Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

Prepared for

GT- CONFERENCE 2019

Pune, 21.01.2019
Sagar Chavan, Emran Ashraf
Content

- Introduction
- Engine and Performance Specification
- Engine Layout and Simulation Models
- Full Load Performance Results with E-Compressor
- Part Load Performance Results with E-Compressor
- NOx Modelling Technique
- Part Load Results
  - With Nox Modelling results
- Conclusion/Summary
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

CO2 TARGETS

<table>
<thead>
<tr>
<th>Year</th>
<th>Target 2006</th>
<th>Target 2015</th>
<th>Target 2020</th>
<th>Target 2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>160</td>
<td>130</td>
<td>95</td>
<td>~80*</td>
</tr>
<tr>
<td>2015</td>
<td>182</td>
<td>132</td>
<td>97*</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td>149</td>
<td>125</td>
<td>105*</td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td>188</td>
<td>167</td>
<td>117*</td>
</tr>
</tbody>
</table>

Source: ICCT, FEV
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**BASE ENGINE SPECIFICATION**

<table>
<thead>
<tr>
<th>Description</th>
<th>Engine Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Segment</td>
<td>SUV</td>
</tr>
<tr>
<td>Fuel</td>
<td>Diesel</td>
</tr>
<tr>
<td>Engine Displacement [L]</td>
<td>2</td>
</tr>
<tr>
<td>Power [kW]</td>
<td>120</td>
</tr>
<tr>
<td>Max Torque [Nm]</td>
<td>382</td>
</tr>
<tr>
<td>EGR</td>
<td>Cooled HP-EGR</td>
</tr>
<tr>
<td>TC</td>
<td>VGT</td>
</tr>
</tbody>
</table>

**SUV Vehicle Example**
## PERFORMANCE SPECIFICATION

<table>
<thead>
<tr>
<th>Description</th>
<th>Base Performance</th>
<th>Target Performance (with E-Compressor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power [kW]</td>
<td>120</td>
<td>135</td>
</tr>
<tr>
<td>Rated Speed [rpm]</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>Rated BMEP [bar]</td>
<td>20.6</td>
<td>23</td>
</tr>
<tr>
<td>Max Torque [Nm]</td>
<td>382</td>
<td>382</td>
</tr>
<tr>
<td>Max Torque Speed [rpm]</td>
<td>1750-3000</td>
<td>1250-3000</td>
</tr>
<tr>
<td>Max Torque BMEP [rpm]</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>
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ENGINE LAYOUT

- Intake throttle
- HP EGR
- E-COMPRESSOR
  - By-pass
- To Turbine
- DOC
- DPF
- SCR
- ASC
- Urea Doser
- To Main Compressor

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GT MODEL

Footnote

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BASE ENGINE PERFORMANCE

Max Torque: 382 Nm

Remark
- Base engine performance
- Max Torque: 382 Nm
- Rated Power: 120 kW

Footnote 11
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PERFORMANCE COMPARISON

- Rated power increased to 135 kW from 120 kW
- Max torque load point for E-Compressor straight from 1250 rpm
- BSFC improvement
  - At 1000 rpm: 6 %
  - At 2000 rpm: 4 %

Remark

- Significant improvement in low end torque → Enhanced drivability
- Power limitation due to limit in compressor outlet temp

Footnote 12
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

PERFORMANCE COMPARISON

- Reduced pumping losses due to E-Compressor assistance
- Improvement in volumetric efficiency and thus air flow rate

Remark:
- Significant improvement in lambda level hence lower emission soot levels
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

PERFORMANCE COMPARISON

Remark

- No change in intercooler sizing despite of higher performance because of increased efficiency in compressor
- Total Power required for E-Compressor: 7 kW at 2000 rpm

Compressor outlet temp limit 200 degC

Footnote
PERFORMANCE COMPARISON

- Decrease in TC efficiency due to change in operation zone
- Slightly penalty in BSFC observed due to decrease in TC efficiency

Remark
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

COMPRESSOR PLOT

- Compressor plot for base performance
- Sufficient surge margin available
- No altitude margin available
- Performance will deteriorate during altitude operation
- Max Speed limit : 174000 rpm
Main compressor map for higher performance
Low surge margin available
Sufficient altitude margin available - NO derating of performance during altitude operation
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

E-COMPRESSOR MAP

- Figure shows E-Compressor operating plots full load 1000-2000 rpm
- Max speed limit for E-Compressor: 70000 rpm

Remark

- \[ \text{Corrected Mass Flow rate [kg/s]} \]
- \[ \text{Pressure Ratio} \]
- \[ \text{Efficiency Map : E-Compressor Compressor part EBooster} \]
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PART LOAD SIMULATION (E-COMPRESSOR ON)

**Remark**
- Case 1: 1500 rpm / 3 bar
- Case 2: 1500 rpm / 6 bar
- Improvement in BSFC due to E-Compressor
  - Case 1: 2.5 %
  - Case 2: 4.9 %
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

PART LOAD SIMULATION (E-COMPRESSOR ON)

Remark

- Case 1: 1500 rpm / 3 bar
- Case 2: 1500 rpm / 6 bar
- Significant improvement in lambda levels
- E-Compressor Power consumption –
  - Case 1: 0.3 kW
  - Case 2: 0.7 kW
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**PART LOAD SIMUATION (E-COMPRESSOR ON)**

- Figure shows E-Compressor operating plots full load 1500 rpm / 3 & 6 bar BMEP
- Max speed limit for E-Compressor: 70000 rpm

---

**Remark**

- Corrected Mass Flow rate [kg/s]
- Pressure Ratio

| Corrected Mass Flow rate [kg/s] | 0.0 | 20.0 | 30.0 | 35.0 | 37.5 | 40.0 | 42.5 | 45.0 | 47.5 | 50.0 | 52.5 | 55.0 | 57.5 | 60.0 | 62.5 | 65.0 | 67.5 | 70.0 | 72.5 | 75.0 | 77.5 | 80.0 | 82.5 | 100.0 |
|--------------------------------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
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AVAILABLE ENERGY FOR E-COMPRESSOR (RDE CYCLE)

Footnote
Reference: [3]
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PARAMETERS AFFECTS NOX EMISSION

- O2 Concentration
- Injection timings
- Rail Pressure
- Intake Manifold temp
- Coolant temp
- Load
- Speed

Remark

- Factors that affects the NOx emission
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EMPIRICAL MODEL

Newly produced NOx after combustion (exclude the recycled part from EGR):

\[
\ln \left( \frac{[\dot{N}O_x]}{[\dot{N}O_x]_0} \right) = k_1 \cdot ([O_2] - [O_2]_0) + k_2 \cdot ([p_{Rail}] - [p_{Rail}]_0) + k_3 \cdot ([SOI] - [SOI]_0) \\
+ k_4 \cdot ([T_2] - [T_2]_0) + k_5 \cdot ([T_{coolant}] - [T_{coolant}]_0)
\]

- \([O_2]\) : O\(_2\) concentration in cylinder before combustion
- \(SOI\) : start of main injection
- \(T_2\) : temperature of mixed gas of fresh air and external EGR
- \(p_{rail}\) : rail pressure
- \(T_{coolant}\) : coolant temperature
- ...0 : corresponding reference values
- \(k_{1-6}\) : parameters

Remark

- Test data required for estimation of NOx emission which is considered as reference
- In current simulation, other parameter excluding O2 concentration which is major contribution for NOx calculation are neglected

Reference: [1], [2]

Footnote
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GT MODELLING

Throttle angle as an input to EGR Valve

- Actual In-cylinder O2 level
- Controller
- Target O2
- Target NOx
- NOx Reference
- In-cylinder O2-Reference
- Engine Load & Speed
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O2 CONCENTRATION MAP - REFERENCE MAP

Remark
- Maps shows the map for In-cylinder O2

Footnote
EGR VS NOX RELATION

Graph shows NOx emission w.r.t. EGR rate variation for 1500 rpm/ 3 & 6 bar.

- It is clearly seen that increase in EGR decreases the NOx emission.
- Above 40% EGR rate, there is minimal effect on NOx emission.
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EGR RATE ESTIMATION W.R.T. NOX TARGET (E-COMPRESSOR OFF)

- **Case 1**: 1500 rpm / 3 bar
- **Case 2**: 1500 rpm / 6 bar

Remark:
- Part load EGR rate estimation done for below two cases using NOx modelling technique for different NOx targets
- Case 1: 1500 rpm / 3 bar
- Case 2: 1500 rpm / 6 bar
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EGR RATE ESTIMATION W.R.T. NOX TARGET (E-COMPRESSOR OFF)

- **Case 1**: 1500 rpm / 3 bar
- **Case 2**: 1500 rpm / 6 bar

<table>
<thead>
<tr>
<th>Case</th>
<th>NOx Target decrease %</th>
<th>EGR Rate increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6%</td>
<td>+5%</td>
</tr>
<tr>
<td>2</td>
<td>37%</td>
<td>+4%</td>
</tr>
</tbody>
</table>

**Remark**

- Target NOx decrease %
  - Case 1: 6%
  - Case 2: 37%
- Estimated increase in EGR Rate for
  - Case 1: +5%
  - Case 2: +4%
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SUMMARY/CONCLUSION

- E-Compressor shows the promising solution considering upcoming BS6 and CO2 targets without comprising the performance
- Increase in low end torque along with increase in rated power
- Below performance was improved with E-Compressor assistance
  - Rated Power: + 12.5 % @ 3500 rpm
  - Low end torque: + 69% @ 1000 rpm
  - BSFC benefit: + 6 % @ 1000 rpm
  - BSFC benefit: + 4 % @ 2000 rpm
- EGR rate can be estimated through NOx modelling as described earlier
Performance Evaluation of 48V E-Compressor Powered Diesel Engine For Meeting Future BS6 Emission Legislation

REFERENCES


END OF PRESENTATION
THANK YOU !!