Reduction of Transient Particulate Matter Spikes with Decision Tree Based Control

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Outline

• Motivation
• The Difficulty in Predicting PM Spikes
• Decision Tree Based Detection
• Possible Applications
Motivation

Targeted PM Reduction: To control PM spikes during the turbocharger lag period with minimum impact on NO\textsubscript{x} spikes, by targeting exclusive regions.
The Difficulty in Predicting Transient PM Spikes

<table>
<thead>
<tr>
<th>Particulate Rate (PM) predictions over 8 test cycles</th>
<th>Average 100*σ/μ over all cycles</th>
<th>Worst 100*σ/μ over any cycle</th>
<th>Cumulative % Error over 8 cycles</th>
<th>Worst % error over any cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Global Regression</td>
<td>112%</td>
<td>183%</td>
<td>27.99%</td>
<td>46.45%</td>
</tr>
<tr>
<td>2. Neural Networks</td>
<td>146%</td>
<td>190%</td>
<td>43.88%</td>
<td>74.22%</td>
</tr>
<tr>
<td>3. Two-Zone Regression</td>
<td>113%</td>
<td>169%</td>
<td>26.46%</td>
<td>40.20%</td>
</tr>
<tr>
<td>4. Localized Regression</td>
<td>123%</td>
<td>181%</td>
<td>29.70%</td>
<td>47.93%</td>
</tr>
<tr>
<td>5. Robust Regression</td>
<td>120%</td>
<td>191%</td>
<td>30.52%</td>
<td>51.44%</td>
</tr>
</tbody>
</table>

-No empirical method could predict PM point-by-point in a satisfactory manner
-This was particularly true when test data originated from a transient calibration that was different than the transient calibration used to generate training data
-Point by Point results become worse as number of parameters are increased
The Difficulty in Predicting Transient PM Spikes

Primary Reasons

- Inaccurate Fuel-Oxygen ratio estimation during transients
- Inaccurate EGR Fraction estimation during transients

![Graph showing opacity vs. average fuel-oxygen ratio. The graph includes data points for model predictions, ECM estimates, and steady state measurements.](image-url)
EGR Fraction Estimation During Transients

For Orifice Based Estimation: Inaccurate and noisy at low EGR flow rates during turbo lag period
For MAF Based estimation: Volumetric Efficiency estimates inaccurate at high pressure ratios seen during turbo lag period
Volumetric Efficiency Estimation During Transients

-Ratio of Exhaust to Intake Pressure (Pressure Ratio) is much larger for transient data
-However volumetric efficiency correlations are usually based on steady state data

Simulations suggest that the decrease in volumetric efficiency and increase in cylinder-to-cylinder variation is difficult to estimate with current techniques.
PM Spike Detection With Decision Trees

Based on:
- Inaccurate Fuel-Oxygen Ratio and EGR Estimate

Corrected by:
- Manifold Pressure Ratio
- Engine Speed
Decision trees trained with snap throttle transients could detect about 94% of the high opacity points during the turbocharger lag periods of the heavy duty FTP cycle, while falsely classifying about 3% of normal points as high opacity points.
Adjusted Rail Pressure Strategy: GT-Power Simulation Over Selected Segment

Integrated PM reduced by 22% over the baseline integrated mass, while integrated NO\textsubscript{x} mass increased by only 2.4%
Adjusted Rail Pressure and Post Injection Strategy: GT-Power Simulation

Integrated PM reduced by 31% over the baseline integrated mass

Emission Tradeoff Over Selected Spike Event

- Predicted - ECU Rail Pressure
- Predicted - 1300 Bar Pulse
- Predicted - 1600 Bar Pulse
- Predicted - 1900 Bar Pulse
- Predicted - 2200 Bar Pulse
- Predicted - 2500 Bar Pulse
- Predicted - 2800 Bar Pulse
- Predicted - 2800 Bar Pulse and Adjusted Post

Integrated PM reduced by 31% over the baseline integrated mass
Conclusions

• It is difficult to predict transient PM point-by-point with parametric models

• This is because it is difficult to estimate volumetric efficiency, EGR fraction and cylinder-to-cylinder variation in real time during the turbo lag period

• A non-parametric decision tree approach could correctly identify 94% of high opacity spikes while incorrectly classifying 3% of ‘normal’ points.

• Because PM and NOx spikes often occur such that there are relatively large exclusive areas, accurate classification could be used to take targeted action to reduce PM without affecting NOx
References

• Brahma, I. “Analysis and prediction of transient opacity spikes using dimensional modeling”, manuscript in revision


• Brahma, I., Reduction of Transient Particulate Matter Spikes with Decision Tree Based Control, *SAE Int. J. Engines May 2012 5:608-621; doi:10.4271/2012-01-0721*

