Uprating of Naturally Aspirated Gasoline Engine Using Hybrid Turbocharging System

Rangarajan S, Sundar S M, Venkata Rao G,
Alain Lefebvre, Anand Gurupatham

Powertrain CAE - Systems
Contents

01 Introduction
02 Turbocharger Modeling
03 E-charger Modelling
04 Simulation Results
05 Conclusion
Introduction

A) Objective
- To enhance the engine performance by using Hybrid Turbocharger - coupling of electric supercharger and mechanical turbocharger with naturally aspirated (NA) engine.

B) Target
- Low end torque (LET), drivability and bsfc are improved by making use of best operating range of both turbo and e-supercharger.

C) Engine specification
- 1.2L gasoline engine model is considered for our study (base model).
- The base model is validated with test data.
- Deviation:
  Test Vs Simulation: +/-5%

<table>
<thead>
<tr>
<th>1.2L NA Engine Parameters:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement Volume</td>
</tr>
<tr>
<td>Bore</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Compression Ratio</td>
</tr>
<tr>
<td>Rated Power</td>
</tr>
<tr>
<td>Maximum Torque</td>
</tr>
<tr>
<td>EGR</td>
</tr>
<tr>
<td>VVT</td>
</tr>
</tbody>
</table>
A) Methodology

**NA Engine**
- Baseline NA-engine model calibrated for Steady and Transient run.
- Deviation is +/-5% with test data.
- This model is considered as base model for all simulations carried out for this work.

**TC Engine**
- Selection of Conventional Turbocharger (TC-Matching) for Steady state operation.
- Validation of Conventional Turbocharger (TC-Matching) for Transient operation (Turbo lag study).
- Results comparison.

**E-charger Engine**
- Selection of e-charger compressor map.
- Selection of Battery, Motor and/or Generator specification.
- E-charger control logic.
- Coupling of Turbocharger and e-Charger (TC & e-Charger Matching) for Transient operation using NEDC cycle.
- Results comparison.
B) Map Selection using DOE

Turbocharger Modelling

- Match input data (Engine data)
- Compressor Model: Inputs: Air flow rate, Pressure ratio, Output: Efficiency and Speed.
- Calculate compressor power (equal to turbine power)
- Compressor test data (From supplier)
- Calculate turbine flow and pressure ratio
- Turbine test data (From supplier)
- Turbine Model: Inputs: Pressure ratio and Turbine corrected speed, Output: Efficiency and Speed.

- Insufficient exhaust energy present:
  1. Allow 'under boost' (lower original A/F ratio target) adjust T3.
  2. Decrease Waste-gate opening.

- Is the point above the flow curve?
  - No
  - Yes: Excessive exhaust energy present:
    1. Allow 'over boost' (raise original A/F ratio target) adjust T3.
    2. Enable Waste-gate operation.

- Is the point on the flow curve?
  - No
  - Yes: Calculations complete.

- Is turbine efficiency error small?
  - Yes
  - No

E-charger selection
C) Layout – Engine + TC + e-charger

Turbocharger Modelling
D) E-charger Control logic

- Operation of e-charger depends mainly on - **engine speed** and **battery SOC**.
- **SOC** is limited between 0.9 and 0.6.
- Discharging and charging of battery is at engine speeds 1000 to 1650 rpm and 2700 to 5600 rpm respectively.

**Battery, Motor and/or Generator Specification:**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor/Generator output</td>
<td>0.5 kW</td>
</tr>
<tr>
<td>Motor maximum current</td>
<td>180 A</td>
</tr>
<tr>
<td>Motor maximum speed (with Gear ratio)</td>
<td>150000 rpm</td>
</tr>
<tr>
<td>Battery</td>
<td>12V DC</td>
</tr>
<tr>
<td>Battery capacity</td>
<td>50A-h</td>
</tr>
</tbody>
</table>
A) Steady state results at WOT

- **Engine Torque**

  - Overall torque improvement is 92% at 1600 rpm.
Simulation Results

A) Steady state results at WOT

- Engine Volumetric efficiency

- At 1600 rpm, overall volumetric efficiency improvement is 79% for NA engine to system-2
Simulation Results

A) Steady state results at WOT

- BSFC

- The maximum BSFC improvement is 6.64% at 1600 rpm from NA to system-2.
Simulation Results

A) Steady state results at WOT

• Compressor performance

- Increase in air flow rate and compressor efficiency at 1000, 1200 and 1600 rpm.
- At higher speeds drop in compressor flow rate due to energy tapping for battery charging.
Simulation Results

A) Steady state results at WOT

- Turbine performance

- Increase in air flow rate and turbine efficiency at 1000, 1200 and 1600 rpm.
- This additional gas flow rate will helps us to reduce Turbo lag.
Simulation Results

A) Steady state results at WOT

- E-charger Map

In e-charger compressor map,
- Compressor efficiency is about 35% to 40%.
- Response is much faster – smaller inertia.
Simulation Results

A) Steady state results at WOT

- Waste Gate (WG) diameter

- Energy recovery using Waste Gate (WG)

During energy recovery (battery charging),

a) WG diameter is reduced – More gas flows via turbine that extracts excess energy.
b) Drop in enthalpy used for re-charging the battery.
B) Time to torque comparison at 1600rpm.

- Time to torque improvement of ~19.62% is observed for electrically powered compressor (0.975 sec.) than the conventional turbocharger (1.21 sec.).
Simulation Results

C) Transient state results - NEDC

- Engine Torque

- Improvement in Torque because of additional mass flow supplied by E-charger.
C) Transient state results - NEDC

- BSFC

- An improvement in BSFC is 4.96% with E-charger over Turbo system.
C) Transient state results - NEDC

- The PMEP is improved with super charging system, this is one of the factor for the BSFC trend improvement.
C) Transient state results - NEDC

- Decrease in SOC is around 6%.
- E-charger is active for 435 sec over 1180 sec based on the logic – it is 37%.
- 50 A-h battery is used to support e-charger operation.
- Existing (12V battery) system is enough to support the e-charger module.
Performance of uprated engine

- Two different types of charging systems [system 1 (Turbo) and system 2 (e-charger)] to uprate the N.A engine performance are studied.

- NA engine to e-charger charger
  - At WOT condition
  - BSFC • 6.64% @ 1600 rpm

- Turbocharger engine to e-charger charger
  - Transient condition
  - BSFC • 4.96% over NEDC cycle
  - Low End Torque • 92.06% @ 1600 rpm
  - Time to Torque • 19.62% over NEDC cycle
References

Acknowledgement

We would like to acknowledge with gratitude, for their extended support provided to our work.

- Vinayaga Moorthy – DGM, RNTBCI.
- Srinivasan Seethapathy – Dy. Manager, Intake and Exhaust system, RNTBCI.
- Badrigari Manishankar – Senior Engineer, Battery Sizing, RNTBCI.
- Gamma Technologies – Global support team.
THANK YOU

Queries?