Super cooling of the combustion air by means of an additional air turbo adopted for a 4-stroke SI-engine

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"Internal Combustion Engine Gasexchange and Boosting"
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- Introduction to air cooling by means of an air turbo
- Application for a 4-stroke SI-engine
- Simulation results
- Recommendations for Further work
- Summary
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Introduction to air cooling

Turbo cooling have been adopted for IC-engines at least since 1975 by I Kalmar and J Antal for NOx reduction in CI-engines.

Engineers from SWRI contributed in the same subject between 1990-1991 with adress to M Shahed and RH Thring in the ”Clean Diesel Project”

Volvo Truck also performed a MSc thesis work carried out by Jan Wiman in 1991
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Introduction to air cooling

Stage efficiency is crucial for success and it is important to select an architecture were the cooling turbo use a compressor/turbine combination with realistic corrected mass rates ratio.

Different approaches was evaluated with respect to the position of the cooling turbo.

One reason for dropping this approach was the narrow speed and load band for proper assistance.
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Introduction to air cooling

Based on these good ideas from the past utilising new available turbocharger technology

Focus on the SI-engine due to the existing unbalance between spent gasoline and diesel in Europe and improve CO2 emissions in downsized turbocharged engines with tough thermal loadings which today use "fuel cooling"
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ZanderExpander

Diagram:
- CAC1 (2) connected to C (1)
- CAC2 (4) connected to C (3)
- W/G (8) connected to 7
- Engine block (6)

1  2  3  4  5  6  7  8
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GT-Power simulation of 4-stroke SI-engine with ZanderExpander

- The baseline engine is a classical 2.0 [L] 4-cylinder turbocharged SI-engine rated at 150 [kW]

- Turbocharger is modified slightly in order to run higher compressor pressure ratios but an existing unit

- Cooling turbo is an existing CI-engine VG-turbo. The VG-turbo allows much wider cooling band than FG:s

- CAC are existing hardware
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- The VG-air turbo is used to control boost pressure and for load control at part load so throttle is not present and the W/G at the ordinary turbo is used to control turbo speed
- VG-trottling at part load may have an impact on boost availability and efficiency but this is not evaluated
- The very low inlet air temperature (-25degC) is utilized to avoid knock and run closer to MBT
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• Cooler gas temperatures in general and earlier position of THB50 both adds to lower exhaust temperatures

• Therefore the engine can run stochiometric at rated point

• Due to larger pressure drop over the engine PMEP is higher but there is still a large efficiency gain with the concept (approx 20%)
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Simulation results

**Simulation Strategy:**
Maintain rated power utilising……

...the very low inlet temperatures obtained by the SuperCool concept…

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**Baseline engine vs SuperCool Engine**

- **Power [kW]** vs **Engine speed [rpm]**

- **Baseline Engine**
- **SuperCool Engine**

**Inlet plenum temperatures for Baseline and SuperCool Engine**

- **Inlet plenum temperature [K]** vs **Engine speed [rpm]**

- **Baseline Engine**
- **SuperCool Engine**
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...using the knock criteria with maintained peak temperature in the unburned zone pushing THB 50% back to MBT....
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Baseline Engine vs SuperCool Engine

Peak cylinder pressure (bar)

Engine speed (rpm)

Turbine temperature (K)

Engine speed (rpm)

……resulting in higher peak cylinder pressure

……maintaining the exhaust temperature at rated point..
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Baseline Engine vs SuperCool Engine

A/F

Baseline Engine
SuperCool Engine

Engine speed (rpm)

Baseline Engine vs SuperCool Engine

Air mass rate (kg/s)

Baseline Engine
SuperCool Engine

Engine speed (rpm)

......under stochiometric conditions..

......so air consumption drops..
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Baseline Engine vs SuperCool Engine

..and PMEP does not deteriorate as might been suspected due to reduced W/G fraction..

...so superior specific fuel consumption is obtained during WOT conditions
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Pressure ratios at different positions in the SuperCool Charging System:

- Pressure downstream turbo compressor
- Pressure downstream SuperCool-compressor
- Pressure downstream SuperCool Turbine or inlet plenum

Engine speed [rpm]: 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500

Pressure [bar a]: 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5

This is how the turbo and the SuperCool Air turbo was utilised in terms of pressure ratios.
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...in the turbo compressor map...

...and in the turbo SuperCool compressor map
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Recommendation for further work:

- An existing VGT was used as the SuperCool turbo.

- Due to the environment in the air stream much smaller clearances should be possible to use indicating higher efficiencies.

- SpecialSuperCool compressor can be made in order to optimise efficiency at lower pressure ratios.
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- Other material than steel can be considered inside turbine with potential cost savings
- SuperCool turbo and inlet plenum may be integrated to minimize unwanted heat gains
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- Gasstand testing must be performed to secure true efficiencies from selected turbo units
- If gasstand testing show promising results engine tests should be performed
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Summary

• An improved version of turbo cooling adopted for a SI-engine have been presented

• Sofar evaluation have only been performed in GT-Power

• However, modest assumptions on component level points out a 20% improvement in BSFC and corresponding gains for CO2 and HC

• Careful turbo machinery selection and possibly an optimised VG-air turbo integrated in the inlet plenum is recommended
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Thanks for your kind attention!