Advanced Transmission Impact on Fuel Displacement

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Sponsored by David Anderson

Project ID #VSS098
Project Overview

Timeline
- Start – September 2012
- End – September 2013
- 50% Complete

Budget
- FY13
  - $200K

Barriers
- Lack of updated transmission model
- Constant advanced in technology
  - Data post-processing and analysis for recent produced transmission
  - Develop and validate model and control

Partnership
- Argonne APRF
- Automotive manufacturer
Relevance
OEMs are Announcing Numerous Advanced Transmission

The new 7+ speed transmission features a wide ratio spread, high numerical first-gear ratio, and quick shifting.

The transmission efficiency and wide ratio spread improve fuel economy by operating at a lower engine rpm in both city and highway environments.

DCT certainly offers smooth acceleration by eliminating the shift shock that accompanies gearshifts in manual transmissions and even some automatics.

Interest in dual-clutch transmissions is particularly strong among OEMs in Europe and major growth markets in Asia, China in particular.

A new continuously variable transmission (CVT) has been developed for midsize vehicles that significantly enhances both driving performance and fuel economy.
Relevance

The objective is to update current transmission models and shifting algorithms as well as develop new ones to evaluate the latest and future technologies

- Argonne has developed and validated shifting algorithms for 4 and 5 speed automatic transmissions, but no extensive work has been done on 6+ speeds or DCTs.
- Transmissions have significantly evolved over the past 5 years and have significant impact on fuel, yet, little work has been done within VTP.
- Validated models and controls will be used to provide more accurately evaluate VTP benefits and guide future R&D.
## Approach

Diverse group of cars/transmissions used for the study

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Type</th>
<th>TM</th>
<th>Engine</th>
<th>EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Honda CIVIC</td>
<td>HEV</td>
<td>CVT</td>
<td>L4 1.6L 82kW</td>
<td>15 kW</td>
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<tr>
<td>2007</td>
<td>Nissan Altima</td>
<td>HEV</td>
<td>CVT</td>
<td>L4 2.5L 118kW</td>
<td>105 kW</td>
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<tr>
<td>2009</td>
<td>VW Jetta 2.0 TDI</td>
<td>Conv</td>
<td>DCT 6spd</td>
<td>Diesel 2.0L 104kW</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>Honda Insight</td>
<td>HEV</td>
<td>CVT</td>
<td>L4 1.3L 73kW</td>
<td>10 kW</td>
</tr>
<tr>
<td>2011</td>
<td>Hyundai Sonata</td>
<td>HEV</td>
<td>AT 6spd</td>
<td>L4 2.4L 154kW</td>
<td>30 kW</td>
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<tr>
<td>2012</td>
<td>Fiat 500</td>
<td>Conv</td>
<td>AT 6spd</td>
<td>L4 1.4L 83kW</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>Ford Focus</td>
<td>Conv</td>
<td>DCT 6spd</td>
<td>L4 2.0L 119kW</td>
<td>-</td>
</tr>
<tr>
<td>2012</td>
<td>Ford Fusion V6</td>
<td>Conv</td>
<td>AT 6spd</td>
<td>V6 3.0L 179kW</td>
<td>-</td>
</tr>
<tr>
<td>2013</td>
<td>Chrysler 300</td>
<td>Conv</td>
<td>AT 8spd</td>
<td>V6 3.6L 224kW</td>
<td>-</td>
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<tr>
<td>2013</td>
<td>Hyundai Sonata</td>
<td>Conv</td>
<td>AT 6spd</td>
<td>L4 2.4L 154kW</td>
<td>-</td>
</tr>
<tr>
<td>2013</td>
<td>Nissan Altima</td>
<td>Conv</td>
<td>CVT</td>
<td>L4 2.5L 136kW</td>
<td>-</td>
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<tr>
<td>2012</td>
<td>Ford F-150</td>
<td>Conv (istop)</td>
<td>AT 6spd</td>
<td>V6 3.5L 272kW</td>
<td>-</td>
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<tr>
<td>2010</td>
<td>Mazda 3</td>
<td>Conv (istop)</td>
<td>MT 5spd</td>
<td>L4 2.0L 110kW</td>
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<tr>
<td>2010</td>
<td>Mercedes S400</td>
<td>HEV (micro)</td>
<td>AT 7spd</td>
<td>L6 3.5L 205kW</td>
<td>15 kW</td>
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<tr>
<td>2010</td>
<td>Mercedes Smart</td>
<td>Conv (istop)</td>
<td>AMT 5spd</td>
<td>L3 1.0L 44kW</td>
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</tr>
<tr>
<td>2012</td>
<td>Peugeot 3008 Hybrid 4</td>
<td>HEV</td>
<td>AMT 6spd</td>
<td>Diesel 2.0L 120kW</td>
<td>27 kW</td>
</tr>
</tbody>
</table>
**Approach**

**Update Current Transmission and Shifting Algorithm**
- **Importing test data**
  - Calculate missing signals and make a process functions for analysis
- **Model calibration and validation**
  - Simulate vehicles
  - Update shifting strategy with the testing data for performance and shifting algorithm

**OEM**
- Collect and integrate transmission data

**ANL APRF**
- Advanced power train research facility
- Vehicle testing work for advanced transmission

**FY14**
- Provide accurate evaluation of VTP benefits guide future R&D

**Adv. Transmission (for DCT, CVT)**
- **Importing test data**
  - Calculate missing signals and make a process functions for analysis
- **Development of adv. transmission**
  - Develop the transmission model
  - Develop algorithm to select optimum gear numbers
  - Validation
<table>
<thead>
<tr>
<th>Milestones</th>
<th>Fist half</th>
<th>Second half</th>
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<tbody>
<tr>
<td>Importing test data</td>
<td></td>
<td></td>
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<tr>
<td>Test data analysis</td>
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<td></td>
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<tr>
<td>Bibliographic search</td>
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<td></td>
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<tr>
<td>Update current transmission and shifting algorithm</td>
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<td></td>
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<tr>
<td>Development of advanced transmission</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model calibration and validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presentation/Report/Paper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Current Status
Technical Accomplishment
Vehicle Test Data Imported in Autonomie for Analysis

1. Import test data into Autonomie
2. Individual sensor evaluation
3. Sensor comparison
4. Calculate effort/flow from sensors
5. Signal comparison/data analysis
6. Shifting strategy
7. Model validation

Quality Analysis (QA)
Analysis & Validation

ANL APRF
Technical Accomplishment
Missing Signals Calculated

- 2013 HMC Sonata Conv. I4 6 speed Automatic Transmission Example

- Calculate missing signals and make a process functions for analysis: Missing signals are computed from measured signals (using component data from Autonomie or OEM)
- The gear ratio is often not present in the data, so an algorithm has to be developed.
Technical Accomplishment
Algorithm Developed to Calculate Gear Ratio

- 2013 HMC Sonata Conv. I4 6 speed Automatic Transmission
  Sonata 6ATX Gear Ratio: 4.212 2.637 1.800 1.386 1.000 0.772

 Gear Ratio Calculation
  0) Signals are aligned based on vehicle speed
  1) \( SR = \frac{\text{Speed In (Measured from Turbine Speed)}}{\text{Speed Out (Calculated from Vehicle Speed)}} \)
  2) \( SR = 1^{st} \) Gear Ratio when Vehicle Speed \( =0 \) & Engine speed < idle speed
  3) Rounds the elements of SR to the nearest value of gear ratio that we know.
  4) Filter out SR to keep current gear ratio for 0.8 sec (minimum)
Technical Accomplishment
Gear Ratio Algorithm Analyzed

- 2013 HMC Sonata Conv. I4 6ATX

- The number of up shifts: 62
- The number of down shifts: 44
- The number of total shifts: 106

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From ANL DOT NHTSA VOLPE Report: Numerous conventional vehicles were tested on the FTP cycle at Argonne’s APRF, including the Fusion (6-speed); the Toyota Echo (5-speed); the Mercedes Benz S400 (7-speed); and the Volkswagen Jetta (7-speed DCT).

1) 5-speed automatic: 110 to 120
2) 6-speed automatic: 110 to 120
3) 7-speed automatic: 130 to 140
4) 7-speed DCT: 130 to 140
Technical Accomplishment
Effort-Flow for Each Component

- 2013 HMC Sonata Conv. I4 6ATX

Torque, Speed In/Out
Torque In = Torque Out / FR * Loss(T)
Speed In = Speed Out * FR

Wheel loss force by rolling resistance
(used rolling resistance coefficient)

Torque In = Torque Out + Loss Or
Torque In = Engine Braking Torque
Speed In = Speed Out

Torque Out = Dyno Force * R
Speed Out = Dyno Speed / R

Dyno Force
Dyno Speed
Speed from CAN

Fixed efficiency (97.5%)

Graphs showing UDDS HS performance with various torque and speed metrics.
Technical Accomplishment

Energy Balance based on Available and Calculated Signals

- 2013 HMC Sonata Conv. I4 6ATX – UDDS under 72F ambient temperature

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Consumption [L/100km]</td>
<td>8.31</td>
</tr>
<tr>
<td>Fuel Economy [mpg]</td>
<td>28.31</td>
</tr>
<tr>
<td>Electrical consumption [Wh/mile]</td>
<td>-1.15</td>
</tr>
<tr>
<td>Initial SOC [%]</td>
<td>70.0</td>
</tr>
<tr>
<td>Final SOC [%]</td>
<td>70.8</td>
</tr>
<tr>
<td>The number of up shifts</td>
<td>62</td>
</tr>
<tr>
<td>The number of down shifts</td>
<td>44</td>
</tr>
<tr>
<td>The number of total shifts</td>
<td>106</td>
</tr>
</tbody>
</table>
Technical Accomplishment
Impact of Higher Gear Number

- F-150 6ATX vs. Chrysler 300 8ATX

By lowering the engine rotational speed, the engine operating torque is expected to increase, leading to lower fuel consumption.
Technical Accomplishment
Impact of Transmission Technology

- Sonata conv. 6ATX vs. Focus 6 DCT vs. Altima conv. CVT

Shifting control rules can be discerned from pedal, v.speed and engine data
Technical Accomplishment
Impact of Powertrain Configuration for Similar Transmissions

- Sonata conv. 6ATX vs. Sonata HEV 6ATX

### Sonata Conv 6ATX

- 1st : 4.21
- 2nd : 2.64
- 3rd : 1.80
- 4th : 1.39
- 5th : 1.00
- 6th : 0.77
- FD : 2.89

### Sonata HEV 6ATX

- 1st : 4.21
- 2nd : 2.64
- 3rd : 1.80
- 4th : 1.39
- 5th : 1.00
- 6th : 0.77
- FD : 3.32

By shifting maps

Load leveling
Technical Accomplishment
Impact of Shifting Modes

- 2013 PSA HEV4 6AMT – One of the modes can be selected manually.

Sport mode uses an aggressive shifting map.
Auto mode map is similar to ZEV mode.
The shifting initializer defines the shifting maps (i.e., values of the parameters of the shifting controller) specific to a selected set of component assumptions.

Example of engine speed range in economical driving, and economical shift

Maximum engine torque at wheels and performance upshift speeds
Technical Accomplishment
Shifting Control Algorithms in Autonomie

- Final shifting curves

- Economical Shifting Speeds

- Performance Shifting Speeds

Design of upshifting and downshifting speed curves for two adjacent gears

Shifting speed curves for a default light-duty vehicle in Autonomie
Collaboration and Coordination with Other Institutions

- Vehicle Testing Data (APRF)
- Component Data (OEM)
- DOE technology evaluation
- Fuel Consumption & Cost Analysis
- R & D Directions
Proposed Future Activities

- **On going work for FY13**
  - Update current transmission models and shifting algorithm in Autonomie
  - Calibrate and validate the models and controls
  - Develop advanced transmission model (i.e. Dual clutch transmission)
  - Develop and validate shifting algorithm to select optimum gear numbers for future transmissions

- **Proposed Future Work**
  - Expand collaborations
    - Validate additional transmission technologies (e.g., 8+ ATX, wet DCT, dry DCT) working with OEMs, government agencies and ANL’s APRF (testing of vehicles with several powertrain)
    - Continue to develop specific advanced transmissions by integrating higher fidelity models, including thermal behavior
    - Evaluate fuel consumptions benefits of advanced technologies
  - Support future medium and heavy duty regulations
Summary

- A process has been developed and implemented to import a wide range of vehicle test data from Argonne APRF representing different transmission technologies in Autonomie.
- Algorithms were developed to calculate missing signals (i.e. gear number).
- Post-processing tools were developed to quickly analyze shifting algorithms from the wide range of data sets, including:
  - Impact of gear number (i.e. AT 6spd vs. AT 8spd)
  - Impact of transmission technology (i.e. 6ATX vs. 6DCT vs. CVT)
  - Impact of powertrain configuration (i.e. Conv 6 ATX vs. HEV 6 ATX)
- Future work will focus on validating the current shifting algorithm in Autonomie for the wide range of transmission considered.
- The updated/new models and controls will be used to evaluate the benefits of VTP developed technologies.