Heavy Duty Gas Engines integrated into Vehicles

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Project partners:

1 - AVL - AVL List GmbH - AT
2 - BWR - Borgwarner Ludwigsburg GmbH - DE
3 - BOSCH - Robert Bosch GmbH - DE
4 - DAI - Daimler AG - DE
5 - DINEX - Dinex Ecocat OY - DK
6 - FPT - FPT Industrial S.p.A. - IT
7 - IDIADA - Idiada Automotive Technology S.A.- ES
8 - IVECO - Iveco Espana SL - ES
9 - MAN - MAN Truck & Bus AG - DE
10 - POLIMI - Politecnico di Milano - IT
11 - RCD - Ricardo UK Limited - UK
12 - SAG - SAG Motion GmbH - AT
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18 - VOLVO - Volvo Technology AB - SE
19 - VIF - Virtual Vehicle Research Center - AT

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Executive summary

Main Objective

The main objectives are to develop the HPGI (=High Pressure Natural Gas Injection) combustion concept and to optimise engine performance under steady-state conditions at agreed load points in order to select an optimized combustion concept for multi cylinder testing.

Initial development and optimization of the new combustion system was carried out in a single-cylinder research engine. The HPGI combustion concept was a so called coaxial injector.

Summary

This report describes the single cylinder engine testing phase of work package six (WP6) of the EU HDGAS project. The development and optimization of the new combustion system was carried out in an AVL single-cylinder research engine.

HPGI (high pressure natural gas injection) uses a diesel micro pilot to provide ignitable conditions for the natural gas. Natural gas is then injected into the cylinder at the end of the compression stroke. The coaxial injector has its diesel path at the inner side and the natural gas path at its outer side of its nozzle.

A fuel injection pressure range of 150 – 500bar was foreseen on both, natural gas and diesel. The 500bar injection pressure was also the layout criteria in view of nozzle flow rate.

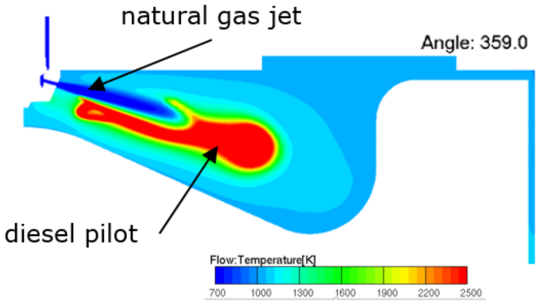

Figure 1: HPGI principle – hot flame from diesel pilot injection at the nozzle bottom side and the natural gas jet above; CFD temperature field analysis with coaxial baseline injector and Volvo D13 Euro VI bowl

For the agreed load points it was possible to operate the engine at ~3.5mg/str, with IMEP cycle-to-cycle variations comparable with diesel engines. However, looking at emissions (methane slip), 6.5mg/str was chosen for most of the variations. 6.5mg/str is seen as a very reasonable quantity for a series application and results in a GER (gas energy ratio) of 97.5% in the considered full load point (equivalent to WHSC mode10) and 90% GER in the load point with lowest engine speed and power (equivalent to WHSC mode6). With the chosen pilot quantities it is very realistic that a gas energy ratio > 90% can be achieved in hot WHTC.

Pilot separation variations showed that the system was very insensitive when changing the pilot diesel injection separation in all the investigated load points, therefore a fixed pilot separation was applied for all further tests.
Swings of MFB50% (without EGR) were performed at different fuel pressure levels. Compared to diesel engines the HPGI combustion resulted in significantly lower soot. The soot level in all investigated load points was below 0.006g/kWh. Higher injection pressure had advantages, lower injection pressure showed disadvantages in THC and CO emissions. The differences in CH_4 emissions were negligible. Compared to diesel, HPGI showed benefits in NOx emissions (~ 30% less at same MFB50%), depending on the chosen injection pressure. When focusing on low NOx emissions (late MFB50%) lower fuel injection pressure was more efficient (decreasing fuel pressure was more efficient than retarding timing).

Variations of injection pressure showed that the necessity of injection pressures above 300bar was more a question of maximum feasible BMEP or peak cylinder pressure instead of emissions. A fuel pressure increase definitely showed benefits in soot (diesel injection pressure was equivalent to natural gas fuel injection pressure), however increased injection pressure at same MFB50 showed NOx penalties. In part load and low load an increased injection pressure did not lower methane slip.

CFD simulations have been performed in order to perform a pre-selection of nozzle variants. Different nozzle configurations have been investigated varying number of holes, hole angle and flow rate of both diesel and gas holes. Four different nozzle configurations have been chosen for further investigation in the single cylinder engine.

All coaxial diesel – natural gas injectors showed very comparable results. The main issue was that the spray angle of the natural gas jet was identical, the hardware differed in diesel spray angle, diesel flow rate and nozzle hole number. The coaxial injector hardware showed definitely benefits in view of minimum diesel quantity – here minimum quantities of 1.1mg/str (with penalties in methane slip) and quantities down to 3.5mg/str (without penalties in methane slip) were possible. What is more, lower soot emissions could be detected. However the smaller diesel spray holes caused problems due to coking at the bottom side of the injector, therefore during SCE test phase ultrasonic bath cleanings were necessary. The hole variation (8 to 10 hole) showed lower differences in terms of performance and emissions than expected.
Swings in excess air ratio at constant MFB50% and load finally showed that the cylinder mass related to the injected fuel quantity was the main parameter for methane emissions and the reason why specific methane emission decreased with increased load. MFB50% also influenced the CH4 slip, methane emissions became less when retarding the timing.

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