Fully Active vs. Reactive AWD coupling systems

How much performance is really needed?

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Manager, Systems Architecture
Overview

1. Market requirements for AWD systems

2. Active and Reactive Systems – two ways of achieving the compromise between performance and cost

3. Performance and costs – what are their major drivers?

4. Control of active and reactive systems

5. System performance requirements

6. How do they compare?

7. The “right“ selection
## Key market requirements

<table>
<thead>
<tr>
<th>Current main focus of OEMs</th>
<th>How to achieve customer targets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>• Reduce complexity</td>
</tr>
<tr>
<td></td>
<td>• Take energy out of the drivetrain</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>• Reduce complexity</td>
</tr>
<tr>
<td></td>
<td>• Optimize control strategy for low clutch wear / oil damage</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>• Reduce number of bearings / bearing positions</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>• Fulfill vehicle dynamics requirement (response / torque distribution)</td>
</tr>
<tr>
<td></td>
<td>• Fulfill torque accuracy requirement</td>
</tr>
<tr>
<td></td>
<td>• Compliance with ABS/ESP</td>
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</table>

**Today's market:**
Achieve sufficient performance at best costs!
Systems overview

Cost vs. Performance

- **Active**: electronic torque w/o delta speed/angle
- **Reactive**: electronic torque with delta speed or angle
- **Passive**: slip dependent only without electronic control

- Slightly better performance leads to significant cost increase
- Slightly lower performance does not fulfill vehicle level requirements
Systems under investigation

- **Active System**
  - Wet multi-plate clutch creating torque with axial force
  - Axial force controlled by the following:
    - Motor/Pump unit
    - Pressure sensor for feedback control

- **Reactive system**
  - Wet multi-plate creating torque with axial force
  - Axial force created by the following:
    - Differential speed sensing pump
    - Controlled by proportional pressure limiting valve
Systems under investigation

- Functional differences

**Active**

- Pump
- Motor
- Pressure Sensor
- ECU
- Clutch

**Reactive**

- Check valve
- Generator pump
- Multi-disc clutch
- Rotational duct
- Oil filter
- Solenoid valve
- ECU

Torque vs. Delta-speed

Control Range
Influencing parameters for performance & cost

- **Active System**
  - High power of actuator
    - Faster system requires stronger motor & ECU
  - High accuracy of torque transfer
    - High quality sensors, elaborate compensations

- **Reactive System**
  - Performance of “reactive element” (=pump) and the possible need for preload
  - Element for control (solenoid)
Influencing parameters – Active System

- **Methods of reducing power requirements**
  - Reduce piston travel \( P = \frac{F \times s}{t} \)
    - Short force path
    - Low compliance friction material
      - Sinter
      - “Stiffer” paper
  - Improve actuator efficiency
    - Operate at best efficiency
  - Implement smart control logic
    - No control with excessive dynamic if not required
Influencing parameters – Active System

- **Methods of improving accuracy**
  - Short tolerance chain by direct pressure measurement

For multi-plate wet clutch:

\[ T = F_a \cdot \mu \cdot R_m \cdot N \]

System must control Force

\[ F_a = P \cdot A_{Piston} \]

Direct pressure measurement
Influencing parameters – Reactive System

- **Method of improving “reactive” element performance**
  - Definition of pump performance
    - \( \frac{dV_{T_{\text{max}}}}{V_{th}} > 5 \rightarrow 30\text{deg} \) delta angle at wheels sufficient to achieve max torque

- **Control element performance**
  - Preload requirement
  - Torque increase/decrease

*No significant need for delta speed*

*Mean delta-\( n = 1.4 \text{rpm})*
Control of Active System

- Active systems are usually used in an overlocked condition unless operated at constant delta speed (ratio mismatch between front and rear axle).

- In this operating condition, the controlled torque capacity is always higher than the actual transferred torque.
Control of Reactive System

- Reactive Systems are transferring the actual required torque according to the tire slip characteristic.
- In this operating condition, the controlled **torque capacity** is always equal to the **actual transferred torque**.
Control of Active and Reactive System

- Rear axle torque transfer
  - Torque Capacity vs. Actual Transferred Torque

### Active System

<table>
<thead>
<tr>
<th>Torque Capacity</th>
<th>Wheel slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
<td></td>
</tr>
<tr>
<td>Vehicle driving torque</td>
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<tr>
<th>Torque capacity</th>
<th>Torque</th>
<th>Vehicle driving torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clutch overlocked</td>
<td>FA Torque</td>
<td>RA Torque</td>
</tr>
<tr>
<td>µFA=1.0</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>µFA=0.5</td>
<td>75%</td>
<td>90%</td>
</tr>
<tr>
<td>µFA=0.2</td>
<td>90%</td>
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### Reactive System

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<th>Torque capacity</th>
<th>Torque</th>
<th>Vehicle driving torque</th>
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<td>Torque</td>
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<tr>
<th>Torque capacity</th>
<th>Torque</th>
<th>Vehicle driving torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clutch not overlocked</td>
<td>µRA=1.0</td>
<td></td>
</tr>
<tr>
<td>Axle load: 50:50</td>
<td>FA=1.0</td>
<td>RA=1.0</td>
</tr>
<tr>
<td>µRA=1.0</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>µRA=0.5</td>
<td>75%</td>
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System performance requirements

• **Fulfill vehicle dynamics requirement**
  – Sufficient torque transferred to the secondary axle
  – Response – increase and decrease torque fast enough
  – Fulfill torque accuracy requirement – if this is an interface with OEM
Sufficient torque transfer

• Possible torque transfer to the rear

\( \mu = \text{const.} \)

Existing potential should be used!

A Open Center Differential (50:50)

B Torque Distribution according Dynamic Axle Loads

Active systems possible Control Range

- Torque on Front Axle [ % ]
- Torque on Rear Axle [ % ]

acceleration [ m/s² ]

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100
Increase and decrease torque fast enough

- **Increase**: Controls algorithms have feedback loop via wheel speeds

**Active System**
- Transition from $T_1$ to $T_2$ when slip detected
- Fast system required

**Reactive System**
- Transition from $T_1$ to $T_2$ is a movement on the characteristic
- Fast response = system feature
Fulfill torque accuracy requirement

- **Common specification**
  - Typical SORs state +/- 10% accuracy

- **What are the real requirements for AWD couplings?**

  ![Diagram showing torque accuracy requirements](Image)

  - Limit torque
  - Eliminate slip at high load
  - Limit binding
  - Low slip for vehicle dynamics

  \[ \frac{\text{Torque actual}}{\text{skid torque}} \]

  \[ \frac{\text{Torque request}}{\text{skid torque}} \]
How do they compare?

- **Key challenges for active system**
  - Low power consumption

- **Key challenges for reactive system**
  - Fast response
  - Accuracy / “Active behavior”
Comparison – Power consumption

Motor
Motor shaft
Pump inner rotor
Pump outer rotor
Pump base plate
Pump mid plate

Integrated Pump – Motor assembly
Optimized for efficiency

$T, \eta$
Operating range

$n$
Comparison – Power consumption

- Actuator Power Measurement in customer driving cycle

Customer driving cycle over time

<table>
<thead>
<tr>
<th></th>
<th>Offroad</th>
<th>Highway</th>
<th>City</th>
</tr>
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<tbody>
<tr>
<td>Power</td>
<td>11.5 W</td>
<td>&lt;2 W</td>
<td>4.2 W</td>
</tr>
</tbody>
</table>

Requested torque

Actual torque
Comparison – Response

- **Vehicle measurement**
  - Reactive system

  
  Same dynamic as active system (<150ms)

  Required torque controlled

  Clutch open

  Slip control

  Time [s]
Comparison – Accuracy

- Rig test evaluation on torque vs. delta-n
  - Significantly worse than active system

Is the same vehicle dynamic with such a variation possible?
Comparison – Accuracy

- **WOT start simulation Reactive System**

![Graph showing acceleration and torque distribution](image)

**Variation between the characteristics**

- 10% absolute variation
- 3% change in torque distribution
Comparison – Accuracy

- Rig test evaluation on torque vs. delta-n
  - Significantly worse than active system

Is the same vehicle dynamic with such a variation possible?

Yes, reactive systems works only together with the tire!
Comparison – Torque transfer

- Required torque transfer

\[ \mu = \text{const.} \]

\[ \mu = 1 \quad \text{dry} \]
\[ \mu = 0.5 \quad \text{wet} \]
\[ \mu = 0.2 \quad \text{snow} \]

A  Open Center Differential (50:50)
B  Torque Distribution according Dynamic Axle Loads
C  Reactive torque transfer

Torque on Front Axle [ % ]
Torque on Rear Axle [ % ]
acceleration \[ m/s^2 \]
Summary

• Active and Reactive systems are almost indistinguishable in the car, also to experienced drivers
  – Same appropriate torque transfer
  – Comparable dynamics
  – Comparable power consumption

• More important requirements for the end customer are:
  – Acoustics / comfort
  – Durability
  – Availability

• There is no “right” selection from a performance perspective

• The “right” selection is driven by other variables
  – Packaging
  – Integration / Interface
  – Customer preference
  – Cost advantages
Open Questions?