Use of cycle simulation for matching a R2S turbo system to a HD diesel engine
Contents

- Motivation
- Engine modeling in GT-Power
- Turbocharger matching
- Discussion of results
- Conclusion
Motivation

Engine information

- Extension of the already existing V8 500 kW engine
- Main engine for excavators, maritime and crawler cranes

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Number of cylinders:</td>
<td>12</td>
</tr>
<tr>
<td>V-angle:</td>
<td>90°</td>
</tr>
<tr>
<td>Capacity:</td>
<td>24 l</td>
</tr>
<tr>
<td>Power:</td>
<td>750 kW @ 1900 rpm</td>
</tr>
<tr>
<td>Torque @ 1000 rpm:</td>
<td>4000 Nm</td>
</tr>
<tr>
<td>Injection system:</td>
<td>Common rail</td>
</tr>
<tr>
<td>Emission compliance:</td>
<td>Tier 4 phase-in (NO\textsubscript{x} 3.5 g / kWh and NTE requirements)</td>
</tr>
<tr>
<td>Emission control:</td>
<td>High pressure, externally cooled EGR</td>
</tr>
</tbody>
</table>
Engine modeling in GT-Power

Preliminary conclusions

- Required EGR Rate based on test bench experience:
  - 10% @ 1000 RPM
  - 20% @ 2100 RPM
- Regulated 2-Stage turbo system required

Modeling basis

- Model based on calibrated V8 model:
  - Combustion profiles in interpolation tables dependent on speed and load
  - Boundary conditions in interpolation tables dependent on speed and load
  - Heat transfer models
- Modified intake and exhaust system
- Modified EGR control system
Model overview
Turbocharger and inter-stage cooler

- Bypass on HP-turbine controlled via boost pressure
- Turbocharger performance maps defined via soft links to standard SAE-files
- Inter-stage cooler modeled as semi-predictive cooler
EGR system

- Externally cooled high-pressure EGR
- Check valves to overcome positive pressure gradient
- EGR cooler with imposed wall temperature
- Heat transfer coefficient calibrated to meet maximum outlet temperature requirement at rated power
EGR control

- EGR Rate controlled via PID controller:
  - Butterfly valve before EGR cooler
  - Intake throttle before EGR injector

- Switches used to impose following constraints:
  - Intake throttle only allowed to restrict airflow if EGR valve fully open
  - EGR valve only allowed to close if intake throttle fully open
Simulation procedure and selection criteria

About 50 combinations were tested and compared to following requirements:

- Minimum air-fuel ratio at 1000 RPM above limit
- Specified EGR rate attainable
- Maximum outlet temperature after compressor below limit
- Maximum blade speed below limit
- Maximum bypass at HP turbine below limit

Remaining combinations finally ranked with the following criteria:

- ISFC
- Transient response
- Intake throttle
- Packaging and cost
ISFC – indicated specific fuel consumption

**ISFC - Indicated Specific Fuel Consumption**

- **A**
- **B**
- **C**
- **D**

**Engine Speed [RPM]**

**ISFC**

900 1200 1500 1800 2100
Air-fuel ratio
Compression ratio

Compressor Pressure Ratio

Pressure Ratio

Engine Speed [RPM]

min

900 1200 1500 1800 2100

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12 Matching a regulated 2-stage turbo system
EGR control

![EGR control graph]

- Throttle -A-
- Valve -A-
- Throttle -B-
- Valve -B-
- Throttle -C-
- Valve -C-
- Throttle -D-
- Valve -D-

max EGR opening

Engine Speed [RPM]

900 1200 1500 1800 2100

EGR Valve and Intake Throttle Opening

Matching a regulated 2-stage turbo system
Transient response

BMEP - Break Mean Effective Pressure

10%  95%

Time

BMEP

Matching a regulated 2-stage turbo system
Turbocharger speed

The graph shows the angular speed of the turbocharger over time for different conditions. The x-axis represents time, and the y-axis represents angular speed. Various lines with different colors and styles indicate different HP and LP (High Pressure and Low Pressure) conditions labeled A to D.
## Summary

<table>
<thead>
<tr>
<th>Criteria</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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</thead>
<tbody>
<tr>
<td>ISFC</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>o</td>
</tr>
<tr>
<td>Intake throttle*</td>
<td>-</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>EGR margin</td>
<td>-</td>
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<td>o</td>
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<tr>
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<td>-</td>
<td>o</td>
<td>o</td>
</tr>
<tr>
<td>Suitability for higher power rating</td>
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<td>o</td>
</tr>
<tr>
<td>Packaging and cost</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>o</td>
</tr>
</tbody>
</table>

*) “+” if no intake throttle required
Conclusion and outlook

- Combinations -C- and -D- will be realized as prototypes for evaluation on test bench
- Combinations -A- and -B- are not suitable for testing
- As soon as first measurements are available the model will be calibrated and a new calculation iteration will be triggered
Thank you for your attention!