Future Passenger Car R2S Charging Systems - using VTG and Low Pressure EGR?

GT-SUITE Conference 2008

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October 20, 2008

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Contents

• Status on Regulated 2-Stage (R2S) Charging System

• Comparison of engine performance and fuel consumption of R2S System vs. VTG (Downsizing)

• Use of Variable Turbine Geometry in R2S Applications

• High Pressure EGR vs. Low Pressure EGR

• Conclusions
Status in R2S™ - Regulated-2-Stage

- EGR Valve
- EGR Cooler
- Charge Air Cooler
- Regulating Valve
- Compressor Bypass
- HP stage Turbo-charger
- LP stage Turbo-charger with Bypass

Product Development
Calculations and Simulations
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R2S™: Compressor Map

Overall pressure ratio

HP compressor pressure ratio

LP compressor pressure ratio

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Comparison of engine performance and fuel consumption

2.7L V6 Diesel with Mono VTG versus 2.0L Diesel I4 with Two Stage System R2S
Downsizing: R2S 2.0 L vs. VTG 2.7 L

Power vs. Engine Speed

- **VTG 2.7 L**
- **R2S 2.0 L**

Engine speed [rpm] vs. Power [kW]

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Downsizing: R2S 2.0 L vs. VTG 2.7 L

Brake spec. Fuel consumption

- VTG 2.7 L
- R2S 2.0 L

<table>
<thead>
<tr>
<th>Engine Speed [rpm]</th>
<th>Spec. Fuel Consumption [g/kWh]</th>
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<tbody>
<tr>
<td>0</td>
<td>290</td>
</tr>
<tr>
<td>1000</td>
<td>280</td>
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<tr>
<td>2000</td>
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<td>4000</td>
<td>250</td>
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<tr>
<td>5000</td>
<td>240</td>
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<tr>
<td>6000</td>
<td>230</td>
</tr>
</tbody>
</table>
VTG in R2S Applications

R2S™ Charging Systems with Variable Turbine Geometry:

Driver:
• Emission Concept to fulfill future Emission Legislation
• Higher EGR rates
• Higher Air-Fuel Ratio
• Fuel Consumption
VTG in R2S Applications

- 2-stage
  - 200-220 Nm/L

- 1-stage
  - 150-180 Nm/L
  - 70-100 kW/L
  - 50-70 kW/L

Legend:
- VTG
- Serial Sequential (R2S)
- Fixed Geometry Turbine (FGT)
- Parallel Sequential
- Serial Sequential (R2S) with VTG

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VTG in High Pressure Stage

or

VTG in Low Pressure Stage:

EGR Valve

EGR Cooler

Charge Air Cooler

Regulating Valve

Compressor Bypass

HP stage Turbocharger

LP stage Turbocharger with Bypass
R2S Charging Systems: Variable Turbine in HP-Stage

High Pressure Stage:
Fix Geometry Turbine + Bypass

improved transition 1-stage ↔ 2-stage
reduced Pressure $p_3$ → improved $b_e$

improved Low End Torque
improved Part Load (EGR, AFR)
R2S Charging Systems: Variable Turbine in LP-Stage

Low Pressure Stage:
Fix Geometry Turbine

Low Pressure Stage:
VTG

closed VTG to improve transition
1-stage ↔ 2-stage
Engine Performance Simulation

2.0L Diesel I4 with
Two Stage System R2S with 2 Fix Geometry T/C
compared to
R2S with Variable Turbine Geometry in HP or LP Stage
GT-Power Model - 2.0 L Diesel Engine

Engine Data:
- Displacement: 2.0 L
- Rated Power: 150 kW
- Max. Torque: 400 Nm
GT-Power Model - 2.0 L Engine

HP Stage

LP Stage

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GT-Power Model - 2.0 L Engine

Torque

Boost Pressure

Test Data
Simulation

Test Data
Simulation

Good Match of Engine Simulation Data vs. Test Data
### GT-Power Model – Turbo Charger Variations

<table>
<thead>
<tr>
<th>Variation</th>
<th>Compressor</th>
<th>Turbine</th>
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<tbody>
<tr>
<td><strong>R2S® (Basis)</strong></td>
<td>HP 1672C (41 mm)</td>
<td>KP35-180.12 A (35 mm)</td>
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<tr>
<td></td>
<td>LP 2471N (62 mm)</td>
<td>K16-250.88 A (53 mm)</td>
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<td><strong>R2S® with HP VTG</strong></td>
<td>HP 1672C (41 mm)</td>
<td>BV38-340.10 P1 (37.5 mm)</td>
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<td>LP 2471N (62 mm)</td>
<td>K16-250.88 A (53 mm)</td>
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<tr>
<td><strong>R2S® with LP VTG</strong></td>
<td>HP 1672C (41 mm)</td>
<td>KP35-240.82 A (35 mm)</td>
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<td></td>
<td>LP 2471N (62 mm)</td>
<td>BV50-380.18 P9 (50 mm)</td>
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</table>
GT-Power Results – Stationary, Full Load

Power

Brake Torque vs. Engine Speed

R2S® Basis

R2S® with High Pressure Stage VTG

R2S® with Low Pressure Stage VTG

Same Engine
Same Torque / Power

R2S® with HDVTG
R2S® with NDVTG

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GT-Power Results – Stationary, Full Load

bsfc

R2S® with High Pressure Stage VTG shows best bsfc

Same Engine
Same Torque / Power

R2S® with High Pressure Stage VTG shows best bsfc
GT-Power Results – Stationary, Full Load

Pressure p3

Turbine Efficiency

R2S® with High Pressure Stage VTG shows lowest p3 at low Engine Speed due to best Turbine Efficiency
GT-Power Results – Part Load 1500 rpm / 4 bar

Benefits in bsfc for VTG in HP and LP Stage

Air-Fuel-Ratio (lambda/14.5) level constant

R2S® with Low Pressure Stage VTG shows best bsfc
GT-Power Results – Part Load 2000 rpm / 2 bar

Benefits in bsfc for VTG in HP and LP Stage

Air-Fuel-Ratio (lambda/14.5) level constant

R2S® with High Pressure Stage VTG shows best bsfc
GT-Power Results – Part Load 2000 rpm / 8 bar

Benefits in bsfc for VTG in HP and LP Stage

Air-Fuel-Ratio (lambda/14.5) level constant

R2S® with Low Pressure Stage VTG shows best bsfc
GT-Power Results – Part Load 2000 rpm / 8 bar

R2S® with Low Pressure Stage VTG shows lowest p3
R2S® with High Pressure Stage VTG shows best transient from 40 to 80 km/h
GT-Power Results – Transient 40 – 80 km/h

R2S® Basis

R2S® with High Pressure Stage VTG

R2S® with Low Pressure Stage VTG

R2S® with High Pressure Stage VTG shows best boost pressure increase
Conclusions VTG in R2S Applications

• R2S became State of the Art Turbocharger System

• R2S Charging System shows benefit in Fuel Consumption (Downsizing)

• Use of VTG in R2S systems shows high potential for
  - improved Fuel Consumption
  - higher Air-Fuel-Ratio
  - higher EGR rates
Conclusions VTG in R2S Applications

• Variable Turbine Geometry in High Pressure Stage shows best results in bsfc at Full Load up to 3000 rpm, Part Load 2000 rpm / 2 bar and Transient Response

• Variable Turbine Geometry in Low Pressure Stage shows best results in bsfc at Part Load 1500 rpm / 4 bar and 2000 rpm / 8 bar

• Use of VTG in High Pressure Stage or Low Pressure Stage depends on:
  - Package (VTG rather in HP Stage for Large Engines)
  - Engine Targets (bsfc vs. transient)
Engine Performance Simulation

High pressure EGR versus Low pressure EGR applied on a 2L turbocharged Engine
Engine Model of 2L Engine

Engine Data:
- Displacement: 2.0 L
- Power: 100 kW
- Torque: 320 Nm
Match of Simulation Data vs. Test Data

Lambda vs. Engine Speed, Part DZ2

Brake Power vs. Engine Speed, Part DZ2

Air Flow vs. Engine Speed, Part DZ2

BSFC vs. Engine Speed, Part DZ2

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Match of Simulation Data vs. Test Data

Boost Temp vs. Engine Speed, Part D22

Pressure vs. Engine Speed, Part D22

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EGR-System: High Pressure EGR

- EGR System
- EGR Cooler
- Fresh Air Manifold
- Exhaust Manifold

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EGR-System: Low Pressure EGR

Alternative the throttle can be appointed on this position.

Fresh air manifold

Exhaust manifold

EGR throttle

LP-EGR-System

EGR cooler

Additional Throttle to generate a back pressure
Part load data points: Lambda (AFR / $L_{st}$)

![Part load data points graph]

- Lambda ($\lambda$) values: 1.40, 1.65, 1.62, 1.65, 1.72, 1.93, 2.24, 2.12, 2.40, 3.00, 3.07
- Engine speed [1/min]
- BMEP [bar]

Product Development
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Part load data points: Lambda (AFR / $L_{st}$)
Results: Maximum EGR-Rates

HP-EGR engine map

LP-EGR engine map

Maximum EGR Rates
Results: Maximum EGR-Rates

BSFC engine speed HP-EGR

BSFC engine map LP-EGR

Specific fuel consumption BSFC
Results: Trade off EGR-Rates - BSFC

Difference EGR-rate (LP-EGR - HP-EGR)

Difference BSFC (LP-EGR - HP-EGR)

Specific fuel consumption BSFC
Conclusions HP-EGR vs. LP-EGR

- Low Pressure EGR System allows higher EGR-rates
- Additional Measures on the EGR System:
  - Throttle (before Compressor or after Turbine to increase pressure drop)
  - Protection of Compressor (Wheel, Housing)
- increased Fuel Consumption
Final Remark

Decision on final R2S system layout based on further Investigations in transient test cycles

Additional Investigations with R2S and Low Pressure EGR

A Combination of R2S with Variable Turbine Geometry and Low Pressure EGR shows:
• a high Potential to reduce Fuel Consumption
• a high Potential to fulfill Future Emission Legislation