Automotive Transmission Control and Driveline Dynamics

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Automotive Transmission Technologies

• Step gear automatic transmission
• Manual transmission
• Starting clutch/friction launch transmission
• Automated manual transmission
• Continuously variable transmission
• Electrical variable transmission
Step Gear Automatic Transmission

- Increasing number of speeds
- Migrate to clutch to clutch shift
Starting Clutch/Friction Launch Transmission

- For better fuel economy and possible lower cost, a starting clutch is used to replace the torque converter.
- Clutch slip control is critical to achieve desirable drivability.

\[
T = f(\mu, P) \quad T: Torque \quad \mu: Friction \ coefficient
\]

\[
V_{slip} = f(P) \quad V_{slip}: Slip speed \quad P: Pressure
\]
Continuous Variable Transmission

- Better fuel economy and drivability

- Unique actuation challenges
  - Belt drive CVT
  - Chain drive CVT
  - Toroidal drive CVT

- Control challenges: enable fast and smooth ratio change while maintain required torque capacity
Electrical Variable Transmission

- New transmission for hybrid electrical vehicles
- Better fuel economy and emission
- Potential control challenges

- Coordination between engine, motor and generator
- Power recirculation issues
- Smooth shift

Two Mode Hybrid Transmission
Clutch Fill Control

- The fill process
- Over fill and under fill
- Potential remedies
Effect of Clutch Over Fill on Upshift

Power-On Upshift

- Engine Speed
- Output Torque
- Offgoing Pressure
- Oncoming Pressure command & actual

Time (s)
Clutch Slip Control

Objective: To reduce fuel consumption and provide driveline damping by clutch slip control

Clutch slip control is essential for many different transmission technologies:

• Starting clutch/Friction launch
• Dual clutch transmission
• Electrical converter clutch control (ECCC)
Effect of Clutch Slip Control

Upshift with No Control Damping

- Engine Speed
- Output Torque
- Oncoming Pressure
- Offgoing Pressure

Time (s)

Upshift with Control Damping

- Engine Speed
- Output Torque
- Oncoming Pressure
- Offgoing Pressure

Time (s)
Transmission Control Calibration

- Challenge: number of calibration variables goes up quickly with more gear ratios and new powertrain features

- Approaches: systematic approach for calibration
  - Automated tuning
  - Model based control
  - Adaptive learning

- Issues: complexity vs robustness
  - Non-model based control: compatible with traditional calibration process, but may not reduce the complexity drastically.
  - Model based control: greatly reduce or potentially eliminate the calibration complexity, but system robustness highly depends on the fidelity of the model
Shift Schedule

- **Objective:** Optimize the fuel economy while maintaining drivability

- **Traditional way of scheduling shifts**
  - Throttle angle
  - Vehicle speed

- **New trend in shift scheduling**
  - Shift business avoidance
  - Dynamic programming, fuzzy logic, learning control
Hardware Development

- Sensing level
  - Torque sensor
  - Pressure sensor

- Actuation level
  - Fast hydraulic control valve
  - Alternative clutch actuation device

- System level
  - Mechatronic transmission (gear-box integrated electronics)
Alternative Clutch Actuation Device

Objective: To replace the electro-hydraulic clutch actuation system

Benefits: Reduced fuel consumption and enhanced clutch controllability and bandwidth

- Electrical motor driven clutch actuation
  - Require some type of gearing
  - Limited power density

- Smart material based clutch actuation
  - Electrorheological (ER) and magnetorheological (MR) material based clutch
  - Torque capacity and durability
Transmission Control and Driveline Dynamics

Objective: Improve fuel economy while maintaining good drivability

Potential sources for exciting driveline resonance:

- The engine dynamics: Disturbance from engine torque
- The road condition
System Block Diagram

Control objective:

- Damp out the driveline resonances
- Shape the torque transmitted to the vehicle
Controllability of the System

\[ J_e \dot{\theta}_e = T_e - T_c \]
\[ J_t \dot{\theta}_t = T_c - T_t \]

Let \( x_1 = \theta_e \), \( x_2 = w_e \), \( x_3 = \theta_t \), \( x_4 = w_t \)

\[
\begin{bmatrix}
\dot{x}_1 \\
\dot{x}_2 \\
\dot{x}_3 \\
\dot{x}_4
\end{bmatrix} =
\begin{bmatrix}
0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
x_1 \\
x_2 \\
x_3 \\
x_4
\end{bmatrix} +
\begin{bmatrix}
0 \\
\frac{1}{J_e} [T_e - T_c] \\
0 \\
\frac{1}{J_t} [T_c - T_t]
\end{bmatrix}
\]

If the only control variable is \( T_c \) the controllability matrix is:

\[
\begin{bmatrix}
0 & 0 & -\frac{1}{J_e} & 0 \\
0 & 0 & 0 & -\frac{1}{J_e} \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

which is not full rank.

This means one can not control both engine speed and transmission speed by controlling the clutch alone.
Controllability of the System (cont’d)

Define \( x_5 = x_1 - x_3 \) \( x_6 = x_2 - x_4 \)

we then have:

\[
\begin{bmatrix}
\dot{x}_5 \\
\dot{x}_6
\end{bmatrix} =
\begin{bmatrix}
0 & 1 \\
0 & 0
\end{bmatrix}
\begin{bmatrix}
x_5 \\
x_6
\end{bmatrix} +
\frac{1}{J_e} T_c + \frac{1}{J_l} T_l - \left( \frac{1}{J_e} + \frac{1}{J_l} \right) T_c
\]

If the control variable is \( T_c \) the controllability matrix is:

\[
\begin{bmatrix}
-(\frac{1}{J_e} + \frac{1}{J_l}) & 0 \\
0 & -(\frac{1}{J_e} + \frac{1}{J_l})
\end{bmatrix}
\]

which is full rank.

This means one can control the slip across the clutch by controlling the clutch alone.
Control objective:

- Damp out the driveline resonances
- Shape the torque transmitted to the vehicle
Control Design Challenges

• Nonlinearity of the actuation device

• Time varying nature of the input and output disturbances

• System robustness requirement
Hardware Design Challenges

- Torque capacity
- Bandwidth requirement
- Sensors
- Cost
Frequency Domain Based Control Design

Control objective:
- Damp out the driveline resonances
- Shape the torque transmitted to the vehicle

\[ T_c = H_1 H_{\text{notch}} (w_{\text{in}} - w_{\text{out}}) \]

- \( H_1 \) used to shape the transmitted torque
- \( H_{\text{notch}} \) used to damp the resonance

![Frequency Response in Fourth Gear](image)
Summary

Key drivers for automotive transmission development:

- Fuel economy and emission
- Market trend
- Cost

Research and development in both control design methodology and hardware are needed to further advance the automotive transmission technology.