Air Handling Considerations for Dynamic Skip Fire Applied to a 1.8L Turbo 4-Cylinder Engine

North American GT Conference
November 6th, 2017

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Tula Technology
What is Dynamic Skip Fire?

- Firing decisions made on a cylinder-by-cylinder basis: *Dynamic Downsizing*
- Determination whether a cylinder’s torque is required, immediately prior to firing
- Firing Density (FD) chosen to minimize fuel consumption, subject to certain constraints
- Production level NVH, drivability, OBD, and emissions
Tula-Delphi DSF Jetta Demonstrator

**GOAL:** Prove DSF gains on an I4 GTDI vehicle

<table>
<thead>
<tr>
<th>Specifications</th>
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</thead>
<tbody>
<tr>
<td><strong>Engine</strong></td>
<td>1.8L TGDI I4 (EA888)</td>
</tr>
<tr>
<td><strong>Test Weight Class</strong></td>
<td>3500 lb.</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>6AT</td>
</tr>
<tr>
<td><strong>Tailpipe Emissions</strong></td>
<td>SULEV</td>
</tr>
<tr>
<td><strong>Evaporative Emissions</strong></td>
<td>Zero Evap</td>
</tr>
<tr>
<td><strong>EMS</strong></td>
<td>Delphi MT92.1 +</td>
</tr>
<tr>
<td></td>
<td>Tula algorithms</td>
</tr>
<tr>
<td><strong>Deactivation Hardware</strong></td>
<td>Delphi DRFF + OCV</td>
</tr>
<tr>
<td><strong>Projected DSF CO₂ Improvement</strong></td>
<td>7 – 9 %</td>
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</table>
Low pressure exhaust spring (LPES) strategy minimizes thermodynamic losses when skipping
Enabling DSF control within GT-POWER engine model

**DSF Control Block**
- Firing pattern algorithm
- Cylinder-specific valve lift and injection deactivation

**Miscellaneous**
- Custom variable calculation window for RLTs – variation from 720CAD window
- Custom fuel injection control – delay with default injector inputs
- Cylinder blowby model – resolve impact of LPES
- Transient thermal solver – steady solver causes jumps between fired and skipped cycles
Greater MAP variation observed with DSF than I4

- Reduction in MAP = reduction in trapped air mass
- Potential cylinder lambda imbalance if equally fueled
Cylinder refire incurs enhanced gas exchange

- Each Fire1 also a cylinder refire (previous cycle cylinder skipped)
- Greater trapped mass for refire due to lack of valve overlap
- During overlap, exhaust pressure drives backflow into intake reducing gas exchange for Fire2 events
- Refire + MAP variation compounds challenge for cylinder lambda control
Cylinder pressures also show effect of air mass variation

- Sim able to dictate stoich fueling per cylinder - more difficult on dyno
- Exp results show initial cal from Tula fuel compensation algorithm
- Air mass variation leads to cylinder pressure and IMEP variations
- Reasonable agreement between sim and measured – observe overprediction in refire air mass
Simulation provides insight into MAP variation impact

**Engine operating points**

<table>
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<th>Parameter</th>
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<td>2000 rpm</td>
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<td>Engine BMEP</td>
<td>0.5 – 4.5 bar</td>
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<tr>
<td>Firing Fraction</td>
<td>3/4</td>
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- Competition between cam advance and MAP lead to peak RGF around 50kPa MAP
- RGF and MAC maintain a consistent sequence between fires
- Normalized RGF and MAC spread from mean relatively consistent

\[ \text{RGF} = \text{residual gas fraction} \]
\[ \text{MAC} = \text{mass air charge} \]
Simulation provides insight into refire + MAP fluctuation impact

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- Again, peak RGF observed at 50kPa MAP for Fire2
- Consistent decrease in RGF for Fire1 - due to increasing int/cyl PR at IVO
- Normalized MAC spread from mean consistently grows with increasing MAP – due to Fire1
Incremental improvement when fueling each fire stoichiometrically

- Sim and measured depict similar benefit compared to equal fueling
- Incremental fuel consumption improvement up to 1% at 4bar
- Smaller improvement for FF=3/4

- Engine-out CO reduced to acceptable level
- NOx and THC emissions largely unchanged
Conclusions

- GT-POWER engine model of 1.8L EA888 with DSF functionality developed
- Special considerations need to be taken with fueling and RLTs
- Custom cycle definition extending past 720deg would be helpful

- Simulation predicts MAP fluctuations well
- Refire breathing overpredicted – requires further investigation
- Model provides insight into RGF and MAC variations in DSF

- Appropriately fueling each fire leads to meaningful improvements in BSFC and engine-out CO
- Simulation supported algorithm development and calibration on a production-type ECU – more details to be presented at SAE WCX18