Thermal and Mechanical Loading in the Combustion Bowl Region of Light Vehicle Diesel AlSiCuNiMg Pistons; Reviewed with Emphasis on Advanced Finite Element Analysis and Instrumented Engine Testing Techniques.

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Light Vehicle Diesel Piston Combustion Bowl Loading and Temperature Measurement.

Contents.

- **LVD Combustion Bowl Failure.**
- FEA Combustion Bowl Loading.
- Instrumented Engine Testing.
- Future Work.
LVD Combustion Bowl Failure.

Dominant Combustion Bowl Rim Failure Locations

Skirt Axis Failure Location

Pin Axis Failure Location

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LVD Combustion Bowl Failure.
Dominant Thermomechanical fatigue (TMF) Load Regimes.

Pin Axis Failure Location

- HCMF: Tensile

Skirt Axis Failure Location

- HCMF: Compressive

- HCTF & LCTF (Theta (θ) Out of Phase (OP))

= Combustion bowl TMF loading
Light Vehicle Diesel Piston Combustion Bowl Loading and Temperature Measurement.

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FEA Combustion Bowl Loading.
In-cylinder axial mechanical loading

Section thrust plane    Section pin plane

Mech. von Mises stress and mech. deformation (scale factor 25) at max. gas pressure (TDCF).
FEA Combustion Bowl Loading.

HC mechanical fatigue loading (HCMF)

Bowl edge mechanical hoop stress.
(Crank angle shown -270-270°)

Circumferential mechanical stress around the bowl edge at max. gas pressure (TDCF)
FEA Combustion Bowl Loading.
HC thermal boundary conditions

Heat transfer coefficients (HTC)

In-cylinder gas temperature.

In-cylinder cycle simulation results.
FEA Combustion Bowl Loading.

HC temperature loading (Max. power)

Cycle averaged temperature prediction maximum power condition. Source 2.0l 150kW LVD engine.
FEA Combustion Bowl Loading.

HC thermal loading: bowl edge (max. power)
FEA Combustion Bowl Loading.

HC thermal fatigue (HCTF) loading “??”

Key Design Critical Factor:

- Penetration of the temperature transient.

Variables to quantify:

- Combustion loading.
- Component surface condition.
- Viscoplastic/creep material response.
Superimposed HCTF + HCMF

Cycle averaged HC temperature distribution.

Transient HC temperature distribution.

\[ \sigma_M + \sigma_T \]

Temperature.
FEA Combustion Bowl Loading.

LC thermal loading: Variable engine operation.

Equivalent FEA cycle

FEA Cycle description i.e.

Point 1: Low Load Parameter (initial)
Point 2: High Load Parameter (A)
Point 3: High Load Parameter (B)
Point 4: Low Load Parameter (A)
Point 5: Low Load Parameter (B)
FEA Combustion Bowl Loading.

LC transient thermal fatigue loading (LCTF)

Design Critical Factors:
• Thermal constraint.
• Temperature range

Variables to quantify:
• Heating and cooling rate.
• Critical cycle temperature profiles.
• Viscous material response.
FEA Combustion Bowl Loading.

Superimposed LCTF + HCMF loading.
Light Vehicle Diesel Piston Combustion Bowl Loading and Temperature Measurement.

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- Instrumented Engine Testing
- Future Work.
Engine Measurement Technique: NTC (Coil Telemetry)

Instrumented Engine Testing

Test Cycle Diagnostics

Time (s) vs. Temp (°C)

ARR Measurements:

1) Power and Torque Curve Statistics
2) Engine sign-off test specifications
3) Calibration and oil flow diagnostics
Instrumented Engine Testing

Engine Measurement Technique: Linkage System

ARR Measurements:
- 1) HF Combustion bowl surface.
- 2) Complex thermal gradient work.
NTC: Variable load Temperatures

Temperature close to the Bowl Edge Location

Simulation validation requires detailed measurements of:

- Critical sign-off cycles.
- Thermal gradients.
- Heating and cooling rates.

Heating and Cooling Rate
High Frequency Transient Temperature.

Simulation validation requires detailed understanding of:

- Crown temperature conditions.
- Thermal gradients.
- Heating and cooling rates.

Measured Temperature @3800rpm
Light Vehicle Diesel Piston Combustion Bowl Loading and Temperature Measurement.

Contents.
- LVD Combustion Bowl Failure.
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- Future Work.
Future Work (ARR Focused)

Instrumented engine testing:
- Minor input errors → major errors in predictive durability results.
- Instrumented testing should be a benchmark during the development of modern LVD platforms.

Engine-like rig tests for deformation and fatigue properties:
- Superimposed HCMF + LCTF

\[ \sigma \varepsilon \text{ hysteresis} \]

- Max.
- Mean
- Min.

\[ \sigma \text{ & } T \text{ verus } t \]
Light Vehicle Diesel Piston Combustion Bowl Loading and Temperature Measurement.

EXTRAS
Circumferential mechanical stress around the bowl edge at max. gas pressure (TDCF)
FEA Combustion Bowl Loading.

Bowl edge pin-axis (front)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Transient Cyclic</th>
<th>Cycle Averaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min (MPa)</td>
<td>-19.90</td>
<td>-1.22</td>
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<tr>
<td>Max (MPa)</td>
<td>18.24</td>
<td>19.40</td>
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<tr>
<td>Amplitude (MPa)</td>
<td>19.07</td>
<td>10.31</td>
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<tr>
<td>FOS(1e8 97.5%)</td>
<td>1.56</td>
<td>2.39</td>
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Bowl Edge Running-axis (Thrust)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Transient Cyclic</th>
<th>Cycle Averaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min (MPa)</td>
<td>-45.24</td>
<td>-29.37</td>
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<tr>
<td>Max (MPa)</td>
<td>4.18</td>
<td>-1.83</td>
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<tr>
<td>Amplitude (MPa)</td>
<td>24.71</td>
<td>13.77</td>
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<tr>
<td>FOS(1e8 97.5%)</td>
<td>1.15</td>
<td>2.06</td>
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</table>
Validating the Design Process.

**Inputs**
- Nominal or worst case values of
  - Dimensions
  - Materials
  - Load(s) …

**Input Variability**
- Dimensions
- Materials
- Load History
- Usage
- Manufacturing …

**Outputs**
- Point Estimate of
  - Performance
  - Life
  - Factor of Strength

**CAE Model**

**Analytical Reliability & Robustness Methodology**

**RRM Performance Variability**
- Assessment
- Design Direction
- Optimum Design

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NTC Measurement: Cooling Oil Flow

Simulation validation requires detailed measurements of:

- The temperatures in the component and throughout the engine.

- Temperature close to the Bowl Edge Location

Graphs showing temperature changes with speed for different cooling flows.

- Gallery Cooled:
  - 3.5l/min 1.2bar
  - 2.5l/min 1.2bar
  - 1.5l/min 1.2bar

- Undercrown Cooled
FEA Combustion Bowl Loading.

Bowl edge pin-axis (front)

Bowl edge running-axis (Thrust)

Min. Stress

Max. Stress

Min. Stress

Max. Stress