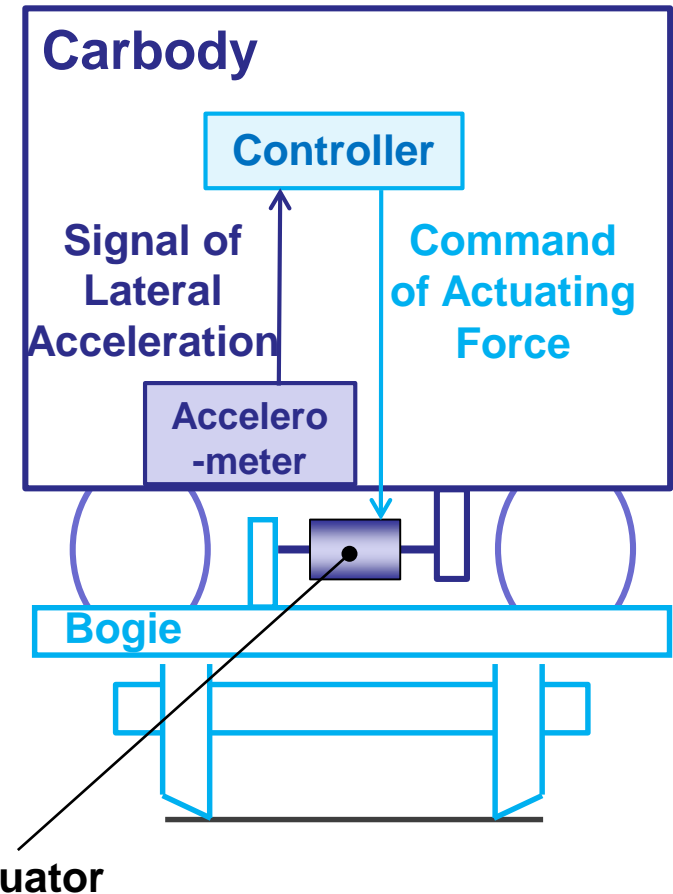
Semi-active Damper



# Vibration control

## ◆Active suspension system

Cancelling lateral vibration of carbody by active controlled actuator



<https://www.moog.co.jp/products/servoactuators/electric-actuators/application-case.html>

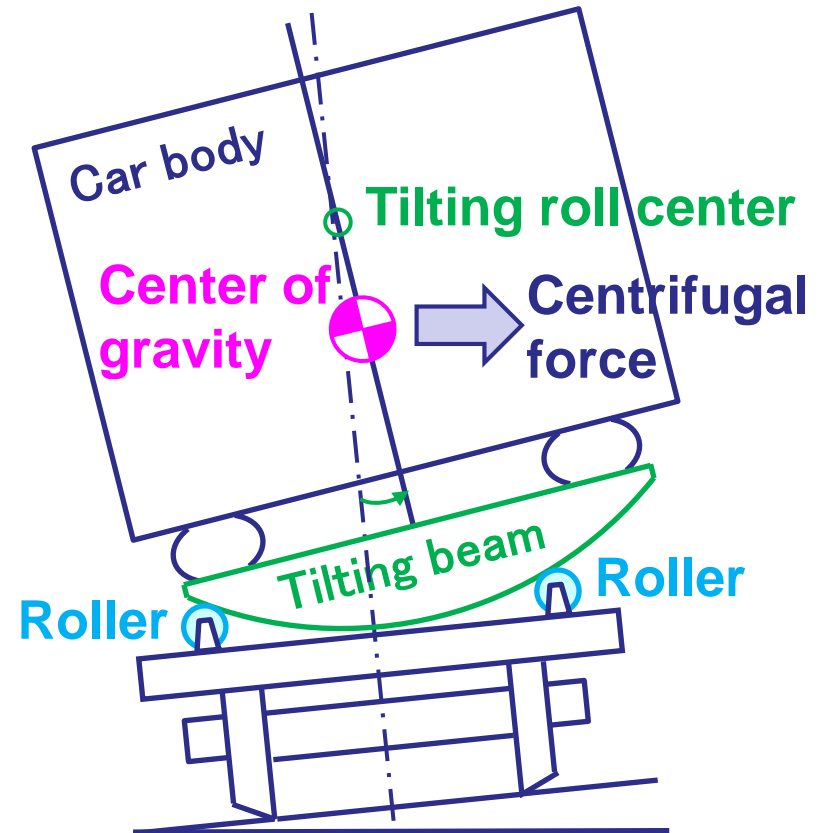
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# Vibration control

## ◆Passive tilting system

Setting car body center of gravity lower than tilting roll center for tilting by centrifugal forces

Max. tilting angle 5 degrees





# Vibration control

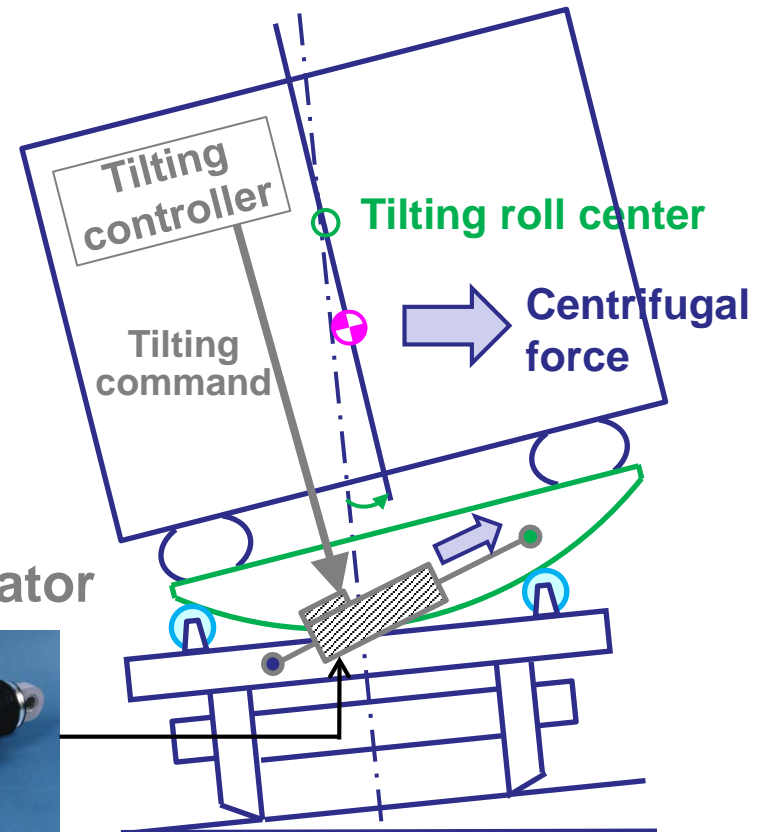
## ◆Controlled tilting system

Pneumatic actuator assist tilting motion to prevent delay and abrupt of tilting motion.

On-board tilting controller stores data about all curves on the train operating section.



Pneumatic actuator



# Vibration control

## ◆Car body tilting system with Air springs

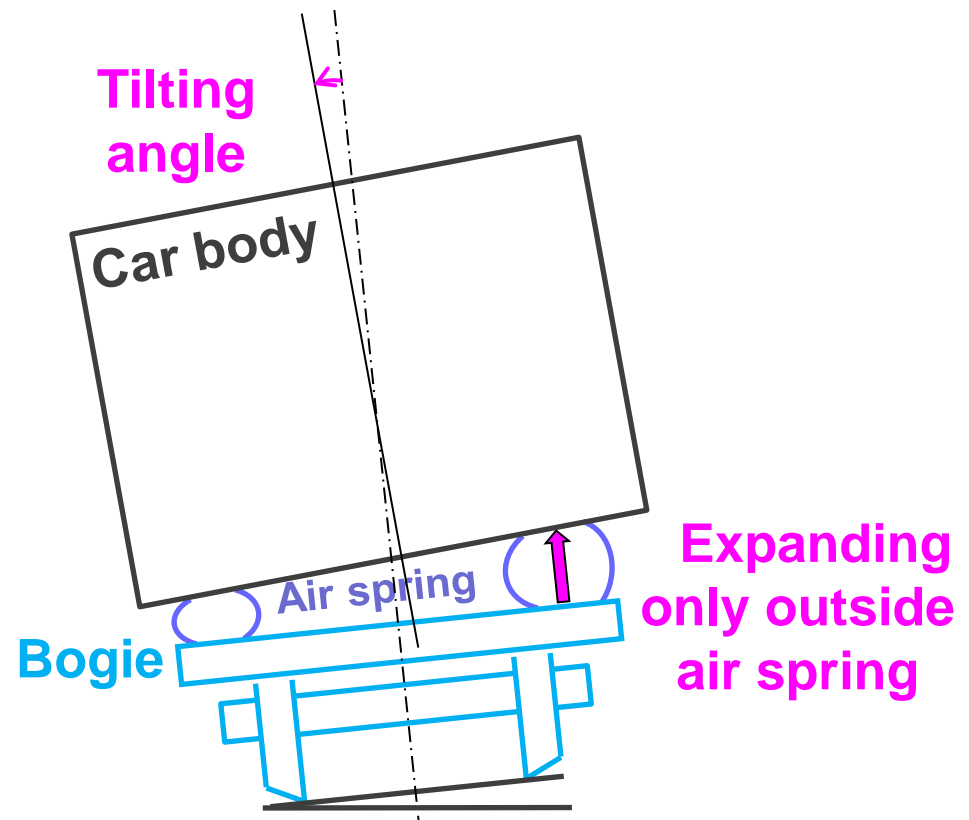
Expanding outside air spring  
by injecting compressed air  
at curve for reducing  
centrifugal forces

Maximum tilting angle

Shinkansen : 1 deg

Meter-gauged : 2deg

(These were not determined  
by regulation)



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**ขอบคุณครับ**  
**Thank you !**

