All Wheel Control for Electric Drive Vehicles
- Outlander PHEV S-AWC -

May, 2019
MITSUBISHI MOTORS
EV/Powertrain Engineering Development Div.
Kaoru SAWASE, Ph.D. & Tomo KATO
All Wheel Control History


8th Galant VR-4 (1996) [AYC/ASC]

3rd Pajero (1999) [SS4 - II]

Grandis (2003) [EC-4WD]

Outlander PHEV (2013)

Lancer Evolution X (2007)

Lancer Evolution VII (2001) [ACD]

8th Galant VR-4 (1996)

Integrated Vehicle Dynamics Control System

S-AWC

Super All Wheel Control

Technology Development Concept

Outlander (2010)

Eclipse Cross (2017)

2nd Pajero (1991) [SS4]

Diamante (1990) [TCL]
To provide “Driving pleasure” and “Toughness & Safety” by making the best use of four tire friction forces (since 1987)
S-AWC : Integrated Vehicle Dynamics Control System

Longitudinal Torque Distribution

Lateral Torque Vectoring

4-wheel Brake Control

acceleration G
lateral G
effective Area
deceleration G

effecti
e

acceleration G
lateral G

effective area
deceleration G

effecti
e

acceleration G
lateral G

effective area
deceleration G

effecti
e
### Longitudinal Torque Distribution

✅ **3 kinds of device with different characteristics**

<table>
<thead>
<tr>
<th>Device</th>
<th>Differential Gear</th>
<th>Clutch</th>
<th>E-Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Configuration</td>
<td><img src="#" alt="Differential Gear Diagram" /></td>
<td><img src="#" alt="Clutch Diagram" /></td>
<td><img src="#" alt="E-Motor Diagram" /></td>
</tr>
<tr>
<td>Torque Distribution Characteristics</td>
<td><img src="#" alt="Torque Distribution Chart" /></td>
<td><img src="#" alt="Torque Distribution Chart" /></td>
<td><img src="#" alt="Torque Distribution Chart" /></td>
</tr>
</tbody>
</table>

- **Fixed Distribution by Design Phase**
  - During only FW speed > RW speed
  - Limit by clutch torque

- **Flexible Distribution**
  - During only FW speed > RW speed
  - Flexible distribution by design phase

< In case of FWD vehicle base >
Target Dynamic Performance of S-AWC

✓ “Confident Driving” as a vehicle behavior is faithful to the driver’s input, namely accelerator, steering, and brake, under any driving condition.
Control Policy of S-AWC

✓ Smooth and seamless control provides predictable vehicle behavior

- **S-AWC (Super All Wheel Control)**
  - Control for traction
  - Control for cornering
  - Control for stability
  - Mixing at anytime
  - 4WD
  - AYC
  - ABS&ASC

- **Usual Control**
  - Control for traction
  - Control for cornering
  - Control for stability
  - Switching by situation
  - 4WD
  - AYC
  - ABS&ASC

Diagram showing control for traction, control for cornering, lateral G, vehicle behavior, control for stability, acceleration G, and deceleration G.
Control Policy of S-AWC

- To realize robust vehicle behavior for various driving conditions

- Predictable cornering limit

- Small difference from dry paved road characteristics

- Steer angle / base steer angle

- Snow road w/o S-AWC
- Snow road w/ S-AWC
- Dry paved road w/o S-AWC
- Dry paved road w/ S-AWC

- Stability factor: A

- Cornering characteristics test

- Drive to course

- Mild acceleration

- 30R
Lancer Evolution X S-AWC

✓ The All Weather Sport Sedan, the first application of S-AWC (2007-2015)

Longitudinal Torque Distribution : ACD
Lateral Torque Vectoring : AYC Differential + Brake AYC
4-wheel Brake Control : ABS & ASC
Outlander PHEV S-AWC

Plugin Hybrid EV equipped with state-of-the-art S-AWC (2013-)

- Longitudinal Torque Distribution: **Twin Motor 4WD**
- Lateral Torque Vectoring: **Brake AYC**
- 4-wheel Brake Control: **ABS & ASC**
Advantage of Twin Motor 4WD

✓ 3 Advantages

- **highly efficient 4WD system**

- **ideal control of longitudinal torque distribution**

- **high flexibility of torque control responses**

**Distribution ratio**

- **Acceleration**
- **Cornering**

**driving torque vs. time**

Response characteristics
Control Diagram of Twin Motor 4WD

✓ Basic Distribution Control to realize Ideal Longitudinal Torque Distribution

Total drive torque $T$

Basic Distribution Control

Front drive torque $T_F$

Rear drive torque $T_R$

Feedback Control

Target Slip Difference Control $T_{DNFB}$

Yaw Rate Feedback Control $T_{YRFB}$

$T_{F0}$

$T_{R0}$

$T_{FB}$
Ideal Longitudinal Torque Distribution

✓ Led from 4-wheel model

\[ G_X : \text{Longitudinal G} \]
\[ G_{Y_{\text{max}}} : \text{Maximum Lateral G} \]
\[ G_{Y_{\text{fmax}}} , G_{Y_{\text{rmax}}} : \text{Maximum} \]
\[ \text{Front / Rear Lateral G} \]
\[ T_f , T_r : \text{Front / Rear Distribution Torque} \]
\[ T_{vf} , T_{vr} : \text{Front / Rear Vectoring Torque} \]
\[ M_f , M_r : \text{Yaw Moment Generated} \]
\[ \text{by Front / Rear Torque Vectoring} \]
\[ R_i : \text{Tire Friction Force of } i \]
\[ D_i : \text{Driving Force of } i \]
\[ C_{mi} : \text{Maximum Cornering Force of } i \]
\[ i = fl, fr, rl, rr : \text{Wheel Position} \]
\[ (\text{Front Left, Front Right, Rear Left, Rear Right}) \]
\[ m_f , m_r : \text{Front / Rear Vehicle Mass} \]
\[ L : \text{Wheel Base} \]
\[ H_g : \text{Height of Center of Gravity} \]
\[ W_f , W_r : \text{Front / Rear Track} \]
\[ K_f , K_r : \text{Front / Rear Vehicle Roll Stiffness} \]
\[ H_f , H_r : \text{Height of Front / Rear Roll Center} \]
\[ H_s : \text{Distance between Center of Gravity and Roll Axis} \]
Ideal Longitudinal Torque Distribution

✓ Analysis result on $\mu = 1.0$

![Graph showing ideal longitudinal torque distribution with analysis result on $\mu = 1.0$.]
Ideal Longitudinal Torque Distribution

✓ Analysis result on $\mu = 0.7$
Ideal Longitudinal Torque Distribution

✓ Analysis result on $\mu = 0.4$
Ideal Longitudinal Torque Distribution

✓ Ideal distribution is achieved from GX and GY as $k_F$

$$k_F = \frac{a}{(a + b)}$$
Effect of Ideal Longitudinal Torque Distribution

✓ Achieve smooth vehicle behavior

Road: Packed snow
Steering: Fix
Accelerator: 50%

R=17.5[m]

Constant Speed

Accelration

Front wheel drive base cont.
Rear wheel drive base cont.
Ideal Distribution cont.
• Technology development concept AWC was described.
• Integrated vehicle dynamics control system S-AWC was defined, and its target performance, control policy and the configuration of each vehicles were described.
• The ideal longitudinal torque distribution, the method to realize it in Twin Motor 4WD, and its effect were described.