FOCUS ON IMAGING

IN APPLICATION

Transient Air/Fuel-Ratio Measurements in RDE Application

Internal Combustion Optical Sensor System

Introduction

In the field of internal combustion engines the engine-out emissions under dynamic conditions (real driving emissions) are of particular interest. In order to take into account complex operating conditions during engine development, elementary transient operating phases were identified from real driving profiles and analyzed in detail.

The basis of the experimental environment is a highly dynamic engine test rig automation system (AVL Puma Open), which offers the option of operating the internal combustion engine in an Engine-in-the-Loop (EIL) environment controlled by an open Hardware-in-the-Loop integration platform (AVL InMotion powered by IPG CarMaker). In contrast to real on road vehicle testing, the simultaneous use of advanced measuring techniques is possible in such laboratory environments. Furthermore, tests with high reproducibility and repetition can be performed in this way.

For the analysis of individual cycle phenomena the LaVision **ICOS** system was used. This system is capable of measuring highly transient and time resolved in-cylinder air/fuel-ratio profiles near the spark plug over hundreds of consecutive cycles. Cycle-to-cycle fluctuations, indicating the engine operation stability, as well as the crank angle based evolution of the fuel mixing process can be analyzed in real time with the **ICOS** system.

***Figure 1**: LaVision ICOS system for highly time-resolved air/fuel-ratio measurements.*

Tip-in: a highly transient real driving condition

The engine run of the WLTP certification cycle (World-Harmonized Light-Duty Vehicles Test Procedure) shows high hydrocarbon (HC) engine-out emissions during load change conditions, for example gear change with tip-in. A tip-in is defined as a load change from coasting to acceleration. During coasting the engine is motored, the accelerator pedal is in its 0% position and no fuel is injected. The accelerator pedal is then transiently "tipped-in" to a predefined position to simulate the acceleration process.

The test engine used is based on a close-to-production six cylinder in-line engine with twin-scroll turbocharging system, fully variable valve train and spray-guided direct injection. A modified spark plug probe of the LaVision **ICOS** system with an ultra-fast response time was installed in place of the original spark plug to measure air/fuel-ratios at crank angle resolution.

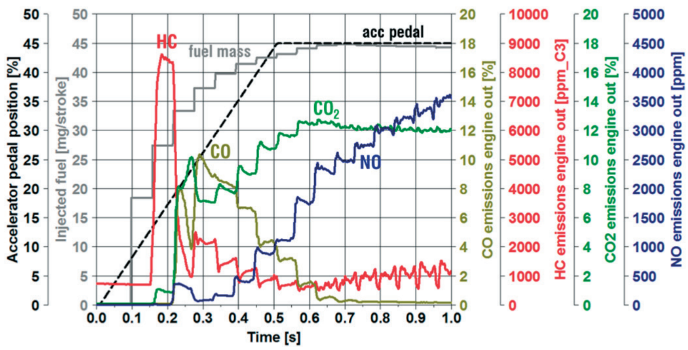

***Figure 2**: Cycle-resolved measurements of injected fuel mass and engine-out emissions after tip-in.*

For the cycle-resolved determination of the gaseous engine-out emissions three fast response gas analyzers for the detection of HC, CO, CO_2 and NO emissions were used in the exhaust port between the two exhaust valves of the cylinder 6. The recorded averaged values of ten tip-ins are shown in Figure 2. Typically, high HC emissions are measured at the beginning of the tip-in followed by high output levels of engine emissions.

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306

LaVision
FOCUS ON IMAGING

Transient Air/Fuel-Ratio Measurements in RDE Application

Internal Combustion Optical Sensor System

Crank angle resolved air/fuel-ratio measuements at spark plug position

The in-cylinder analysis of the tip-in conditions with the **ICOS** system reveals the reason for the high HC emissions in more detail. Figure 3 shows the crank angle resolved air/fuel-ratio evolution of the first 40 cycles after tip-in starting with cycle number 0 (from back to front). The first combustion cycle after injection starts with an over-stoichiometric air/fuel-ratio mixture causing the measured HC peak emissions shown in Figure 2. During the next cycles the cylinder charge develops from rich conditions (low Lambda value) back to a stoichiometric mixture at the time of ignition.

The cycle and crank angle resolved waterfall diagram in Figure 3 also gives a good overview of the mixing procedure and the differences between individual cycles. During the first 30 cycles a "moving wave" structure can be seen (indicated by the white arrow). This is a direct result of the changing in-cylinder flow structure induced by the variable valve timing active during the first 30 cycles (see Figure 4). The influence of the start of injection time on the flow structure and on the homogenization of the gas mixture is investigated in more detail in the cited reference papers.

This application shows the high potential of ultra-fast in-cylinder air/fuel-ratio detection for engine development. The **ICOS** system measures over consecutive cycles crank angle resolved air/fuel-ratio profiles before ignition and, therefore, links in-cylinder mixture information with external engine emissions.

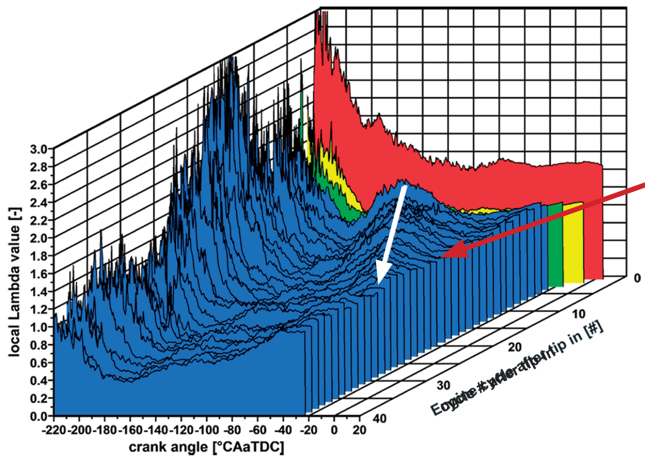

Figure 3: Crank angle resolved air/fuel-ratio profiles of the first 40 cycles after the tip-in (10 tip-ins averaged).

changes of mixture formation
due to inlet valve control

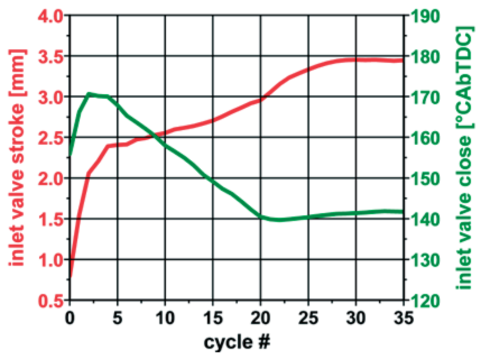

Figure 4: Changes of the inlet valve timing during tip-in.

References

"Experimental Investigations of a DISI Engine in Transient Operation with Regard to Particulate and Gaseous Engine-out Emissions", C. Disch, J, Pfeil, T. Koch, U. Spicher, O.Thiele, JSAE 201509125, SAE 2015-01-1990

"Cycle-resolved combustion diagnostics of a direct injection gasoline engine in transient operation", C. Disch, H. Kubach, J. Pfeil, T. Koch, U. Spicher, O. Thiele and C. Donn, 11th International Symposium on Combustion Diagnostics, Baden-Baden, 2014

02/18

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306