EVS35
OSL2022

NISSAN
MOTOR CORPORATION

Vertical vibration reduction by new electric motor control in dry sand condition

Nissan Motor Co., Ltd.
Akira Sawada

Outline

- 1. Introduction
- 2. Vertical vibration under dry sand condition
  - Electric vehicle behavior
  - Vertical vibration simulation model
- 3. Vertical vibration motor control and effect
- 4. Summary

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1. Introduction

▪Torsional vibration reduces comfort during riding.
• We proposed a vibration motor control method for EVs.

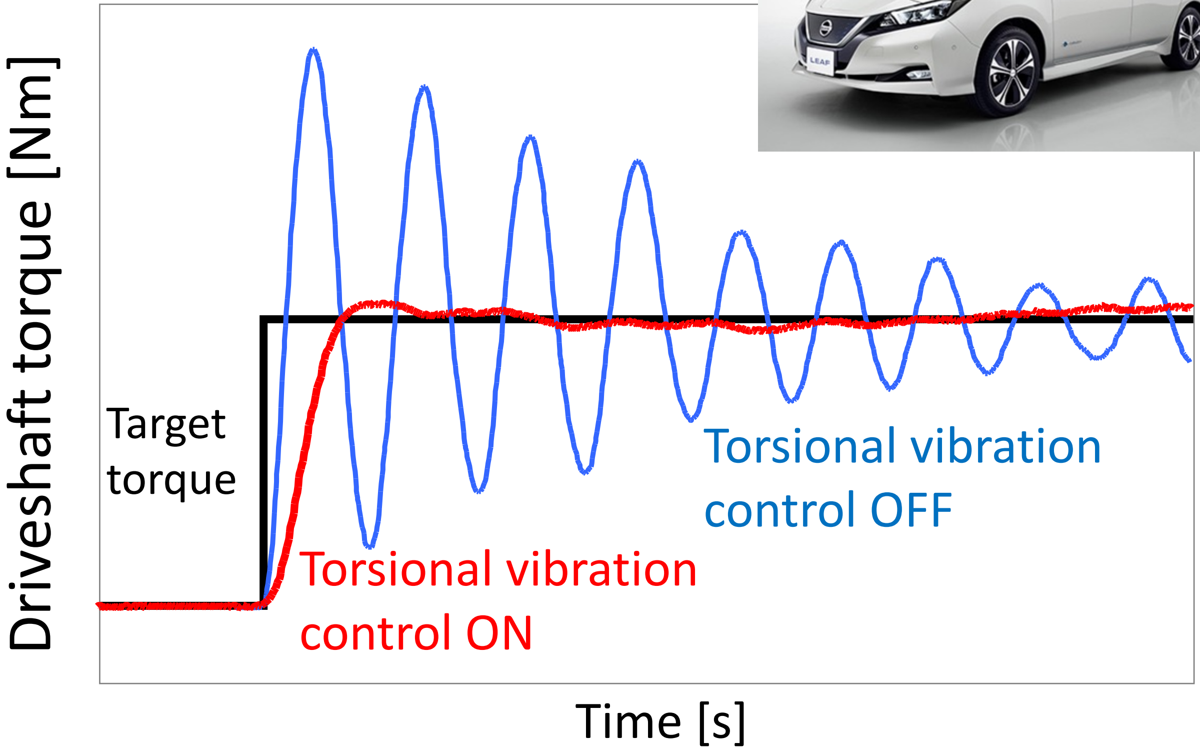
<EV characteristics>

- High torque response
- High torque accuracy

<Stiffness of driveshaft>

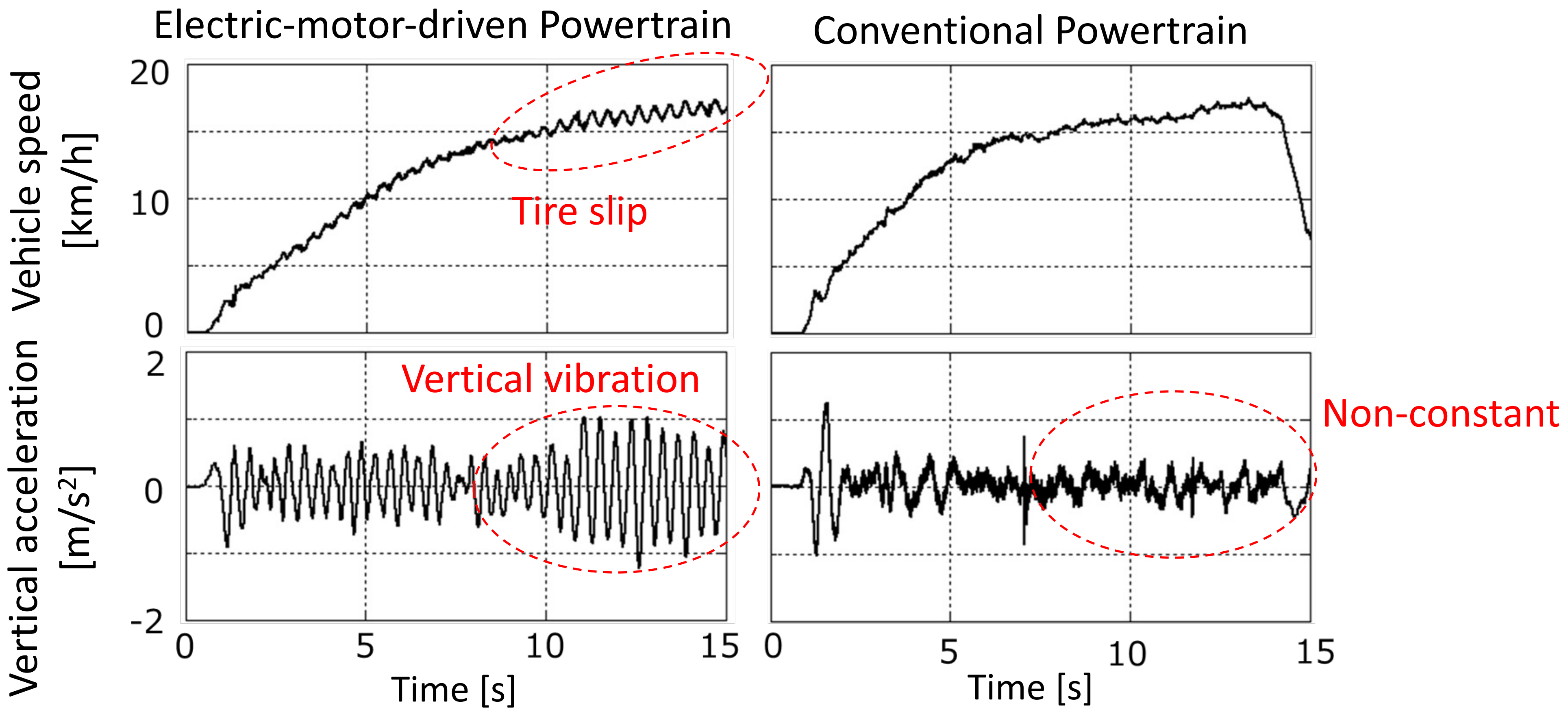
- Steep torque input to produce torsional vibration

Torsional vibration control



1. Introduction

▪Electric-motor-driven vehicle not avoid vertical vibration under dry sand condition.



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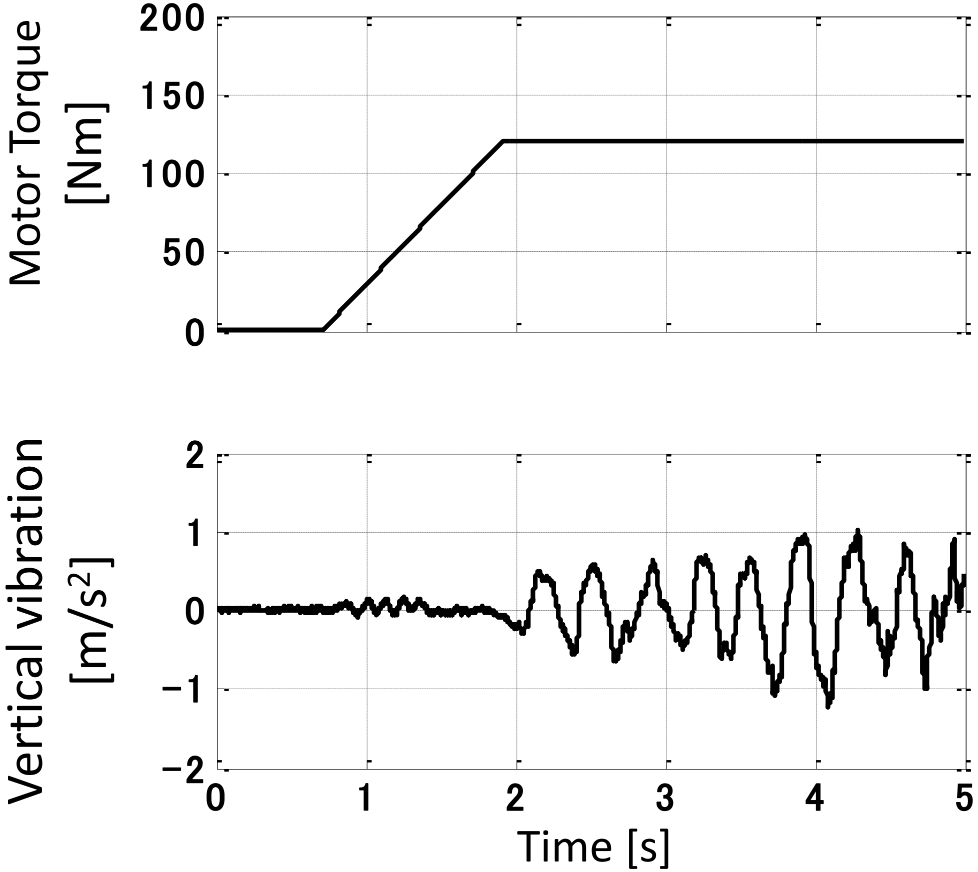
2. Vertical vibration-EV behavior under dry sand condition

・Tires sink in dry sand depending on wheel load.
・Motor torque is constant, but Car body only vertical vibrates.



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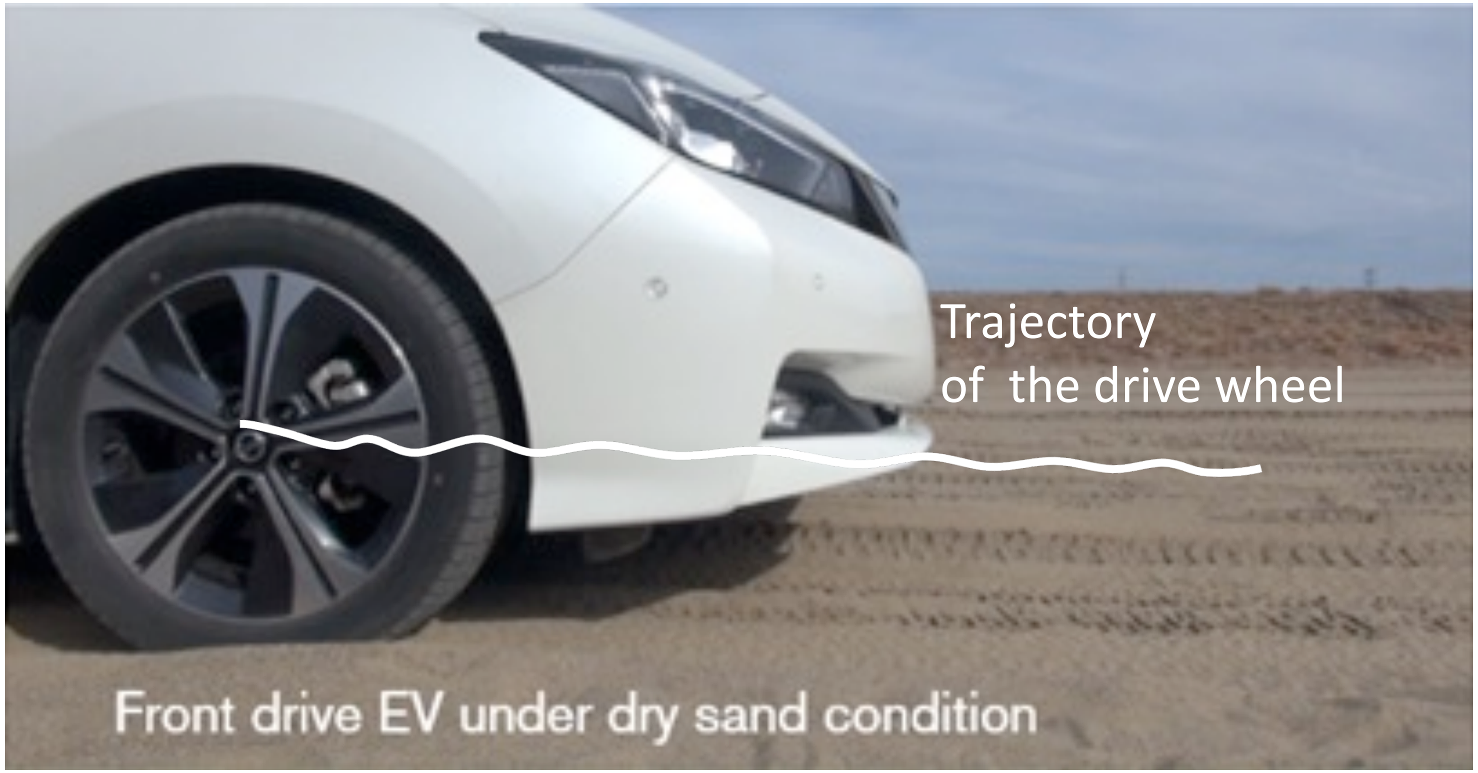
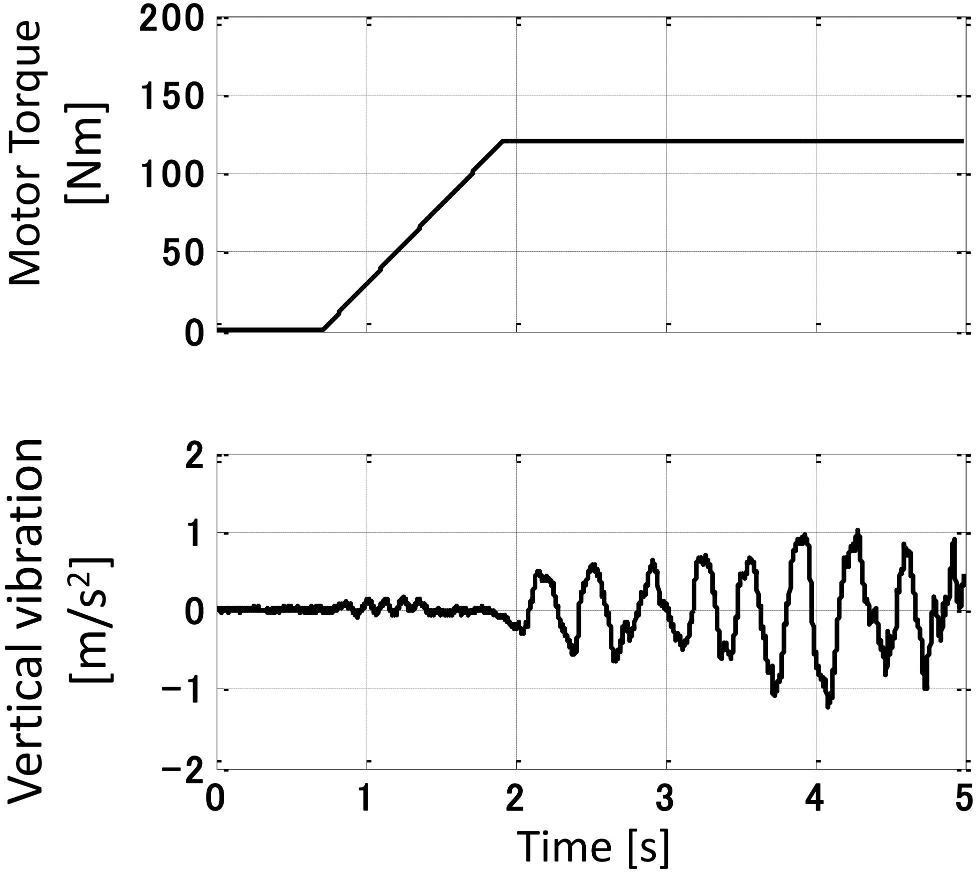
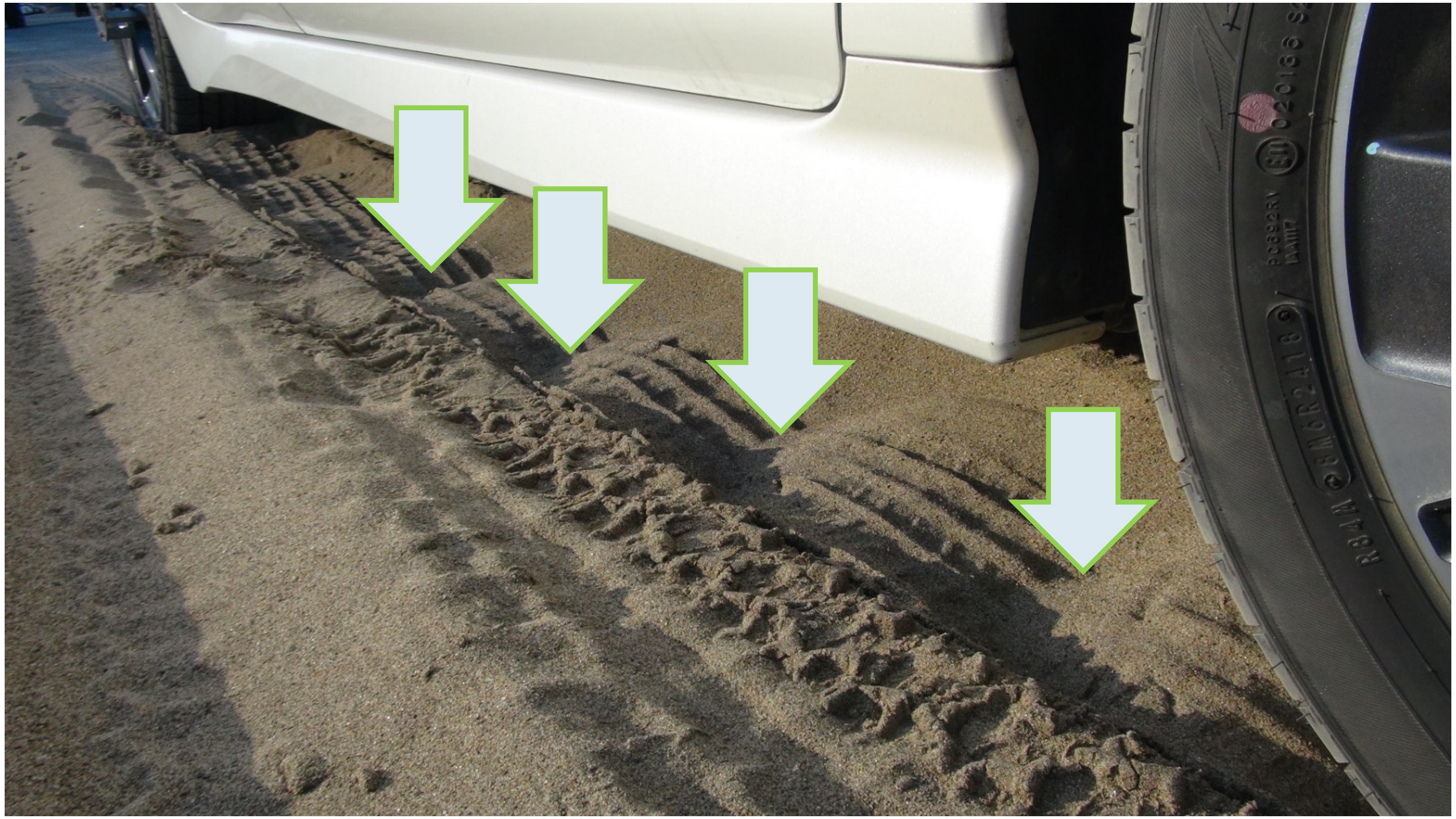




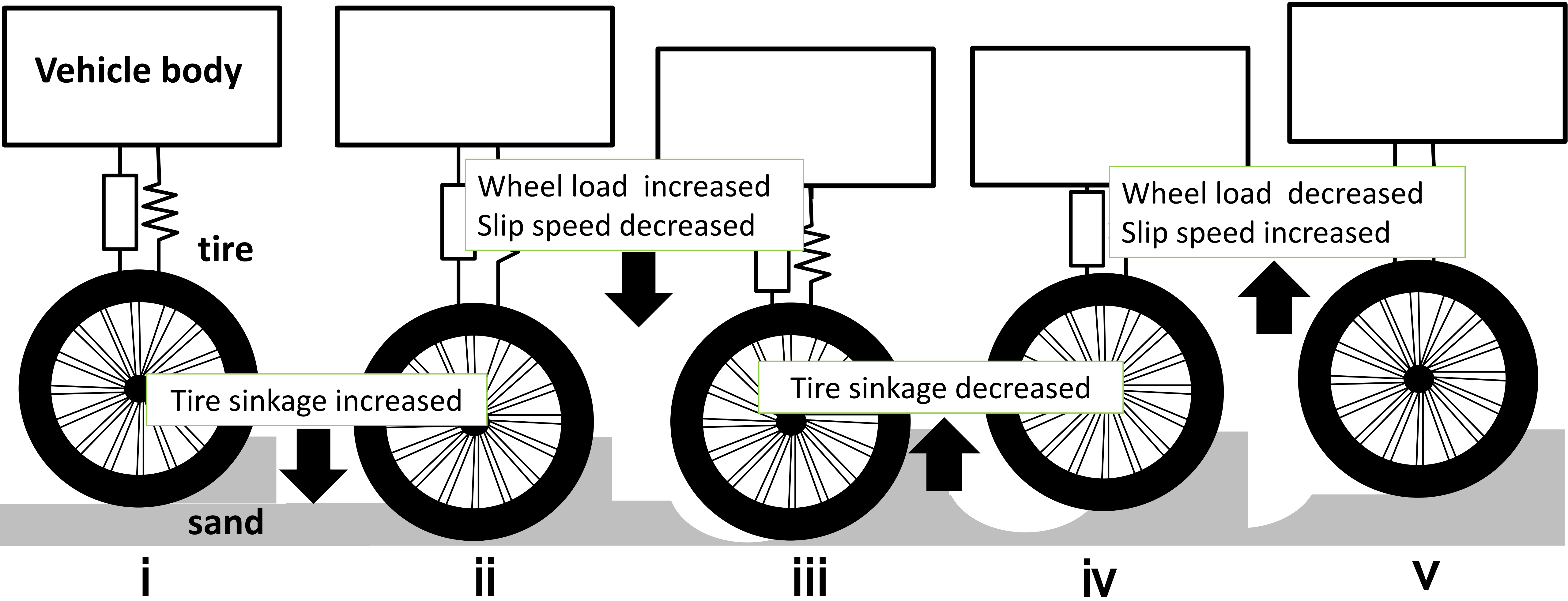
2. Vertical vibration-EV behavior under dry sand condition

・Trajectory of the dents can be observed,
and the tires are sinking.



2. Vertical vibration-EV behavior under dry sand condition

・The vertical movement of the drive wheel is related to the vertical vibration of the vehicle body.



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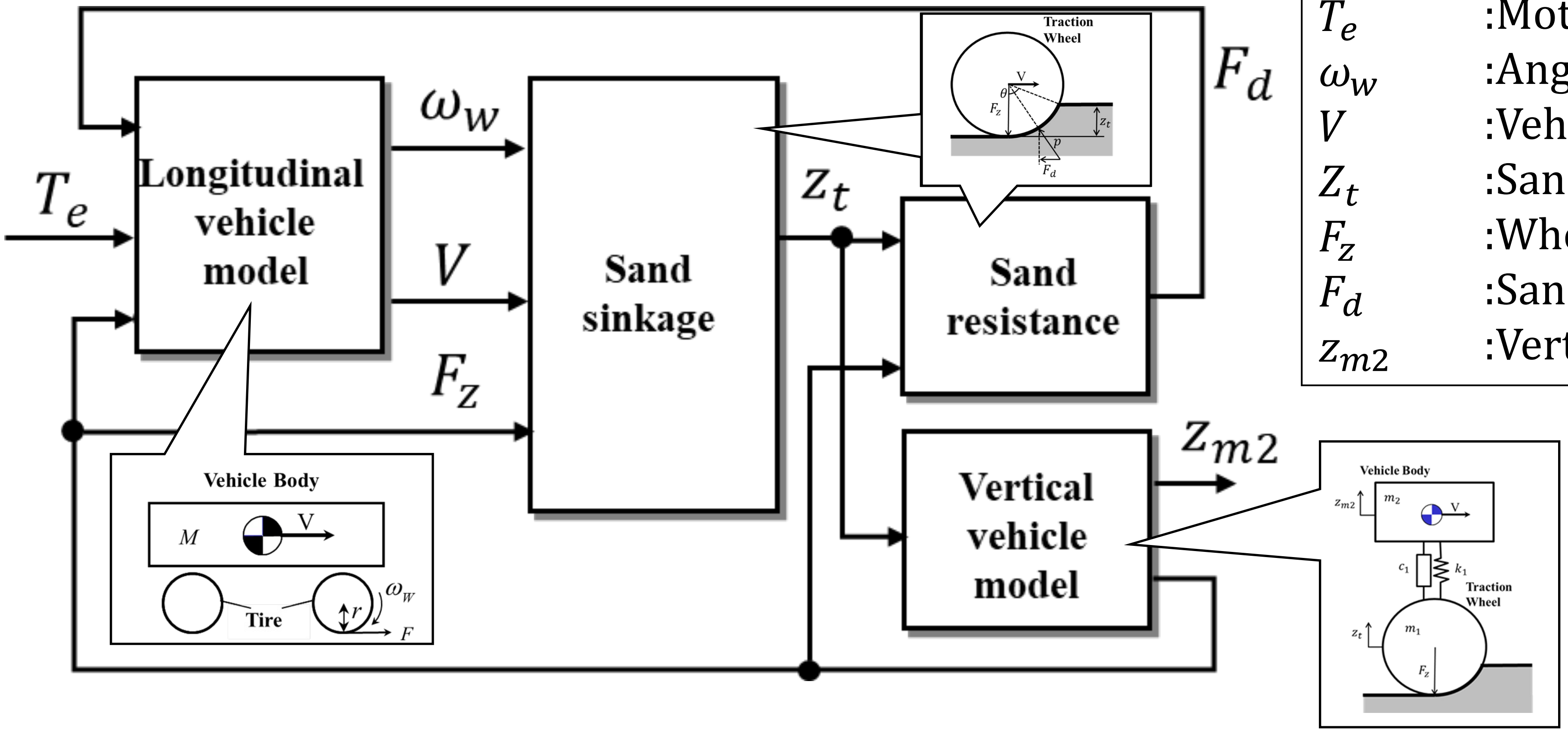
2. Vertical vibration-Vertical vibration simulation model

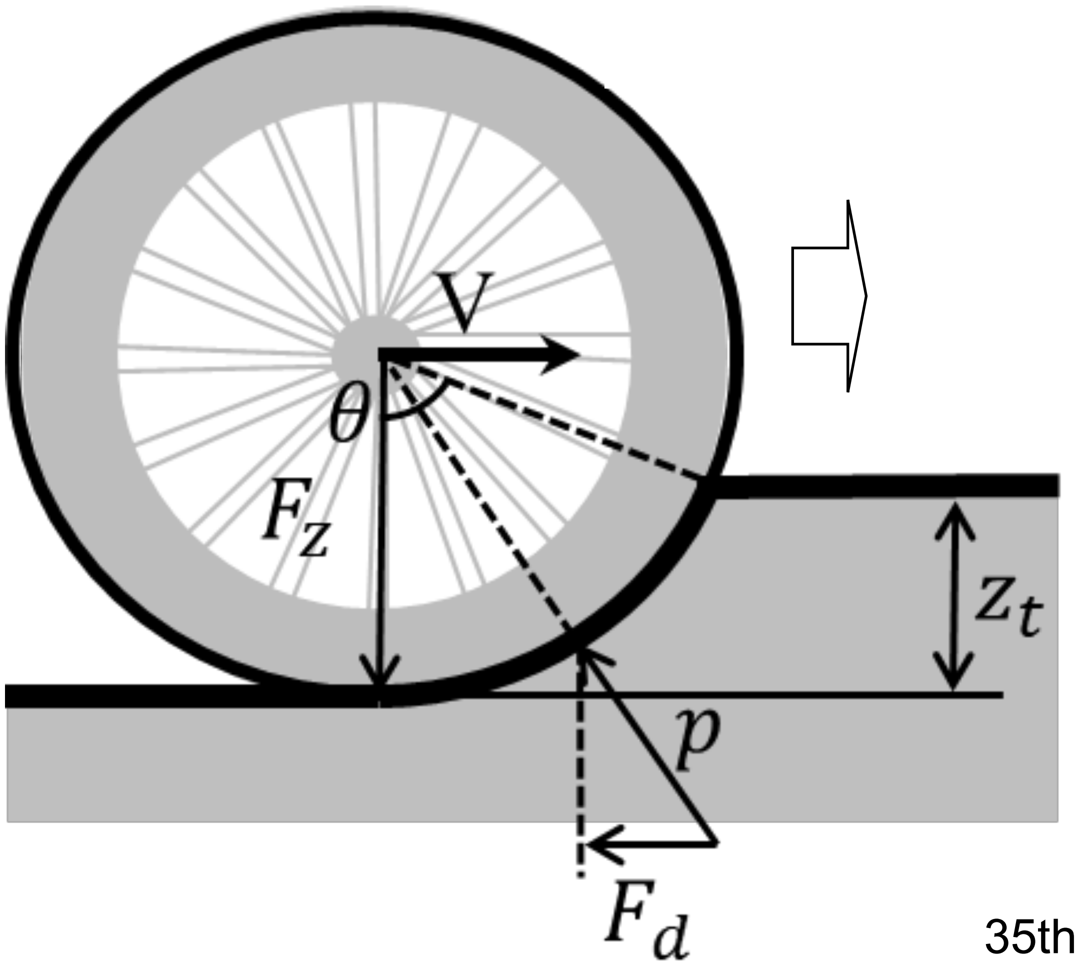
・To make a driving force transmission system model focusing Sand sinkage and Sand resistance and vertical motion.



T_e	:Motor torque
ω_w	:Angular velocity of drive wheel
V	:Vehicle velocity
Z_t	:Sand sinkage
F_z	:Wheel load
F_d	:Sand resistance
z_{m2}	:Vertical displacement of body

2. Vertical vibration-Vertical vibration simulation model

・The sand sinkage (z_t) exhibits transient response on dry sand.
・The sand resistance (F_d) is calculated using z_t.



z_t: Sand sinkage

s: Laplace operator

$$z_t = \frac{1}{\tau_z s + 1} z_{max}$$

z_{max}	: transient and steady sinkage
τ_z	: transient response parameter

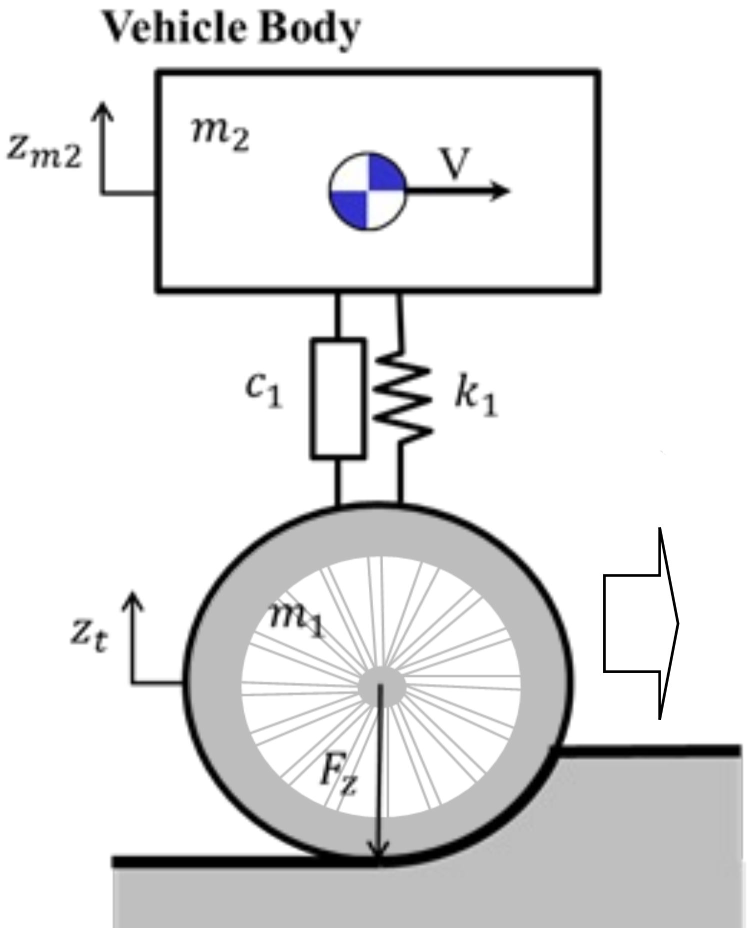
F_d: Sand resistance

$$F_d = f(z_t) + g(F_z)$$

$f(z_t)$: Sand resistance factor	
$g(F_z)$: Road friction coefficient	

2. Vertical vibration-Vertical vibration simulation model

・Vertical displacement of body (z_{m2}) is calculated based on the suspension characteristics and wheel load.



z_{m2}: Vertical displacement

s: Laplace operator

$$z_{m2} = \frac{c_1 s + k_1}{m_2 s^2 + c_1 s + k_1} z_t$$

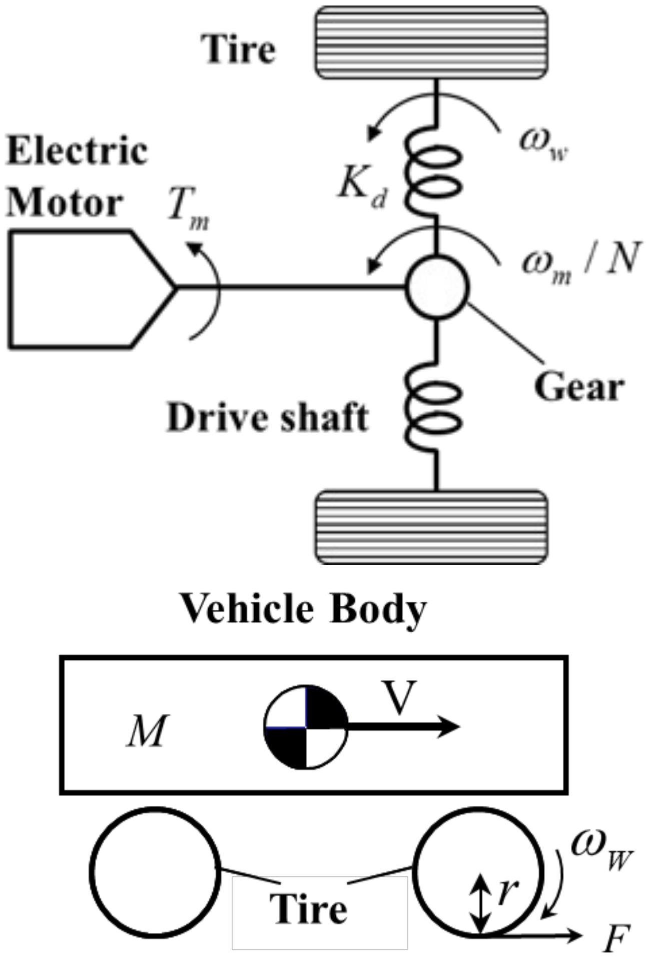
m_2: sprung mass
m_1: upsprung mass
k_1: spring constant
c_1: spring damping coefficient

F_z: wheel load

$$F_z = (m_1 + m_2)g + c_1 \frac{\mathrm{d}}{\mathrm{dt}}(z_{m2} - z_t) + k_1(z_{m2} - z_t)$$

2. Vertical vibration-Vertical vibration simulation model

・The longitudinal vehicle model mechanism is applied to electric-motor-driven vehicles.



Equations

Motor speed motion：

$$J_m \frac{\mathrm{d}}{\mathrm{dt}} \omega_m = T_m - \frac{T_d}{N}$$

$$2J_W \frac{\mathrm{d}}{\mathrm{dt}} \omega_W = T_d - rF$$

Driveshaft speed motion：

$$T_d = K_d \int \left(\frac{\omega_m}{N} - \omega_W \right) \mathrm{dt}$$

$$F = K_t (r\omega_W - V)$$

Forward and back movements:

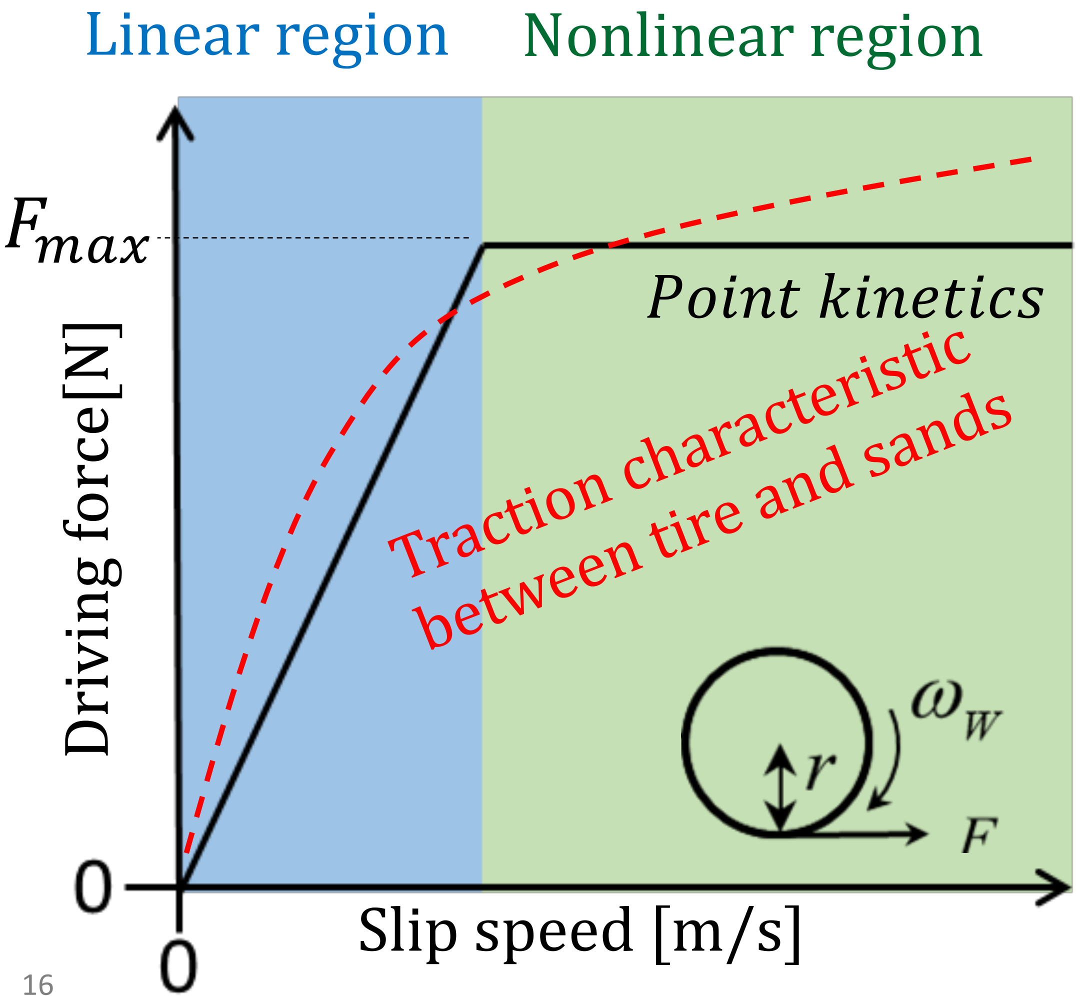
$$M \frac{\mathrm{d}}{\mathrm{dt}} V = F - F_d$$

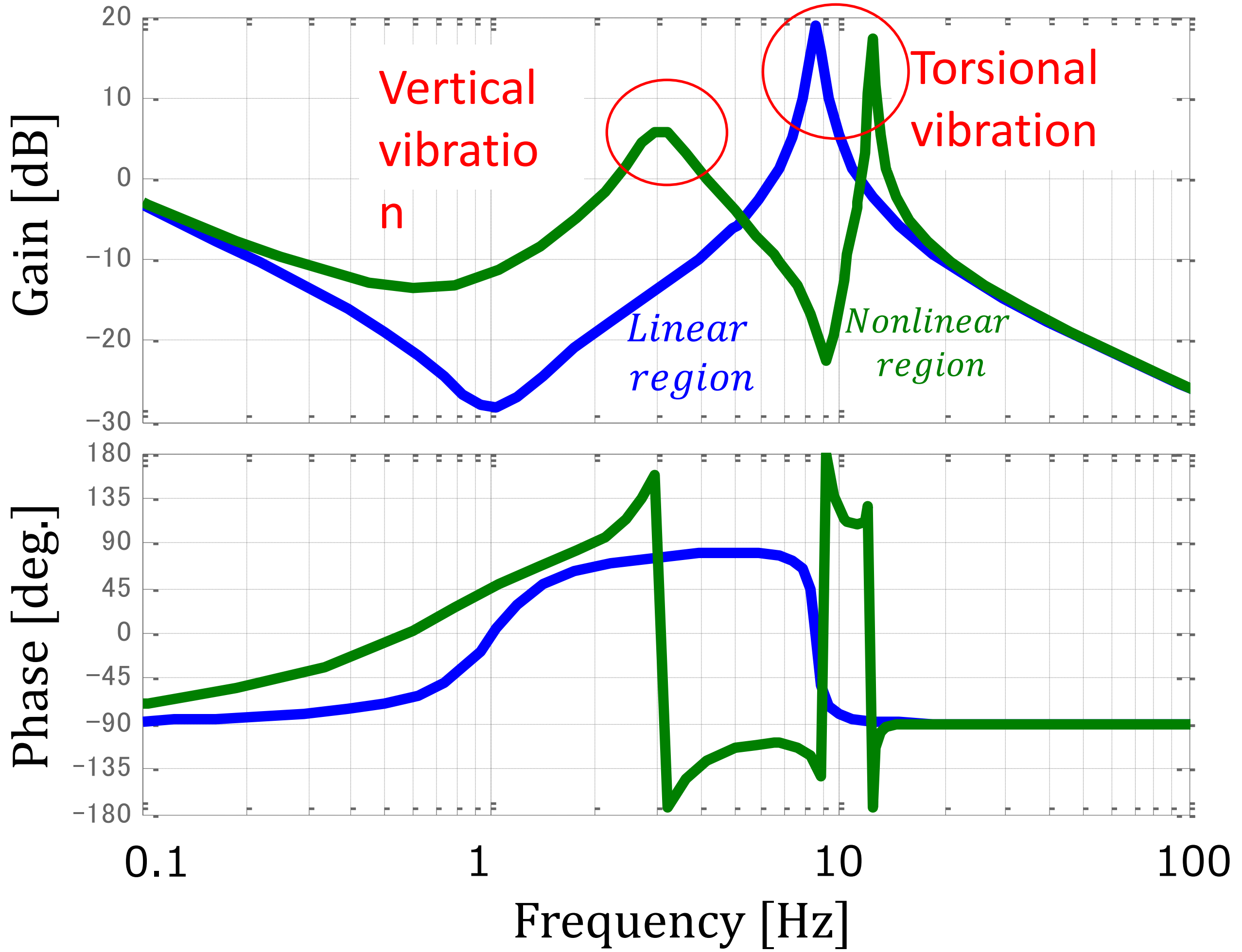
Transmission characteristics of the motor speed based on torque:

$$G_p(s) = \frac{1}{s} \frac{\beta_3 s^3 + \beta_2 s^2 + \beta_1 s + \beta_0}{\alpha_3 s^3 + \alpha_2 s^2 + \alpha_1 s + \alpha_0}$$

2. Vertical vibration-Vertical vibration simulation model

- In the linear region, the driving force increases according to slip.
- In the nonlinear region, the driving force is limited to the wheel load.

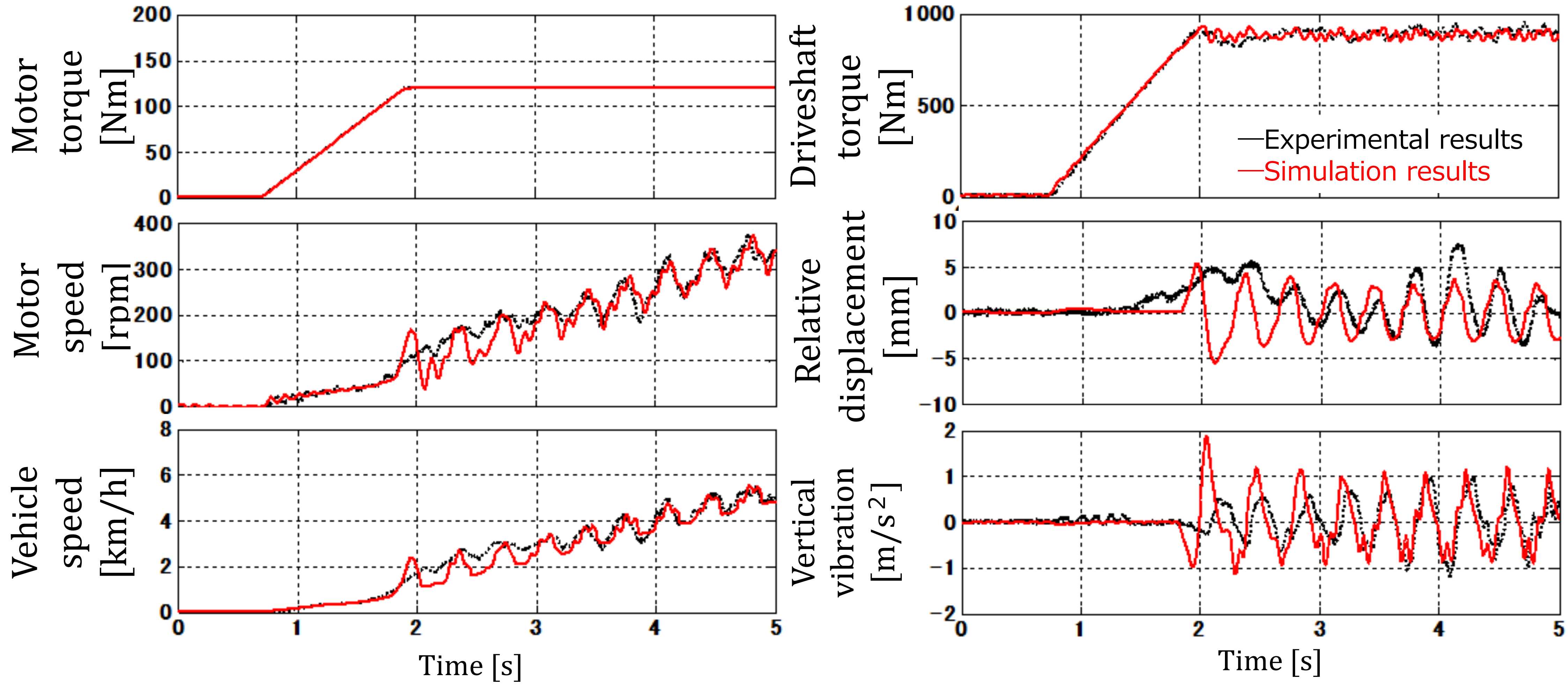




2. Vertical vibration-Vertical vibration simulation model

・Simulation results under the same experiment condition.

・Calibrating the motor speed fluctuations and vertical vibration.



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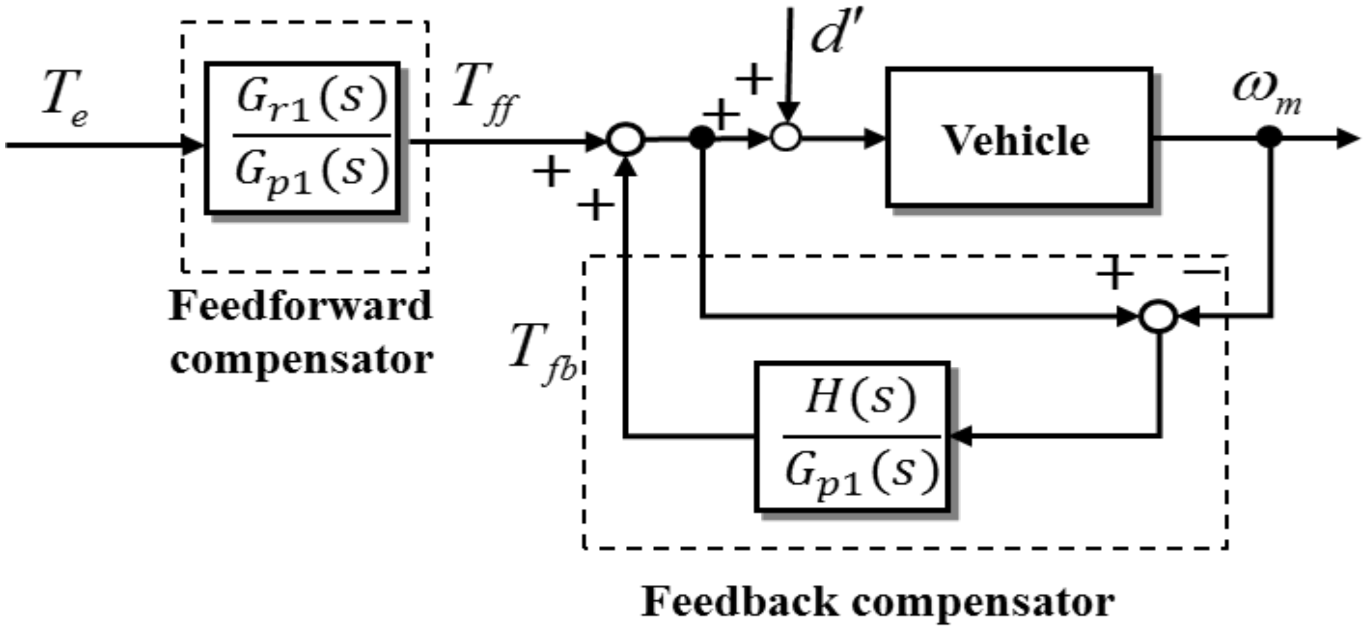
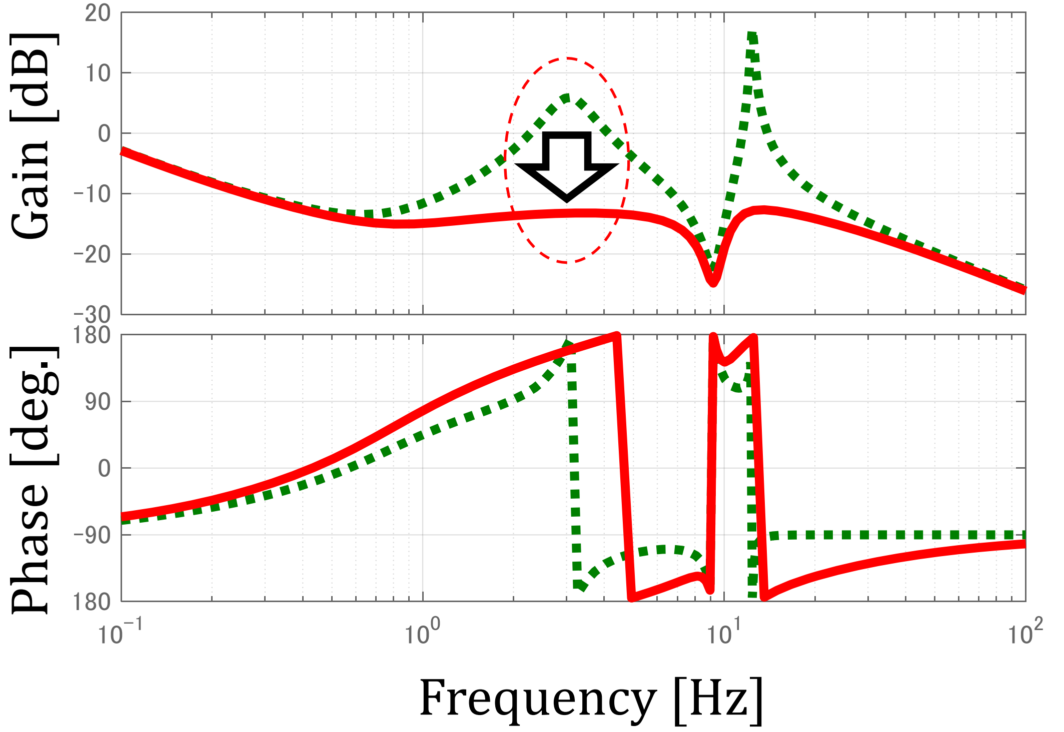
3. Vertical vibration motor control and effect

▪Proposed vibration control for the dry sand condition

▪Reducing the motor speed gain of vertical vibration frequency

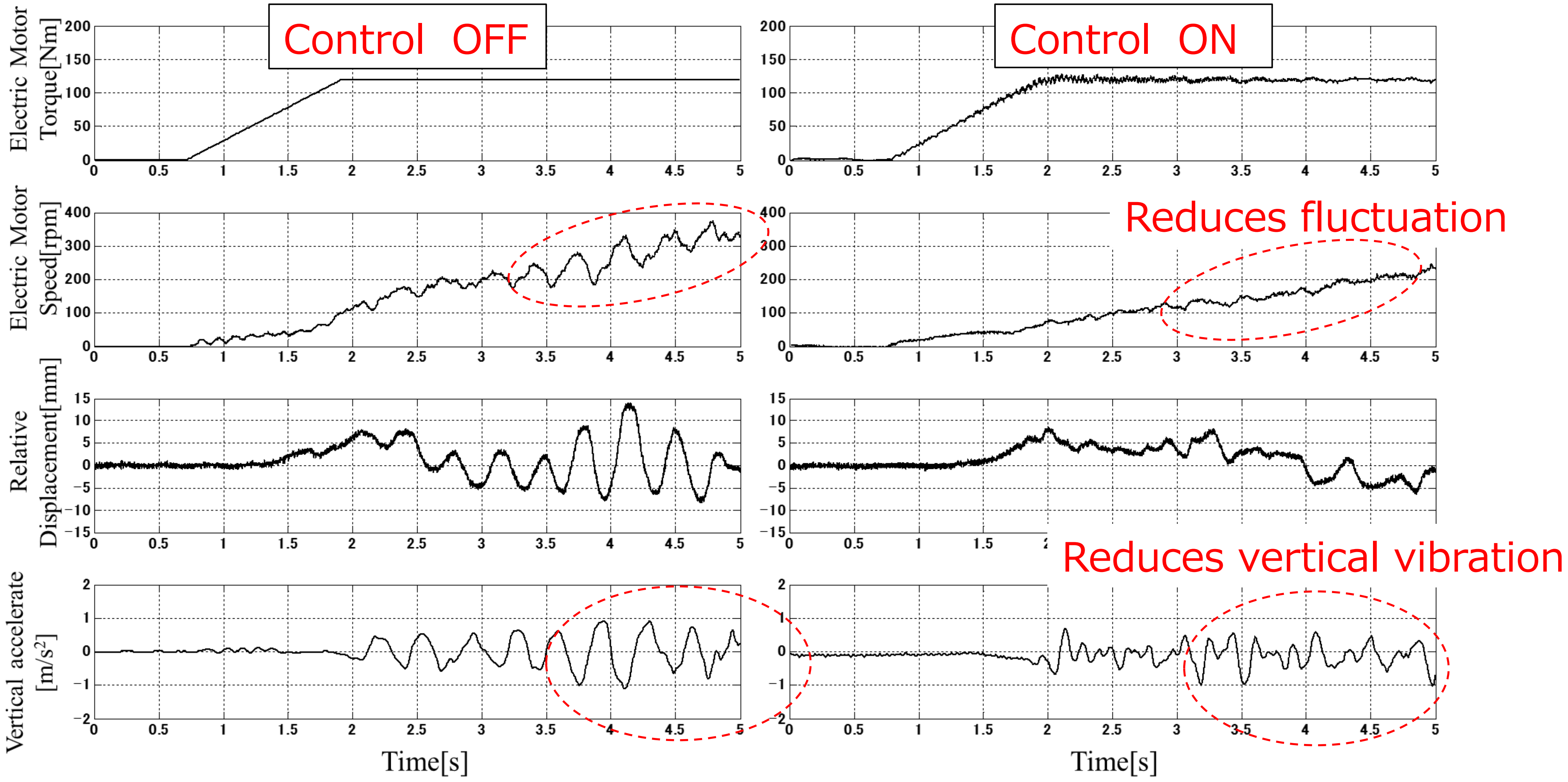


T_e	:Motor torque
ω_m	:Motor speed
T_{ff}	:Feed forward torque
T_{fb}	:Feedback torque
d'	:Disturbance torque



3. Vertical vibration motor control and effect

・Proposed vibration control effects on motor speed fluctuation reduction.
・In the result, low-frequency vertical vibration is reduced.

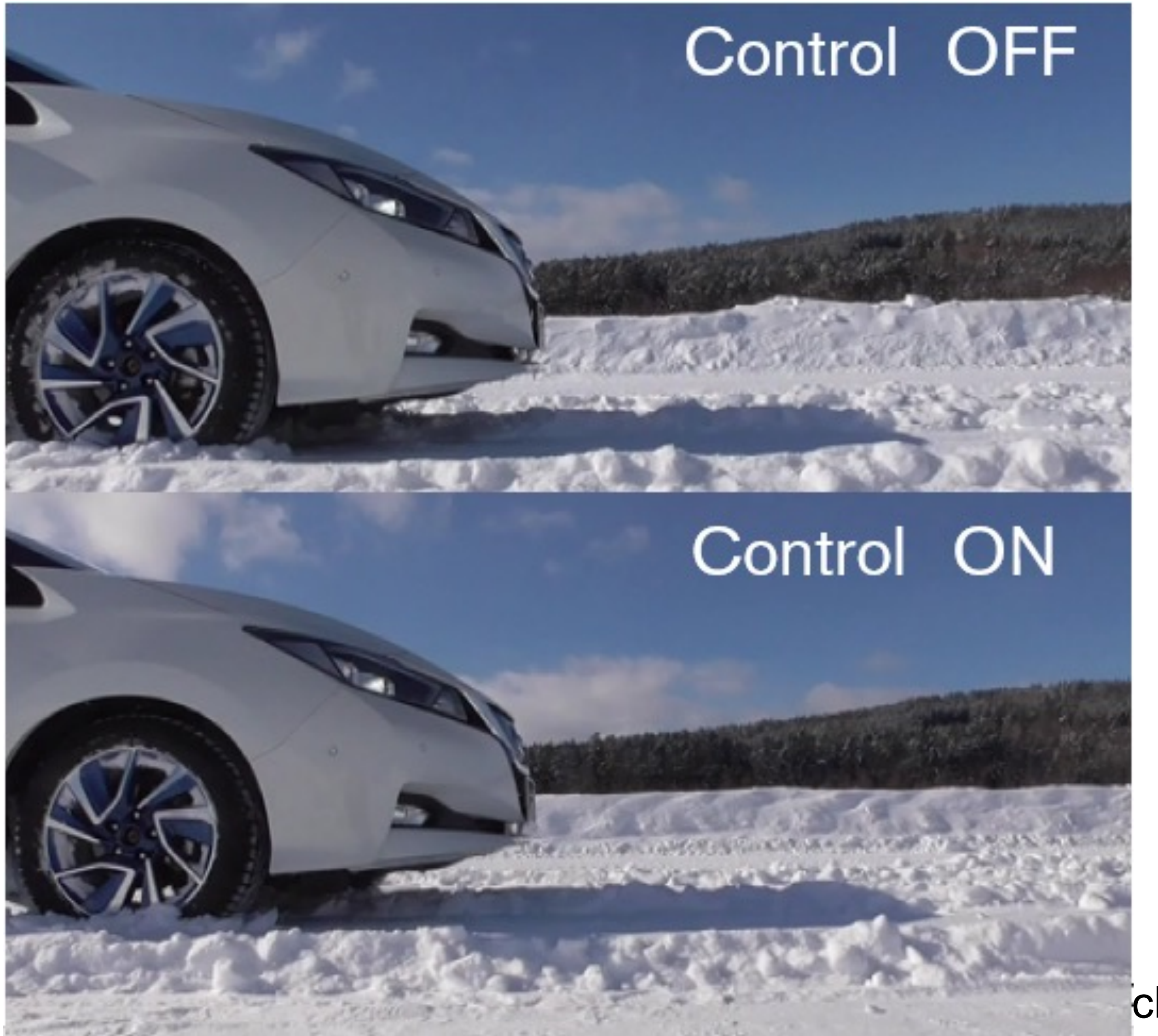


3. Vertical vibration motor control and effect

▪To reduce vertical vibration using motor control

3. Vertical vibration motor control and effect

▪ **Getting the same effect on deep snow as well.**



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4. Summary

・The simulation model was designed based on the transient characteristics under dry sand condition.

・New electric motor control was proposed; it took motor speed fluctuations and vertical vibrations into account.

・Vertical vibration was reduced using the new control method under dry sand condition.

It realized the smooth running also under snow condition.

Thank you for your attention