Design Challenges of Locomotive Diesel Engines

Roy J. Primus
GE Global Research Center

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Typical Locomotive Configuration

- The longest locomotives are 74-76 feet (track radius restrictions)
- Average height is 15 feet and 5-1/4 inches (infrastructure restrictions)
- Fully-serviced locomotives weigh up to 420,000 pounds (35 ton/axel)
- The life expectancy for locomotives is approximately 20 years
Locomotive Operation

- **Locomotive Consist**
  - Two or more locomotives in same train
  - Can face either forward or backward
  - Can be located anywhere in the train

- **Tunnel operation**
  - Trailing locomotive(s) see exhaust from lead loco(s)
  - Effective ambient > 180 F (emissions, durability)

- **Shock & Bending loads**
  - 3g's longitudinal with more than 400,000 lbs
  - Mechanical loading on pipes & attachments
GE Evolution Locomotive Diesel Engine

Four-stroke
Direct-injected (unit pump system)
Single-stage turbocharged (axial-radial)
Hybrid air-to-air charge air cooling

Bore mm 250
Stroke mm 320
Displacement l/cyl 15.7
# Cylinders - 12
Total Displacement l 188
Power hp 4500
Power/cyl hp/cyl 375
BMEP bar 20.3
Speed rev/min 1050
Mean Piston Speed m/s 11.2
Locomotive Operation Points - Notches

Percent of Maximum Power

Idle  DB2  N1  N2  N3  N4  N5  N6  N7  N8
Emissions Certification

• Ambient condition range
  > Ambient temperature from 45°F to 105°F
  > Sea level to 7000 ft

• Useful life
  > $7.5 \times (\text{rated HP}) \text{ [MW-hrs]}$
  > 33,750 \text{ MW-hrs for a 4500hp engine}
  > 10 years

• In-use testing
EPA Locomotive Switcher Weighting

<table>
<thead>
<tr>
<th>Cycle Weighting factors</th>
<th>EPA switcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notch</td>
<td>0.299</td>
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<tr>
<td>Low Idle</td>
<td>0.299</td>
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<tr>
<td>Idle</td>
<td>0.299</td>
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<tr>
<td>DB-2</td>
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<tr>
<td>N1</td>
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<tr>
<td>N2</td>
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<td>N3</td>
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<tr>
<td>N4</td>
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<td>N5</td>
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<tr>
<td>N6</td>
<td>0.015</td>
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<td>N7</td>
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<tr>
<td>N8</td>
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<tr>
<td>Total</td>
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EPA Locomotive Freight Weighting

**Cycle Weighting factors**

<table>
<thead>
<tr>
<th>Notch</th>
<th>EPA</th>
<th>Freight</th>
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<tr>
<td>Idle</td>
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<td>N1</td>
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<td>N3</td>
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<td>N4</td>
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<td>N5</td>
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<td>0.078</td>
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<tr>
<td>N7</td>
<td>0.030</td>
<td>0.060</td>
</tr>
<tr>
<td>N8</td>
<td>0.162</td>
<td>0.324</td>
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<td><strong>Total</strong></td>
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<td>2.000</td>
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</table>

- **Engine Speed (rpm)**
  - **Torque (ft-lbs)**

**Notation**:
- LI: Low Idle
- Idle
- DB2
- N1 - N8

**Legend**:
- N1: 400 rpm
- N2: 600 rpm
- N3: 800 rpm
- N4: 1000 rpm
- N5: 1200 rpm
- N6: 1400 rpm
- N7: 1600 rpm
- N8: 1800 rpm
### EPA Locomotive Standards

<table>
<thead>
<tr>
<th>Tier</th>
<th>Cycle</th>
<th>NOx</th>
<th>PM</th>
<th>HC</th>
<th>CO</th>
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<tbody>
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<td>(2002-2004)</td>
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<td>(2005-?)</td>
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NOx Emissions

NOx formation function of Temperature and Time

Data from SAE 2000-01-1177
EPA Locomotive Rule Making Timeline

- ANPRM published June 29, 2004
- Comment period closed August 30, 2004
- NPRM expected ~ Q1-2006
- Final rule expected ~ 2007
- 500 ppm sulfur fuel June 2007
- Compliance time frame
  > Not clear if 1 or 2 steps
  > Expect new reg. ~ 2011
- 15 ppm sulfur fuel 2012
Summary

• Consist operation and tunnel environment are major design concerns
• The lower speed of the locomotive engine provides longer residence time for NOx formation
• Soot not as speed sensitive as NOx (combination of formation and oxidation)
• Expect EPA to publish NPRM for Tier 3/4 locomotive emissions standards in early 2006