Knock Analysis and Prediction: Application to Motorcycle Engines

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1. Background
2. Knock Analysis
3. Knock Prediction
3. Application to Engine Model
4. New Knock Correlation
5. Conclusion
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Characteristics of Motorcycles Engine

- Small engine displacement
- High engine speed
- Wide valve overlap
- Rich combustion
- Air or water cooled

Motorcycle

Automobile
Goal

To predict the knock-limited spark timing of motorcycle engines within GT-Power with sufficient accuracy for use in the engine development cycle.
## Test Engine Specifications

<table>
<thead>
<tr>
<th></th>
<th>Engine 1</th>
<th>Engine 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine type</td>
<td>single cylinder</td>
<td>single cylinder</td>
</tr>
<tr>
<td>Cooling type</td>
<td>Air cooled</td>
<td>Water cooled</td>
</tr>
<tr>
<td>Bore × Stroke (mm)</td>
<td>50.0 × 55.6</td>
<td>76.0 × 55.0</td>
</tr>
<tr>
<td>Displacement (cm³)</td>
<td>109</td>
<td>249</td>
</tr>
<tr>
<td>Valve layout</td>
<td>1 intake, 1 exhaust</td>
<td>2 intake, 2 exhaust</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>9.0</td>
<td>10.7</td>
</tr>
<tr>
<td>Combustion chamber</td>
<td>Hemispherical type</td>
<td>Pent roof type</td>
</tr>
</tbody>
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Multi-Cycle Three Pressure Analysis

- Pressure Analysis of consecutive cycles

Engine 2: 249cc water cooled engine
Knock Analysis

Theoretical knock frequencies:

\[ f = \frac{c \alpha_{m,n}}{\pi B} \]

- \( a_{1,0} \)
- \( a_{2,0} \)
Gamma Technologies

Knock Analysis

Fourier Analysis

Theoretical knock frequencies:

\[ f = \frac{c \alpha_{m,n}}{\pi B} \]
Knock Analysis

Theoretical knock frequencies:

\[ f = \frac{c \alpha_m}{\pi B} \]

Knock Strength:
Maximum Amplitude of Pressure Oscillation (MAPO)
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Empirical correlation of ignition delay

\[ \tau = A p^{-n} \exp\left( \frac{B}{T} \right) \]

Autoignition criteria

\[ \int_{t=0}^{t_a} \frac{d \tau}{\tau} = 1 \]

Available correlations

- **Douaud & Eyzat** (SAE Paper 780080)
Douaud & Eyzat predicts knock onset well for individual cycles, within the range of measurement and analysis error.
Full Engine Models

- Calibrated for performance prediction for usual production development
- Measured wall temperatures
- SITurb combustion model
  - Single set of constants for each engine
  - Good overall performance prediction, larger error at lower loads
Knock Model Calibration

- **Goal:** Predict the knock-limited spark advance (KLSA)
- **Measurement**
  - KLSA determined on the test bench
- **Prediction**
  - KLSA determined in the full engine model
- **Douaud & Eyzat**
  - Calibrated with Knock Induction Time Multiplier
  - Knock boundary defined by Knock Index = 0
Knock-Limited Spark Advance: Engine 1

W.O.T.

Throttle 65%

Throttle 42%

good correlation with the measured data
Knock-Limited Spark Advance: Engine 2

W.O.T.

Throttle 78%

Throttle 52%

Throttle 33%
Douaud & Eyzat Results

• Application of D&E knock model to test engines is able to predict the knock-limited spark advance with sufficient accuracy for use in the engine development cycle

• However, this application has low residual content and nearly constant air/fuel ratio

• For other applications, need improved knock correlation that takes into account larger residual content, varying air/fuel ratio, and fuel effects
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New Knock Correlation (V7.3)

- Based on detailed kinetics simulations – MultiChem kinetics mechanism (113 species and 487 reactions)
- Valid over a wide temperature range
- Negative temperature coefficient (NTC) behavior
  - Effect of Air-Fuel ratio
  - Effect of EGR
  - Fuel effects

NTC behavior depends mainly on the

- Fuel
- Air-Fuel ratio
- Pressure
New Knock Correlation (V7.3)

\[ \tau_i = a_i \left( \frac{ON}{100} \right)^{b_i} [Fuel]^{c_i} [O_2]^{d_i} [Diluent]^{e_i} \exp \left( \frac{F_i}{T} \right) \quad i = 1, 2, \text{and } 3 \]

ON is the fuel octane number

[Fuel], [O2], and [Diluent] are the concentration expressed in mol/m3

[Diluent] is the sum of N2, CO2, and H2O concentrations

\[ \frac{1}{\tau} = \frac{1}{\tau_1 + \tau_2} + \frac{1}{\tau_3} \]

Yates, Andy D. B. et al., SAE 2005-01-2083
New Correlation vs Kinetics Predictions

Effect of Pressure

Effect of Octane Number

Effect of Air-Fuel ratio

Effect of EGR
New Correlation vs. Experiment

- New Correlation-2500RPM 100% Throttle
- D&E

- New Correlation-2500RPM 21% Throttle EGR
- D&E
New Correlation vs. Experiment

1. New Correlation-2500RPM 100% Throttle vs. D&E
2. New Correlation-2500RPM 21% Throttle EGR vs. D&E

Douaud & Eyzat captures average effect
New Correlation – EGR Sweep

Knock Limited Spark Advance

- 1500 RPM
- 2000 RPM
- 2500 RPM

KLSA - KLSA(eg=0)

EGR%

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Conclusion

- GT-Suite tools provide convenient capability to perform pressure analysis of consecutive cycles and/or average cycle
  - Burn rate
  - Knock onset and strength

- Existing knock correlations
  - Douaud & Eyzat model can predict knock onset for individual and average cycle for cases of low residuals and constant air-fuel ratio despite NTC behavior
  - Application of Douaud & Eyzat model to 2 motorcycle engines showed good predictive capability for identifying knock-limited spark advance

- New knock correlation
  - Accurate over full engine operating temperature range
  - Built-in sensitivity for EGR and air-fuel ratio
  - Applicable to varying fuel characteristics such as octane number and composition