Potentials for Efficiency Improvement of Gas Engines

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Content

“Fuel Efficiency – Are Improvements Possible?”

- Examples of AVL Gas Engine Projects for Efficiency Improvement
- Potentials for Further Efficiency Improvement
- Summary and Conclusion
Examples of AVL Gas Engine Projects

Example 1
- High speed gas engine 1500 rpm
- Open chamber combustion concept with pre-chamber spark plug
- Targets
  - Efficiency increase by 2.7 % points
  - BMEP increase by 3.4 bar
  - THC 1200 mg/Nm³ at 3 % O₂
  - NOx TA-Luft
- Tasks
  - SCE testing (set-up and commissioning + 5.5 months testing)
  - CFD simulations for optimization of charge motion and piston bowl geometry
- Results
  - All targets achieved
  - Efficiency increased by 2.8 % points
AVL Gas Engine Project - Example 1

Summary of development steps

- Reduction of dead volume
- Optimization of Miller timing and BMEP increase
- Swirl optimization
- Optimization of combustion chamber geometry and compression ratio
- Optimization of pre-chamber spark plug geometry

**Reduction of Dead Volume**

```
Top land height relative [%]  |  ΔBrake Thermal Efficiency [%]
------------------------------+--------------------------------
reduced                      |  [Diagram showing decrease in top land height with increased ΔBrake Thermal Efficiency]
base                         |  [Diagram showing decrease in top land height with increased ΔBrake Thermal Efficiency]
```

**Miller Timing and BMEP**

```
BMEP [bar]  |  Efficiency [%]
-------------+-----------------
1 bar        |  [Diagram showing ΔBrake Thermal Efficiency and THC raw emission with increased BMEP]
```

**Efficiency [%]**

- ΔBrake Thermal Efficiency [%]
  - Knock limit IVC 20° adv.
  - Knock limit base IVC

**Top land height relative [%]**

- Top land height reduced
- Top land height base

**ΔBrake Thermal Efficiency [%]**

- Decrease in top land height with increased ΔBrake Thermal Efficiency
AVL Gas Engine Project - Example 1

Swirl Optimization

- SCE Test
- 5 different swirl ratio tested
- constant BMEP / 1500 rpm
- constant MFB50% location
- constant NOx at TA-Luft

Conclusions

→ Too high swirl ratio deteriorates knock margin significantly
→ Too low swirl ratio deteriorates THC emission and COV
→ Swirl ratio optimized
AVL Gas Engine Project - Example 1

Optimization of Piston Bowl Geometry

- Pre-optimization by CFD
- SCE Test
- 4 bowl shapes tested
- 4 compression ratios tested
- constant BMEP / 1500 rpm
- constant NOx at TA-Luft

Conclusions

→ Piston contour to be matched with the half-spherical flame propagation
→ Minimize piston to head clearance to enhance squish flow effect
→ Piston bowl design and compression ratio optimized
AVL Gas Engine Project - Example 1

Optimization of Pre-chamber Spark Plug

- SCE Test accompanied by CFD to understand the phenomena
- 10 variants tested
  - Volume
  - number of holes, diameter
  - hole direction
- constant BMEP / 1500 rpm
- constant NOx at TA-Luft

Conclusions

→ Pre-chamber optimized for both efficiency and COV_IMEP
AVL Gas Engine Project - Example 1

Summary of development steps

- Reduction of dead volume
- Optimization of Miller timing and BMEP increase
- Swirl optimization
- Optimization of combustion chamber geometry and compression ratio
- Optimization of pre-chamber spark plug geometry

Summary of development results

Efficiency improvement of 2.8 %pt. achieved.
Examples of AVL Gas Engine Projects

Example 2

- Medium Speed Gas Engine 750 rpm
- Fuel-fed pre-chamber with spark ignition

Targets
  - Efficiency increase by 2 % points
  - COV_Pmax reduction from 5~6 % to 3 %
  - NOx TA-Luft

Tasks
  - SCE and MCE testing support
  - CFD simulations for optimization of piston bowl and pre-chamber geometries

Results
  - COV_Pmax significantly reduced
  - Efficiency increase by 2.1 % points
Summary of development steps

- Reduction of dead volume
- Optimization of combustion stability
- Optimization of Miller timing and compression ratio
- Optimization of piston bowl geometry
- Optimization of pre-chamber geometry

AVL Gas Engine Project - Example 2

Optimization of combustion stability

SCE test result | constant BMEP | same ave. PFP

Design PFP limit

Higher ave. PFP possible

Miller Timing and Compression Ratio

SCE test result constant BMEP

Knock limit

Break thermal efficiency [%]

Ignition timing [deg.bTDC]

0.2 %pt
AVL Gas Engine Project - Example 2

Optimization of Combustion Stability
- Pre-optimization by CFD
- SCE Test
- MCE Test for confirmation
- Gas supply to pre-chamber
- Pre-chamber geometry
- constant BMEP / 750 rpm
- constant NOx at TA-Luft

Conclusions
- Even combustion in the pre-chamber to be targeted
- Flow separation at holes to be avoided
- Significant improvement of combustion stability confirmed by MCE testing

Uneven combustion in PC
- Plug location
- Mixture distribution

MCE test results
Optimization of Piston Bowl Geometry

- Pre-optimization by CFD
- SCE Test
- MCE Test for confirmation
- 3 bowl shapes tested
- 5 compression ratios tested
- constant BMEP / 750 rpm
- constant NOx at TA-Luft

Conclusions

→ Piston bowl contour to be matched with the flame propagation from the flame jet out of pre-chamber

→ Piston bowl to be optimized together with pre-chamber nozzle configuration
AVL Gas Engine Project - Example 2

Summary of development steps

- Reduction of dead volume
- Optimization of combustion stability
- Optimization of Miller timing and compression ratio
- Optimization of piston bowl geometry
- Optimization of pre-chamber geometry

Summary of development results

Efficiency improvement of 2.1 %pt. achieved.
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Looking Back

- Efficiency improvement coupled with BMEP increase.
- Higher BMEP for higher efficiency?
Required Compressor Pressure Ratio

- Model-Based Analysis
- 1500 min⁻¹
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- const. $\varepsilon$ of 12

Key Technologies to achieve higher BMEP

→ Aggressive Miller timing and Two-Stage Turbocharging
Model-Based Analysis
- 1500 min\(^{-1}\)
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- const. \(\varepsilon\) of 12

The higher the BMEP, the higher the efficiency at constant \(\varepsilon\).
The higher the BMEP ≠ the higher the knock limited efficiency.
BMEP – Miller – $\varepsilon$ Matrix at Knock Limit

- Model-Based Analysis
- 1500 min$^{-1}$
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- $\varepsilon$ at knock limit

➢ High BMEP with low $\varepsilon$ or high $\varepsilon$ with low BMEP?
BMEP – Miller – BTE Matrix at Knock Limit

- Model-Based Analysis
- 1500 min\(^{-1}\)
- Pre-chamber
- Spark ignition
- NOx TA-Luft
- MN 80
- \(\epsilon\) at knock limit

- Optimum BMEP Target for the highest efficiency \(\rightarrow\) 24 – 26 bar
- Design PFP requirement of 250 bar
Content

- Examples of AVL Gas Engine Projects for Efficiency Improvement
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Summary

- Examples of AVL Gas Engine Projects for Efficiency Improvement were reviewed.

- Incremental development will result in “Many a little makes a mickle.”
  - CFD Simulation and SCE Testing are effective for rapid development.

- Key Enablers for the further efficiency improvement are:
  - High BMEP of 24 – 26 bar
  - Aggressive Miller Timing
  - Two-stage turbocharging
  - High PFP capability
Conclusion

“Fuel Efficiency – Are Improvements Possible?”

“Where there is a will, there is a way!”
Thank you for your attention!