Analyse of Clutch-brake System Control Based on Experimental Tests and Applied in Hybrid Power Train

Antoni Szumanowski, Zhiyin Liu, Pawel Krawczyk

Warsaw University of Technology (Poland)
Contents

1. Introduction of the Compact Hybrid Planetary Transmission Drive (CHPTD)
2. Simulation model of CHPTD with the innovative clutch-brake system
3. Simulation results
4. Bench test results on laboratory stand
5. Conclusions
Targets of research

1. Modeling of hybrid power train with clutch-brake system
2. Modeling of control
3. Verification of power train with clutch-brake system based on laboratory bench test
Introduction of CHPTD

The newly improved Compact Hybrid Planetary Transmission Drive

Organized by Hosted by In collaboration with Supported by
Introduction of CHPTD

Pure electric mode

By cooperating with proper control method, clutch/brake system can reduce the degree of freedom of planetary transmission from 2 to 1, which means the drivetrain could work in different modes.

Hybrid mode

<table>
<thead>
<tr>
<th>Operation mode of plug-in hybrid powertrain</th>
<th>Control signal of clutch/brake systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brake I*</td>
</tr>
<tr>
<td>Pure electric drive and regenerative brake</td>
<td>off</td>
</tr>
<tr>
<td>Pure engine drive</td>
<td>on</td>
</tr>
<tr>
<td>Hybrid drive</td>
<td>off</td>
</tr>
<tr>
<td>Engine charge battery (when vehicle stop)</td>
<td>off</td>
</tr>
</tbody>
</table>
Introduction of CHPTD

ICE starting without additional starter motor

Motor

Motor works in braking mode for short time

Brake (Released)

ICE

ICE accelerates

Clutch-brake (Controlled clutch engaging)

Planetary Gear

Multi-speed transmission

Differential
Why controllable clutch-brake system?

- With clutch-brake system, the operation modes of power train can be changed.
- Dynamic control of the clutch engagement time and torque capacity results in smooth and fast ICE start.
- Better efficiency and less abrasion of clutch.
Zero steady-states electrical energy consuming clutch-brake system in CHPTD

1-Electromagnetic actuator  
2-Clutch release plate  
3-friction plate  
4-diaphragm spring
Laboratory stand of CHPTD
Simulation model based on laboratory stand
Simulation model of clutch unit and its controller

- Clutch enable signal
- Current shape in clutch electromagnet coil
- Maximum voltage on clutch electromagnet coil
- Clutch actuation time

Clutch controller

Clutch actuation signal

Clutch torque transfer function and limitation

Clutch torque capacity

Organized by
Hosted by
In collaboration with
Supported by
Clutch engaging with operation modes

Pure electric drive

Hybrid drive

Clutch engaging time
Momentarily generator mode of EM
Speed control basic algorithm in powertrain

Hybrid drive

\[
\begin{align*}
\omega_{\text{ice\_min}}, \omega_{\text{ice\_max}} \quad & \omega_{\text{ice}} = a \omega_{\text{load}} + b \\
\omega_{\text{ice}} &= \omega_{\text{ice\_min}} \quad \text{and} \quad \omega_{\text{ice}} = \omega_{\text{ice\_max}} \\
\omega_{\text{load}} &= \omega_{\text{load\_Th}} \\
\end{align*}
\]

\[
\omega_{\text{ice}} = \frac{\omega_{\text{ice\_max}} - \omega_{\text{ice\_min}}}{\omega_{\text{load\_max}} - \omega_{\text{load\_Th}}} \omega_{\text{load}} + \left( \omega_{\text{ice\_max}} - \frac{\omega_{\text{ice\_max}} - \omega_{\text{ice\_min}}}{\omega_{\text{load\_max}} - \omega_{\text{load\_Th}}} \omega_{\text{load\_max}} \right)
\]

\[
\omega_{\text{em}} = \frac{(1 + k_p) \omega_{\text{load}} - \omega_{\text{ice}}}{k_p} i_{\text{reducer}}
\]
Simulation results of ICE start

- **Point A**: Brake of sun shaft is released.
- **Point B**: The negative torque is generated on ring of planetary by braking the PM motor - the sun shaft is accelerating positively.
- **Point C**: The clutch on sun shaft is engaging with ICE shaft.
- **Point C’ to D**: ICE shaft keeps accelerating while ICE has resistance torque.
- **Point D**: When ICE speed is over the threshold of starting, ICE starts and generates positive torque.
- **Point E**: Speed of sun shaft is synchronized to the ICE shaft, which means the clutch is fully engaged.
Influence of different timing of electric motor braking and clutch engaging

Simulation results
Influence of Different clutch actuation time

Simulation results
Simulation results

The current in clutch electromagnet coil [A]

Time [s]

The clutch actuation time

The maximum current in clutch electromagnet coil

Shape 5
Shape 4
Shape 3
Shape 2
Shape 1

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

Organized by
Hosted by
In collaboration with
Supported by
Simulation results

Influence of different shapes of increasing current in clutch electromagnet coil
Comparison of simulation and bench test results

![Graph comparing simulation and test results](image-url)
Conclusions

- Special clutch-brake system design is necessary for proper hybrid planetary power train operation;
- Proper control strategy for clutch is designed;
- Both different timing of electric motor braking and clutch engaging and current in clutch electromagnet coil could strongly influence the engine start performance which are proved by simulation results.
- The bench test results verify that the simulation model could simulate the behaviours of laboratory stand correctly.
Thank you for attention!

Email: asz@simr.pw.edu.pl