Performance Simulation of Small Turbo GDI Engines

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Overview

Introduction
Target, Dimensions and Package Considerations
Mass Balance and Friction
Comparison of T/C Engines w/ 2 & 3 cylinders
Conclusion
Downsizing = possible path to meet CO₂ targets for 2012/2019
Coping with CO2 targets: Load point shift by Downsizing

Downsized engine drivability requires boosting
Downsizing: Improved Engine Length

Package improvement

- Base: 1.4 dm³ 4-cyl. NA, 74 kW
  - Stroke/bore = 80/74.5
  - Bore pitch = 85.5 mm
- Mk #1: 0.9 dm³ 4-cyl. Turbo, 74 kW
  - Stroke/bore = 69.1/64.3
  - Bore pitch = 73 mm
- Mk #2: 0.9 dm³ 3-cyl. Turbo, 74 kW
  - Stroke/bore = 76/70.8
  - Bore pitch 80.4 mm
- Mk #3: 0.9 dm³ 2-cyl. Turbo, 74 kW
  - Stroke/bore=87/81
  - Bore pitch 92 mm

- 7%
- 17%
- 28%

2- and 3-cylinder engine bore sizes suitable for GDI
Mass Balance and Friction
Example of 2-cylinder Parallel Twin Cranktrain

Parallel Twin needs 1st order balancer shaft, FMEP ↑
Equal TC: Full load performance and fuel consumption

- target of 74 kW achievable with both, but 3-cyl has reserves
Compressor operation at full load

Similar risk of surge
2-cylinder @ higher rpm:
- Higher boost pressure
- Larger loops
- Excursion into $\eta_{sc}$ ↓

larger fluctuations in 2-cyl at med. & high engine speeds
Turbine characteristics at full load

TC match to 3-cyl. Appears too small for 2-cylinder engine
Larger excursions to low BSR in 2-cyl. Engine
⇒ Turbine appears too small
Pulsation effects on turbine side, 2500 min-1, equal T/C

- Slight backflow

- 2-cyl flow rate discontinued between exhaust strokes
CFD Assisted Turbine Map Extension to Cover Pulsation Effects

Model must cover Stagnation and Reversal of turbine flow
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Model must cover Stagnation and Reversal of turbine flow
2- and 3-cylinder turbocharging
Interim conclusion

Surge limited low end torque
- Applies to both 2- and 3-cylinder engine
- Already with small base turbocharger

2-cylinder needs larger turbine
Larger turbine only available with larger compressor
Larger compressor in conflict with low end torque
- Map of larger compressor ranges in larger flow rates
- Required boost pressure at low speeds exceeds surge line
Larger turbo for 2-cylinder engine

Pre-swirl device
- Converts standard compressor into VGC
- Extends operation range to small flow rate
- Wide open blades
  - New generation: negligible pressure loss
- Closing blades:
  - Swirl ↑, pCin ↓, turbo rpm ↑
  - Makes compressor virtually smaller

High boost at low speeds from large compressor with preswirl
Larger turbo for 2-cylinder engine

3-cyl with KP35  
2-cyl with KP39

- w/o &  
- w/ pre-swirl device

2-cyl. low end torque can be recovered by larger VGC
Different T/C’s on 2-cylinder engine

Compressor: Efficiency Map - Reduced
2-cylinder w/ Base KP35 TC

Compressor: Efficiency Map - Reduced
2-cylinder w/ KP39 TC

Compressor: Efficiency Map - Reduced
2-cylinder w/ KP39 TC & var. compressor

Variable pre-swirl helps compressor operation:
smaller loops, better surge margin, better efficiency
Conclusions

GT-POWER study on small turbo engines
Different T/C matching for 2-cylinder engines
- Larger turbine than for 3-cylinder engine
- Larger compressor than for 3-cylinder engine
- Larger fluctuations due to less continuous flow

3-cyl with better NVH and fuel consumption
Package and cost advantageous for 2-cyl, e.g. for HEV
2-cyl’s larger bore likely to cause less oil dilution
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Acknowledgements
BWTS: Frank Schmitt
Polito: Federico Millo
FEV: Richard Aymanns, Raimund Vedder, Johannes Scharf, Franz-Gerd Hermsen