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Increasing the Downsizing Level in Combination with Reduced Fuel Consumption

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Content

- Introduction
- Turbocharging concepts
- Potential of turbocharging concepts
- Component protection enrichment
- Technologies to reduce enrichment
- Conclusions
Introduction

35 years of Porsche Turbo history:
- Doubled specific power
- Increased specific torque by 66%
- Improved acceleration from 0-100 km/h by 35%

In the last decades engine power has significantly increased due to turbocharging
Nowadays the same technology can be used to reduce fuel consumption without any disadvantages in vehicle performance

<table>
<thead>
<tr>
<th>Internal type number</th>
<th>Model years</th>
<th>Displacement</th>
<th>Power Output</th>
<th>Torque</th>
<th>Top Speed</th>
<th>0 – 100 kph</th>
</tr>
</thead>
<tbody>
<tr>
<td>930 1. Generation</td>
<td>1975 – 1977</td>
<td>2993 cm$^3$</td>
<td>260 hp</td>
<td>350 Nm</td>
<td>over 250 kph</td>
<td>5.4 s</td>
</tr>
<tr>
<td>997 II 7. Generation</td>
<td>since 2010</td>
<td>3800 cm$^3$</td>
<td>500 hp</td>
<td>650 Nm</td>
<td>312 kph</td>
<td>3.6 s</td>
</tr>
<tr>
<td>997 II GT2 RS limited edition</td>
<td>since 2010</td>
<td>3600 cm$^3$</td>
<td>620 hp</td>
<td>700 Nm</td>
<td>330 kph</td>
<td>3.5 s</td>
</tr>
</tbody>
</table>
Introduction

Increase of low-end torque:
- Improved gas exchange (VarioCamPlus)
- Improved use of turbocharger map (VTG)

Increase of peak performance:
- Higher manifold pressure
- Cooling system
- Expension intake manifold

Increasing the Downsizing Level in Combination with Reduced Fuel Consumption
Turbocharging concepts

- Single turbocharging
- Regulated two-stage turbocharging
- Sequential turbocharging

- TC + mechanical assistance
- TC + eBooster
- eTurbo
Turbocharging concepts

- 2.9 l NA engine as a reference

- Comparison of the following downsizing concepts:
  
  2.0 l Turbo engine
  1.6 l Turbo engine
  1.6 l TC + mechanical assistance
  1.6 l Sequential turbocharging
Potential of turbocharging concepts

- All concepts achieve the target power of 195 kW
- Downsizing requires higher steady state torque in order to compensate turbolag
- Downsizing leads to a mean effective pressure of approximately 25 bar
- A higher downsizing level can be achieved by an increased inlet manifold pressure
- Later P50 to avoid knocking
Potential of turbocharging concepts

Sports car

<table>
<thead>
<tr>
<th></th>
<th>5. gear</th>
<th>6. gear</th>
<th>6. gear</th>
<th>6. gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 – 120 km/h</td>
<td>80.00%</td>
<td>130.00%</td>
<td>120.00%</td>
<td>110.00%</td>
</tr>
<tr>
<td>60 – 100 km/h</td>
<td>80.00%</td>
<td>130.00%</td>
<td>120.00%</td>
<td>110.00%</td>
</tr>
<tr>
<td>80 – 120 km/h</td>
<td>80.00%</td>
<td>130.00%</td>
<td>120.00%</td>
<td>110.00%</td>
</tr>
<tr>
<td>100 – 200 km/h</td>
<td>80.00%</td>
<td>130.00%</td>
<td>120.00%</td>
<td>110.00%</td>
</tr>
</tbody>
</table>

Elasticity [%]

<table>
<thead>
<tr>
<th></th>
<th>NEDC (MT)</th>
<th>NEDC (AT)</th>
<th>US (MT)</th>
<th>US (AT)</th>
<th>Customer cycle A (AT)</th>
<th>Customer cycle B (AT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70.00%</td>
<td>85.00%</td>
<td>90.00%</td>
<td>87.00%</td>
<td>92.00%</td>
<td>88.00%</td>
<td>95.00%</td>
</tr>
<tr>
<td>80.00%</td>
<td>75.00%</td>
<td>85.00%</td>
<td>80.00%</td>
<td>85.00%</td>
<td>82.00%</td>
<td>85.00%</td>
</tr>
<tr>
<td>90.00%</td>
<td>65.00%</td>
<td>75.00%</td>
<td>70.00%</td>
<td>75.00%</td>
<td>72.00%</td>
<td>75.00%</td>
</tr>
<tr>
<td>100.00%</td>
<td>55.00%</td>
<td>65.00%</td>
<td>60.00%</td>
<td>65.00%</td>
<td>62.00%</td>
<td>65.00%</td>
</tr>
</tbody>
</table>

Consumption [%]

Increasing the Downsizing Level in Combination with Reduced Fuel Consumption
Potential of turbocharging concepts

SUV

Elasticity [%]

Consumption [%]

NEDC (MT)  NEDC (AT)  US (MT)  US (AT)  Customer cycle A (AT)  Customer cycle B (AT)

- 3.2 l NA
- 2 l – 1 TC
- 1.6 l – 1 TC
- 1.6 l – 1 TC + n.
- 1.6 l – Seq.turbocharging

Increasing the Downsizing Level in Combination with Reduced Fuel Consumption
Component protection enrichment

- Enrichment to decrease turbine inlet temperature at high engine speeds
  - Higher fuel consumption in customer operating conditions

**Target:**
**Prevention or reduction of enrichment**

Systems to decrease enrichment:
- Cooled exhaust gas recirculation
- Cooled exhaust manifold
- High temperature resistant materials
- Water injection
Cooled exhaust gas recirculation

- Low- and high pressure EGR are able to decrease enrichment
  - Low pressure EGR: Higher exhaust back pressure
  - High pressure EGR: Higher temperatures after CAC
  - No improvement on knock tendency
  - Positive secondary effect: Reduced pumping losses at part load
Cooled exhaust manifold

- Reduction of enrichment
- Complete avoidance of enrichment is difficult to accomplish due to high amount of dissipative heat flux
- System is not able to decrease knock tendency

Wall temperature exhaust manifold [K]

Heat flow exhaust manifold [kW]

Lambda

BSFC [g/kWh]

P50 [CADeg]

Limit

HF = 20 kW

FS = 9.3 %

n = 5000 rpm - BMEP = 24 bar
High temperature-resistant materials

- Reduction of enrichment but no complete avoidance
- System has no positive influence on knock tendency

T3 = 920°C → T3 = 1020°C

Increasing the Downsizing Level in Combination with Reduced Fuel Consumption
**Water injection**

**Methodology to implement water injection**

- Evaporation in the intake manifold:
  - "Condense/Evaporate Water Vapor" needs to be changed to "on gas" in pipes and flowsplits

- Evaporation in the cylinder:
  - Add water as fluid in "EngCylEvaporation" object (possible since GT-Suite version 7.1)

Fuel injection and post processing:

- Correction needs to be done due to the definition that GT-Suite uses the instantaneous mass flow rate of non-fuel gases past all intake valves
Water injection

- Water injection into the exhaust manifold decreases enrichment but a complete avoidance could not be achieved during engine simulations
  - System has no positive influence on knock tendency of the engine
- Water injection into the intake manifold prevents enrichment completely
  - Knock tendency can be reduced
  - Improvement on P50
  - Lower manifold pressure necessary
Technologies to reduce enrichment

- Advantages are dependent on customer profile, gear ratio and shifting strategy.
- EGR has low potential at this operating condition due to exhaust gas tolerance of the engine.

<table>
<thead>
<tr>
<th>n=5000 rpm</th>
<th>Base</th>
<th>EGR</th>
<th>Temp. resistant materials</th>
<th>CEM</th>
<th>Waterinjection</th>
</tr>
</thead>
<tbody>
<tr>
<td>bmep=24 bar T=308 Nm</td>
<td>1.6 l 1 TC + mech.</td>
<td>LP</td>
<td>HP</td>
<td></td>
<td>Intake manifold</td>
</tr>
<tr>
<td>BSFC</td>
<td>326 g/kWh</td>
<td>317 g/kWh</td>
<td>321 g/kWh</td>
<td>278 g/kWh</td>
<td>308 g/kWh</td>
</tr>
<tr>
<td>Fuel improvement</td>
<td>-</td>
<td>2,9 %</td>
<td>1,6 %</td>
<td>14,9 %</td>
<td>9,3 %</td>
</tr>
<tr>
<td>Lambda</td>
<td>0,73</td>
<td>0,84</td>
<td>0,82</td>
<td>0,91</td>
<td>0,83</td>
</tr>
<tr>
<td>Comment</td>
<td>-</td>
<td>EGR-rate 2%</td>
<td>EGR-rate 1,7%</td>
<td>T3 + 100 K</td>
<td>Heat flux. +20kW</td>
</tr>
</tbody>
</table>

- Temperature-resistant materials, cooled exhaust manifold and water injection into the exhaust manifold offer a comparable reduction of fuel consumption.
- Water injection into the inlet manifold shows significant potential due to combination of decreased enrichment and improved combustion efficiency.
Conclusions

- Nowadays, turbocharging allows a reduction of engine displacement by 25 – 33 % with comparable vehicle dynamics
  - As a consequence, fuel consumption is reduced by approx. 20 % in NEDC
- Increased downsizing level can lead to negative effects in customer operating conditions at vehicles with high mass and drag coefficient in particular at high engine speeds
- Use of temperature resistant materials, cooled exhaust manifold and cooled EGR are able to reduce enrichment
  - Knock tendency of the engine can not be improved
  - Series production
- Water injection into the intake manifold offers high potential
  - Prevention of enrichment
  - Improved combustion
  - No series production
- Technologies which reduce the intake temperature offer a high potential to reduce fuel consumption in customer operating conditions.
Thank you for your attention!

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Porsche Engineering Services GmbH