HDGAS

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
13 - TNO - Nederlands organisatie voor toegepast natuurwetenschappelijk onderzoek - NL
14 - TUG - Technische Universitaet Graz - AT
15 - UEF - ITA-Suomen Ylipisto (University of Eastern Finland) - FI
16 - UASE - Hochschule Esslingen - DE
17 - UNR - Uniresearch BV - NL
18 - VOLVO - Volvo Technology AB - SE
19 - VIF - Virtual Vehicle Research Center - AT

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Executive summary

Main Objective

Main objective is the development of a stoichiometric combustion system for a natural gas heavy duty engine. After design, thermodynamic simulations and 3D CFD calculations, a single cylinder engine test campaign was performed that proved feasibility. Also a hardware recommendation was done for multi cylinder engine test phase.

Summary

This report describes the development of a stoichiometric natural gas combustion system for a FPT Cursor 13 engine. The development included the following tasks:

- 1D thermodynamic calculations and layout (TU Graz)
- Layout and design of cylinder head and combustion chamber (FPT supported by AVL)
- 3D in-cylinder CFD calculations (Politecnico di Milano)
- Single cylinder engine testing and hence hardware recommendation (AVL)

The engine concept included the following technology features that differ from state of the art positive ignited natural gas heavy duty engines:

- Tumble supported combusting system with parallel valve pattern and pent roof cylinder head design
- Natural gas direct injection
- Corona ignition system
- Two overhead cam shafts enabling cam phasing
- High pressure EGR (exhaust gas recirculation)

1D thermodynamic investigations included the choice of a suitable turbocharger, the evaluation of different EGR layouts, the evaluation of different valve lift profiles and strategies for the gas exchange. Finally, an operating strategy for the cam phasing mechanism was developed and simulations were performed to assist the single cylinder engine measurements.

In order to reach the challenging goals of the HDGAS project, a new approach was followed during the design of the combustion chamber, referring to the design guidelines currently employed in passenger car SI engines: The cylinder head is no longer flat and has a pent roof shape, the combustion chamber is almost entirely located in the cylinder head, only marginal part in the piston, which no longer has a bowl.
Valves are inclined with respect to the vertical axis and are preferably actuated by a double overhead camshaft in order to enable the implementation of variable valve timing. The intake ports are shaped in order to create tumble motion during the intake phase. The tumble motion decays during the compression stroke, creating micro-scale turbulence which is beneficial for flame-front propagation.

CFD simulations were carried out by PoliMi using the Lib-ICE code, based on the OpenFOAM technology to support the NG engine design operating under stoichiometric conditions. Calculations were carried out in order to:

- Identify an optimal design of the engine intake ports, reached by means of steady-state flow-bench simulations. The aim was to achieve the best compromise between a high value of tumble flow motion in the chamber and an adequate flow discharge coefficient;
- Verify the estimated performances of the intake ports in terms of flow coefficient and tumble ratio during the engine cycle, for different operating conditions (part-load, full-load and full-torque);
- Evaluate the performances of the adopted injection system (targeting and injection pressure) in terms of effects on charge motions, in-cylinder turbulence intensity and mixture homogeneity at spark-timing.

The single cylinder engine research proved the feasibility of the combustion. Different injectors, injector nozzles and intake camshafts were tested, to accomplish the possibility making hardware recommendations for the multi cylinder engine test campaign. All the start of injection variations (SOI variations) showed the trend, that early injection is beneficial for efficiency and emissions. For a retarded SOI, particulate number emissions (PN) start to increase. The direct injection of natural gas in this particular case requires an overlap of injection window and intake stroke in order to reach homogeneous mixture.

In combination with a 24V injector driver, operation with the desired pressure level of 50bar is not possible in the whole engine map. An update on the injector driver is necessary to obtain reasonable operation of a MCE possible.

SOI swings and MFB50%-EGR rate variations in all considered load points showed that the early Miller camshaft is not an appropriate hardware for the given boundaries. It significantly stretches the heat release, which is an issue especially at rated power, where the high exhaust gas temperature narrows the range of variation. Especially in the low end torque area the lack in air motion, caused by the early intake valve closure, leads to worse air-fuel mixing.

With the standard camshaft and the late Miller camshaft the engine can be operated in all considered load points. The desired EGR rates could be reached, except the 25% EGR at rated power, here 22% is the misfire limit.

The late Miller camshaft combines the thermodynamic benefits of a Miller timing with the same burn duration as with standard camshaft and it is therefore the preferable hardware. It needs to be mentioned that cam phasing in the part load, which is planned to be applied at part load on the MCE, is useless with a late Miller timing.

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