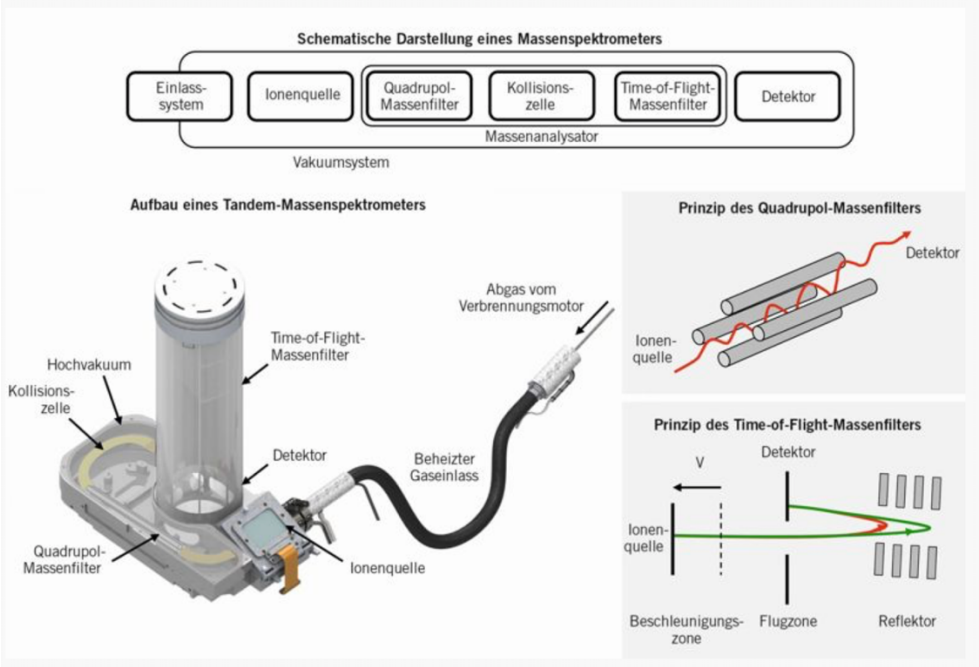
2018 - Methods for Analysis of HC and Particle Emission

MTZ worldwide, Ausgabe 11/2018
Christian Lensch-Franzen , Michael Friedmann, Marcus Gohl, Gunther Müller

The combination of electrification and alternative operating fluids offers considerable optimization potential for future powertrain concepts in terms of efficiency and emission behavior for sustainable mobility. To examine the effects of new lubricating oil and fuel formulations in this context, the APL Group uses state-of-the-art, highly dynamic exhaust gas measuring technology and new development methods. ...



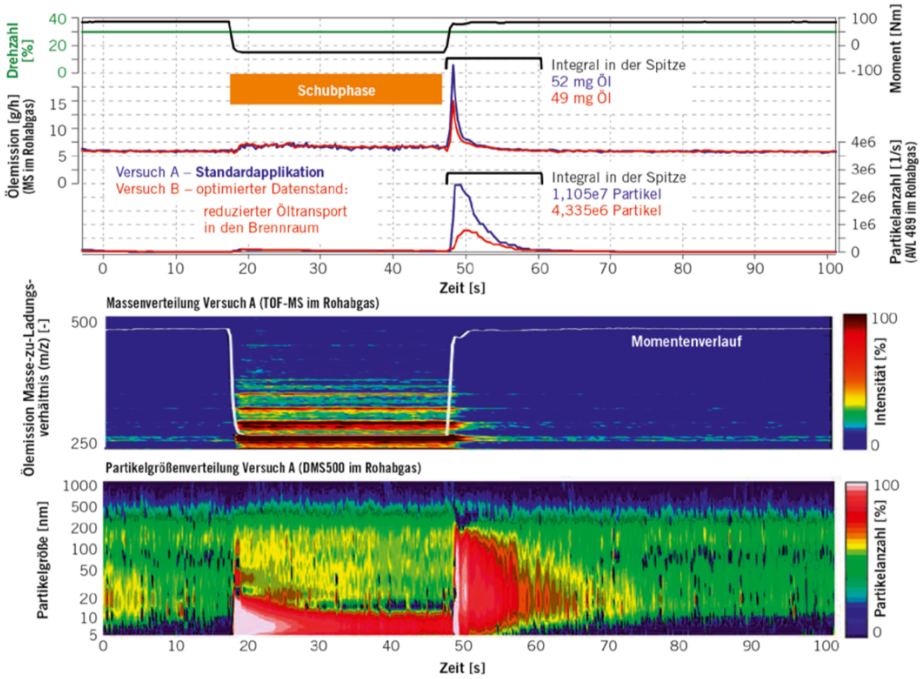


BILD 6 Betrachtung unterschiedlicher Emissionsmechanismen im dynamischen Motorbetrieb (© APL)

2018-Real-Time Measurement of the Piston Ring Gap Positions and Their Effect on Exhaust Engine Oil Emission

SAE - 2018-01-5006

Uhlig, B., Kirner, C., Preuss, A., and Wachtmeister, G., "Real-Time Measurement of the Piston Ring Gap Positions and Their Effect on Exhaust Engine Oil Emission," SAE Technical Paper 2018-01-5006, 2018

Measurement techniques for piston ring rotation, engine oil emission and blow by have been implemented on a single-cylinder petrol engine. A novel method of analysis allows continuous and fast real-time identification of the piston ring rotation of the two compression rings, while the mass-spectrometric analysis of the exhaust gas delivers the cylinder oil emission instantly and with a high temporal resolution.
Only minor modifications to the piston rings were made for the insertion of the γ-emitters, the rings rotate freely around the circumference of the piston.
The idea of this setup is that through online observation at the test bench, instant feedback of the measured variables is available, making it possible to purposefully select and compare measurement points. The high time resolution of the measurement methods enables the analysis of dynamic effects.
In this article, the measurement setup and evaluation method is described. Results monitoring the ring gap positions and the exhaust engine oil emission are discussed together with results of blow-by measurements for different speeds and loads. With the production piston assembly, only minor rotational movement of piston rings was apparent at stationary operation. Measurement results of the dynamic effects are discussed.

2018 – Real-time on-road oil consumption measurements for a commercial heavy-duty Diesel engine

5th international Motoren Kongress, February 2018.

Tom George, Co-author: Volker Schille, both IAV GmbH, Thomas McKinley Ph.D., Co-author: Trenton Berardi, both Cummins Inc., USA

Abstract:

"Oil consumption rate is a critically important parameter for modern commercial Diesel engines which commonly use cooled EGR and exhaust aftertreatment for emissions control. Specifically, it is related to several failure modes such as EGR cooler fouling, EGR valve sticking, Diesel oxidation catalyst poisoning and Diesel particulate filter ash loading. In addition, a low oil consumption leads to longer service intervals and a higher uptime of the vehicle.

In response, oil consumption rate measurement technology has dramatically improved. With mass spectrometry, it is now possible to measure oil emission (and thereby oil consumption) with an accuracy of 1 to 2 grams per hour and response times shorter than one second.

While these methods have been applied during dynamometer testing, that is only an approximation of real-world operation, which includes factors such as ambient pressure and temperature variation, angularity and g-loading. In-situ, on-road oil consumption measurement capability would be an important step forward, analogous to development of portable emissions measurement equipment that has revealed a new understanding of real-world emissions under real-world driving cycles and operating conditions.

To that end, this presentation presents on-road application of mass spectrometry to measure transient oil consumption in a heavy-duty truck. Approaches to address instru- mentation application and calibration are described, along with test measurements over a range of urban and intra-city highway driving conditions."

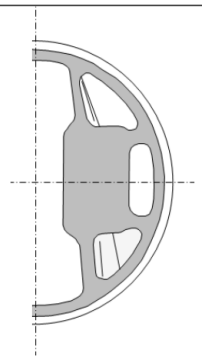
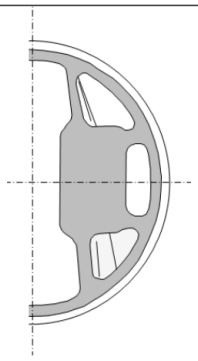
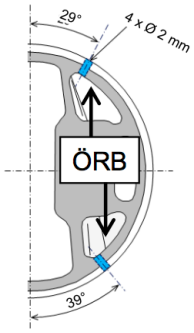
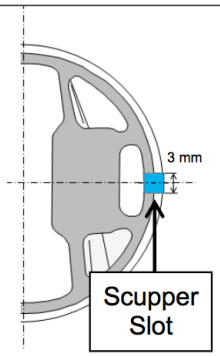
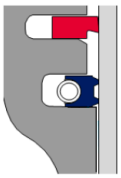
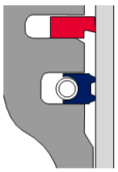
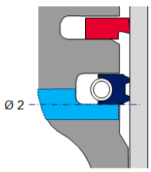
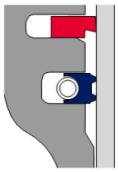
2017 – Influence of Oil Drain Holes on Oil Emission of a Turbocharged Gasoline Engine

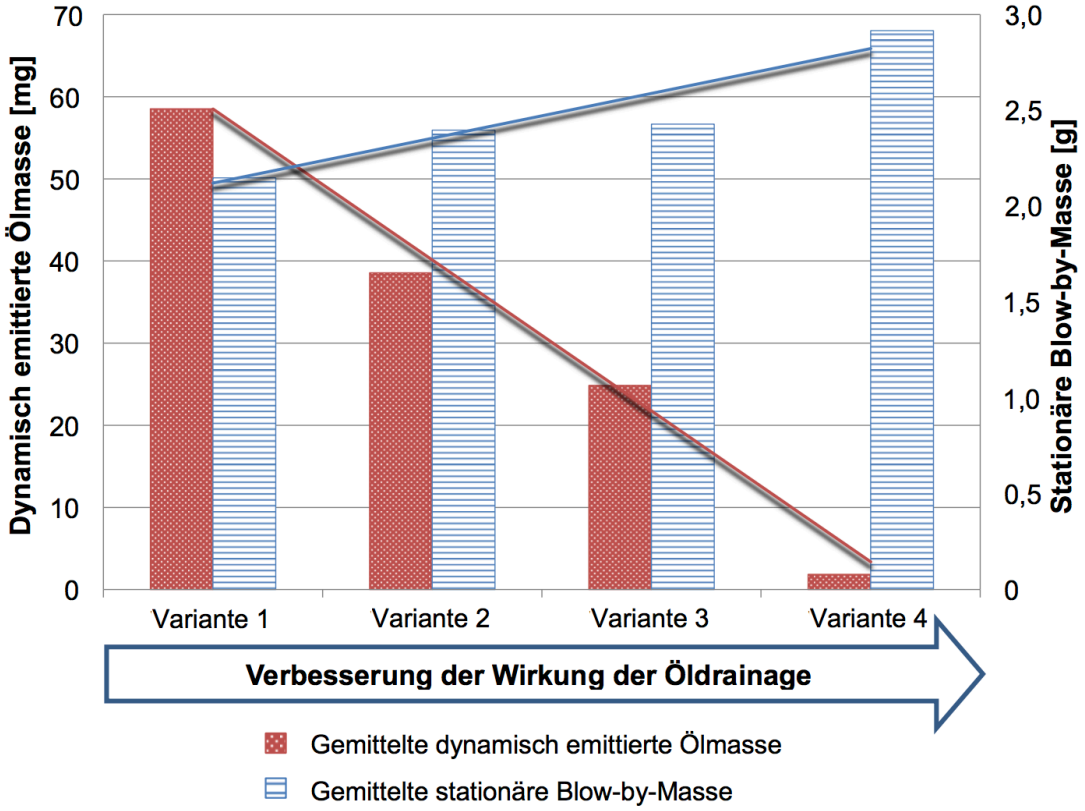
SAE-2017-01-1045, April 2017

Papadopoulos, I., Becker, S., Ehnis, H., Kunzel, R. et al.

Abstract:

The oil emission of a combustion engine has a direct influence on CO2 and particulate emissions. The focus on reducing oil emission is thus particularly growing in the context of stricter emissions limits for the automotive industry. To reach this goal requires a deeper understanding of the mechanism behind the genesis of oil emission in a combustion engine. In order to determine oil emission caused specifically by the piston group, part of the exhaust gas flow is taken and analyzed using a mass spectrometer directly downstream of the exhaust valve in the exhaust manifold. In the process, the mass spectrometer is operated in high-pass filter mode to detect long-chain hydrocarbons associated with the lubricating oil. In order to make differentiated and detailed statements about oil emission mechanisms, oil emission and blow-by in steady-state and transient engine operation are determined for specific design parameters of the piston group. A highly transient test cycle developed specially for this purpose is used when investigating transient engine operation. Using a standardized and fully automated evaluation tool, characteristic key figures can be calculated for oil emission and blow-by. They reflect the influence of various piston and ring designs on oil emission. This article describes the measurement system, the proprietary test cycle, and the influence of piston designs, such as oil drain holes in the area of the oil control ring and breaks along the third piston groove lower flank on oil emission and blow-by. A better understanding of mechanisms can contribute to more effectively minimizing oil emission and consequently CO2 emissions.

Variante 1 (V1)	Variante 2 (V2)	Variante 3 (V3)	Variante 4 (V4)
- Keine ÖRB - Kein Volumen unter Ölabstreifring	- Keine ÖRB - Mit Volumen unter Ölabstreifring	- 4 ÖRB - Mit Volumen unter Ölabstreifring	- Keine ÖRB - 2 Scupper Slots - Mit Volumen unter Ölabstreifring
			
			


Dynamisch emittierte Ölmasse [mg]
70
60
50
40
30
20
10
0
3,0
2,5
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Stationäre Blow-by-Masse [g]
Variante 1
Variante 2
Variante 3
Variante 4
Verbesserung der Wirkung der Öldrainage
Gemittelte dynamisch emittierte Ölmasse
Gemittelte stationäre Blow-by-Masse

2016 – Massenspektrometrische Untersuchung des Ölemissionsverhaltens von Verbrennungsmotoren bei stationärem und transientem Betrieb

Dissertation, Hamburg 2016, ISBN 978-3-8440-3977-1,
Armin Frommer, MAHLE GmbH, Stuttgart

Abstract:

Further reduction of emissions from internal combustion engines requires further reduction of their oil emission behavior as unburned oil emitted through the exhaust contributes to hydrocarbon raw emissions as well as CO2 emissions. As lube oil consumption behavior is different for steady-state and transient engine operation, both aspects need to analyzed in order to identify remaining potential for oil emission reduction while maintaining sufficient lubrication in all engine operating conditions. The results of oil emission measurements on different passenger car engines disclose oil emission characteristics for the whole load-speed range of these engines at steady-state operation. The development of a transient test cycle for standardized dynamic oil emission analysis and the introduction of methods for quantification and evaluation of dynamic oil emission effects allow identification of the mechanisms involved and thus their optimization.

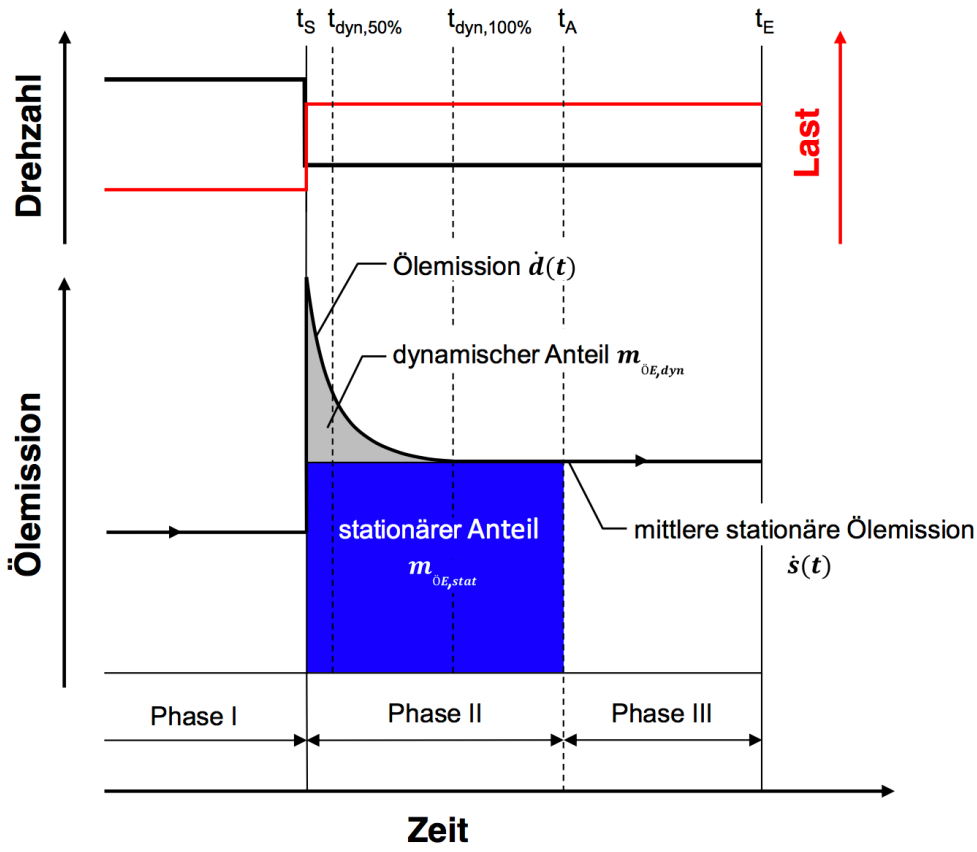

***Abbildung 56**: Schematische Darstellung des Einflusses einer Betriebspunktänderung auf die Ölemission und Definitionen zur kennzahlenbasierten Auswertung dynamischer Ölemissionsvorgänge*

2016 – Untersuchung des Ölhaushalts an der Kolbengruppe

MTZ April 2016,

B. Uhlig., C. Kirner, A. Behn, M. Feindt

Abstract:

Die Untersuchung des Schmierölhaushalts an der Kolbengruppe und dessen Einflussgrößen sind ein wichtiger Beitrag, um zukünftige Motorenkonzepte hinsichtlich Verbrauch und Emissionen zu optimieren. Am Lehrstuhl für Verbrennungskraftmaschinen der Technischen Universität München wurde im Rahmen des FVV-Vorhabens Kolbenring- Öltransport 1 ein neuartiger Motor entwickelt, der für detaillierte Untersuchungen der Schmierfilmdicken sowie der komplexen Bewegungen und Druckverhältnisse am System Kolbengruppe eingesetzt wird. Gleichzeitig entwickelte das Institut für Messtechnik der Technischen Universität Hamburg-Harburg ein Messsystem, um Schmieröltransportvorgänge innerhalb der Kolbengruppe zu bestimmen.

2016 –Auslegung der Tangentialkraft des Ölabstreifrings — Ölemission versus Reibung

MTZ January 2016,

Armin Frommer M. Sc., Dr.-Ing. Thomas Deuß, Dipl.-Ing. Holger Ehnis, Dr.-Ing. Reiner Künzel

Abstract:

Die konstruktive Gestaltung der Kolbengruppe hat einen erheblichen Einfluss auf die mechanischen Verluste von Verbrennungsmotoren. Maßnahmen zur Reibungsreduzierung stehen jedoch häufig im Zielkonflikt mit dem Ölverbrauch – insbesondere bei der Auslegung der Tangentialkraft des Ölabstreifrings. Mahle nutzt im Folgenden eine Kombination moderner Messmethoden, um diese Zielkonflikte zu quantifizieren und anwendungsspezifisch optimal aufzulösen

2015 – Fuel Transport across the Piston Ring Pack

Measurement System Development and Experiments for Online Fuel Transport and Oil Dilution Measurements

A. Behn, M. Feindt, G. Matz, S. Krause, M. Gohl, SAE, SAE Technical Paper 2015-24-2535, Capri, Italy.

Abstract:

The limitation of fuel entry into the oil sump of an internal combustion engine during operation is important to preserve the tribological properties of the lubricant and limit component wear. For observation and quantification of the effects leading to fuel entry, a highly sensitive and versatile measurement system is essential. While oil sampling from the sump followed by laboratory analysis is a common procedure, there is no system for automatic sampling of all the positions and fast online analysis of the samples.

For the research project 'Fuel in Oil', a measurement system was developed especially for the described tasks. The system is placed next to the engine in the test cell. Sampling points are the target point of the fuel injector jet and the liner below, the oil sump and the crankcase ventilation system. The system consists of a microliter volume and an aerosol sampling setup, a probe evaporator, an isothermal gas chromatograph and a triple quadrupole mass spectrometer with a modified ion source.

To quantify the fuel emission from the cylinder wall into the exhaust, an online exhaust gas measurement was carried out using a direct inlet system with the same mass spectrometer.

With the use of the described setup, it was possible to observe and quantify the effects leading to fuel entry into the oil sump as well as fuel leaving the sump.

2015 – Emission Reduction A Solution of Lubricant Composition, Calibration and Mechanical Development

MTZ worldwide, August 2015, Volume 76, Issue 9, pp 30-33
Prof. Dr.-Ing. Jens Hadler, Dipl.-Ing. Christian Lensch-Franzen, Dr.-Ing. Marcus Gohl, Dipl.-Ing. Tobias Mink
http://www.atzonline.com/Article/18204/Emission-Reduction-–-A-Solution-of-Lubricant-Compositionkomma-Calibration-and-Mechanical-Development.html
http://link.springer.com/article/10.1007/s38313-015-0040-8

Abstract:
In combustion engines, the piston group system mainly determines the mechanical and thermodynamic losses and exhaust emissions resulting from the lubricant oil, like particles and hydrocarbons. To understand the tribological processes and the different oil transport and emission mechanisms better, APL Group has developed a method to reduce oil-caused pollutant emissions and irregular combustion phenomena with targed-oriented measures.

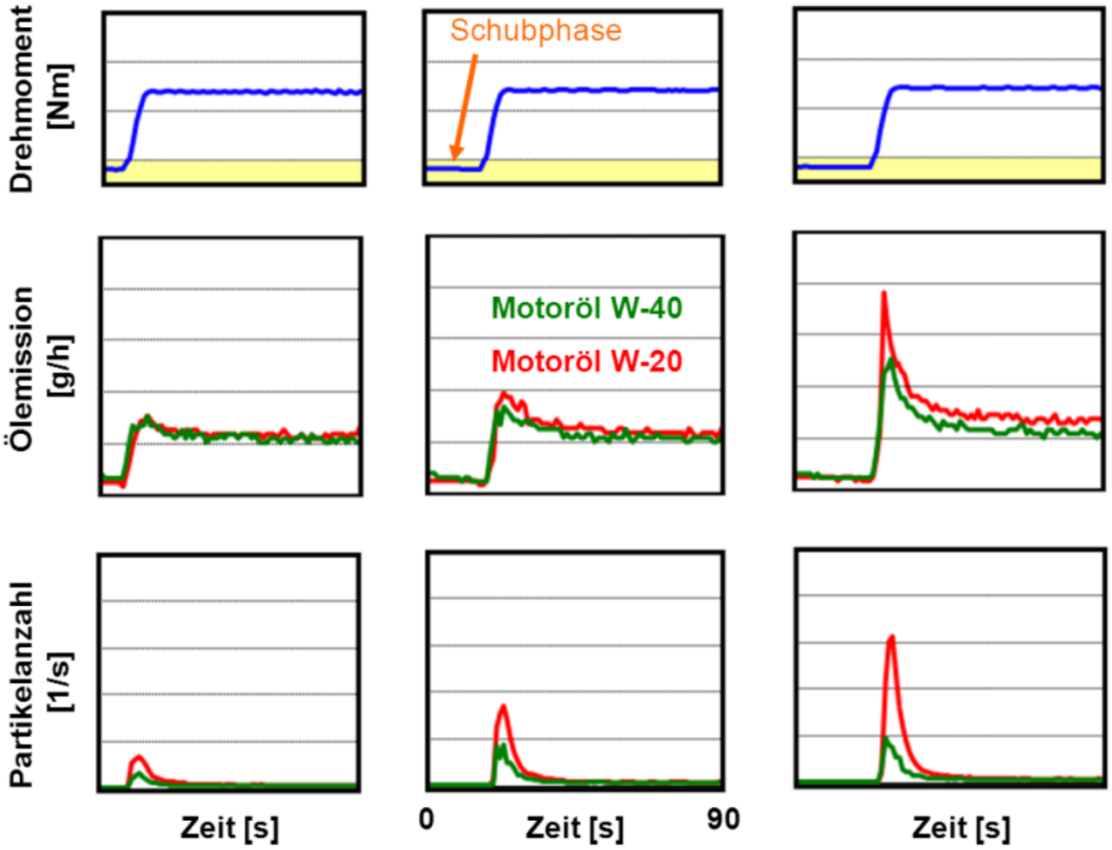

Figure 1 – Effect of the oil emission on the particle generation

2015 – Methods for the development of a RDE-capable powertrain

MTZ worldwide, June 2015, Volume 76, Issue 7-8, pp 32-37
Prof. Dr.-Ing. Jens Hadler, Dipl.-Ing. Christian Lensch-Franzen, Dr.-Ing. Marcus Gohl, Dr.-Ing. Carsten Guhr

Abstract:
On the background of the continuously changing statutory regulations, increasing customer requirements for efficiency and dynamic, as well as competition for market shares, the complexity in automotive engineering, with at the same time shorter development cycles, has dramatically increased. Near future emission regulations like the limitation of particle number for direct injection gasoline engines or the RDE legislation are going to increase the necessary effort for development, validation and compliance considerably over the current level, as the APL Group shows.

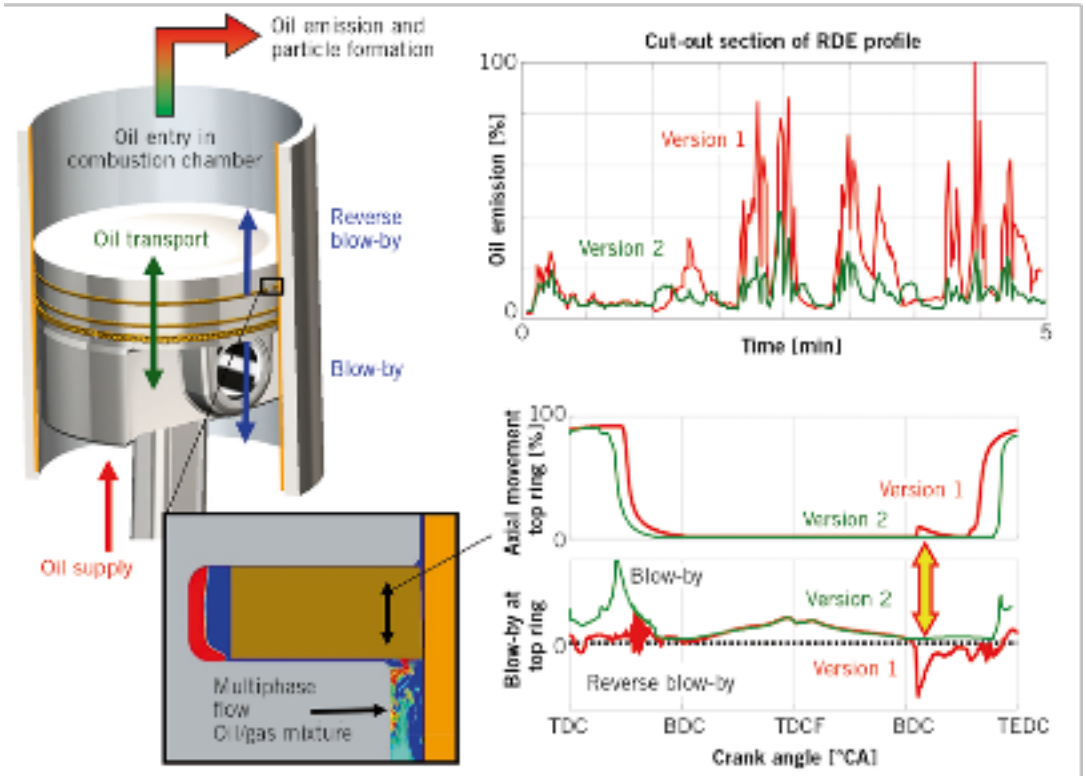

Figure 2 – Oil emission measurement and simulation of the functional group piston/pistion ring/cylinder wall for optimisation

2015 – Fuel in Oil

Investigation of the fuel lubrication oil interaction on oil dilution during particulate filter/ NO_x storage catalyst regeneration
Informationstagung Motoren, Frühjahr 2015, Bad Neuenahr, Heft R 570

Abstract:

The aim of the research cluster “Fuel in Oil” is the investigation and quantification of the interaction between the fuel and the lubrication oil caused by late post injections, which are applied for the regeneration of the particulate filter or the NO_x storage catalyst. To achieve the objectives, different phenomena like the fuel entry into the lubrication film, the fuel-oil transport by means of the piston rings, the evaporation of fuel out of the oil pan and the impact of the oil separator of the oil dilution were investigated. A variety of fundamental experiments and engine tests, were set up and performed, during these investigations. Advanced measurement techniques were developed to quantify the phenomena. The droplet diameter und velocity of the post injection spray was measured with the help of high pressure chambers. The droplet film interaction was investigated with fundamental experiments. Furthermore, the film thickness of the wall film deposited by the post injection was measured in a diesel engine. To investigate the impact of the oil separator on the oil dilution process, the fuel concentration upstream and downstream of the separator and the droplet diameter of the aerosol was measured.

Another topic of the research cluster is the development of CFD simulation methods to simulate the effects of the oil dilution. For this purpose, a simulation method to calculate the fuel entry into the lubrication film und a simulation method to simulate the lubrication film and blow by gas transport by means of the piston rings was developed. Moreover, it was possible to understand the fuel entry and fuel evaporation process with the help of CFD simulations of

the crank train. The simulation methods will be validated with the measurements. Furthermore, a model based simulation method to determine the complete oil dilution considering engine and operating parameters as input was developed.

Results:

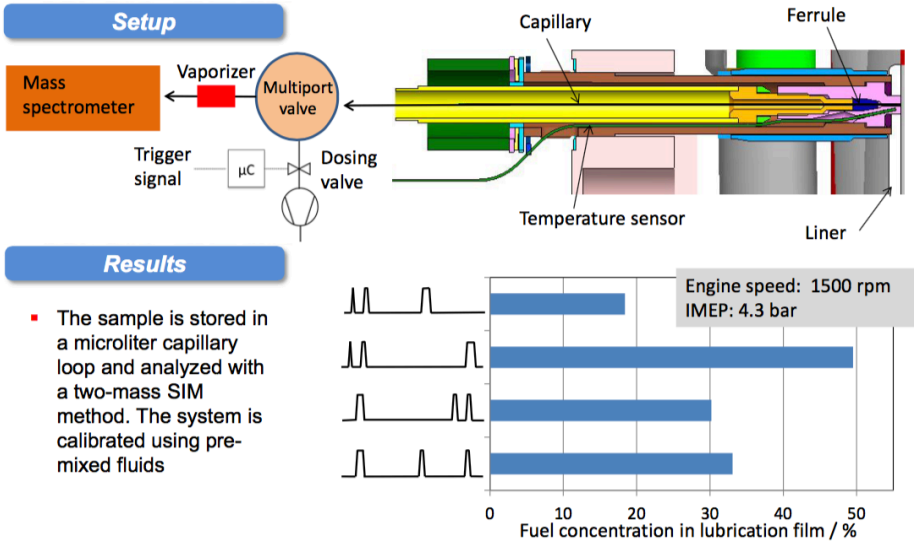

Figure 3 – Online Liner-Oil-Analysis

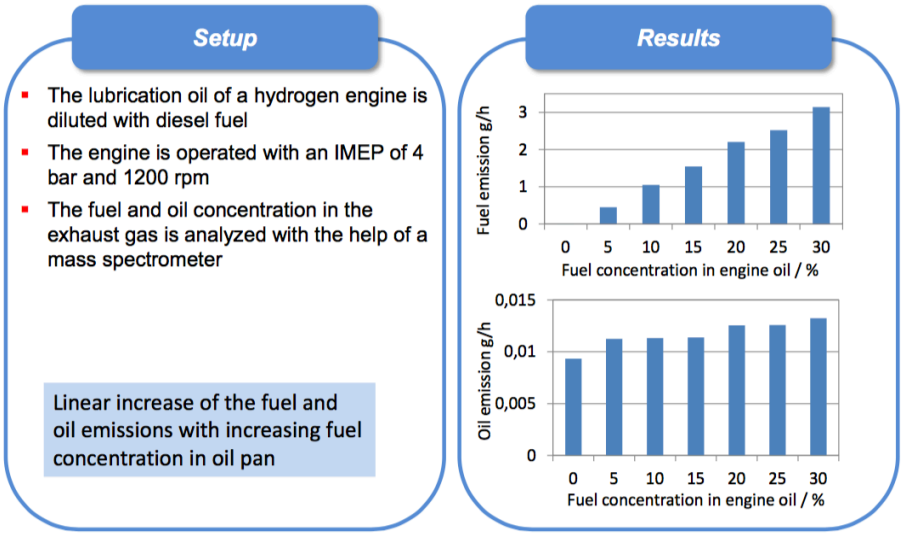

Figure 4 – Fuel and Oil Emission of a hydrogen engine with diesel-diluted engine oil

2014 – Tools for the Development of the Mechanical Components of Turbochargers

MTZ worldwide, July 2014, Volume 75, Issue 7-8, pp 12-17
Authors B. Kehrwald, A. Jäger, M. Sailer, J. Hadler
Source: Springer Automotive Media Wiesbaden GmbH (2014)
http://link.springer.com/article/10.1007/s38313-014-0167-z
http://www.atzonline.com/Artikel/3/17860/Tools-for-the-Development-of-the-Mechanical-Components-of-Turbochargers.html

Abstract:
Turbocharging is one of the key technologies in current and future engine development. Due to the increasing requirements that extend beyond power output and torque alone, the internal and external mechanical components of turbochargers are being subjected to an ever-increasing load spectrum. In this report, APL and IAVF Antriebstechnik present development and testing tools for the laboratory and test bed environments that can be used to design the mechanical components of the turbocharger system in accordance with the new requirements.

Summary:
In order to fulfill emission restrictions the functional requirements of exhaust gas turbochargers have increased. Using Lubrisense mass spectrometers the oil consumption of exhaust gas turbochargers can be obtained by calculating the difference of the oil emission before and after the turbocharger. Oil consumption can be measured with an accuracy of 0.1 g/h. The mass spectrometer is fast enough to measure a total engine map for two different turbocharger setups in one day. Figure 3 shows the oil emission of different turbocharger setups.

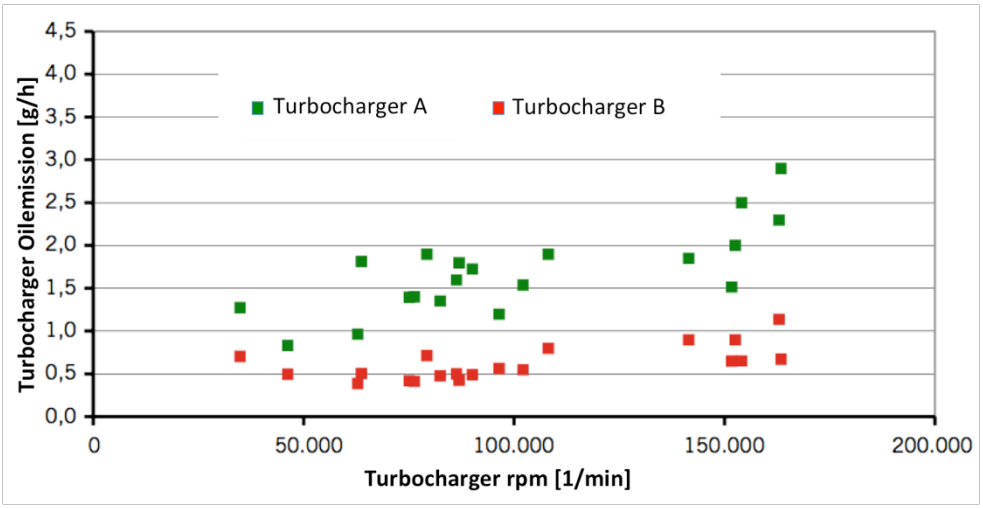

Figure 5 – Oilemission of different Turbocharger-Setups

2014 – Concept for Analysing and Optimising Oil Emission

MTZ worldwide, January 2014, Volume 75, Issue 1, pp 24-29
Authors: J. Hadler, C. Lensch-Franzen, M. Gohl, T. Mink
Quelle: Springer Automotive Media Wiesbaden GmbH (2014)
http://link.springer.com/article/10.1007/s38313-014-0006-2
http://www.atzonline.com/Artikel/3/17702/Concept-for-Analysing-and-Optimising-Oil-Emission.html

Abstract:
Modern downsizing in connection with the future more rigorous exhaust limit values for cars, commercial vehicles and off-highway applications, is a great challenge for internal combustion engine systems and components. In this context, increased oil emission leads to increased particle and HC emissions. Additionally, the efficiency of the exhaust gas aftertreatment and the pre-ignition tendency due to the oil consumption can be negatively influenced. The APL Group has developed an integral concept for targeted analysis of oil emission mechanisms and reduction oil emission using cutting edge online measuring techniques, metallographic and chemical analytics as well as simulation tools.

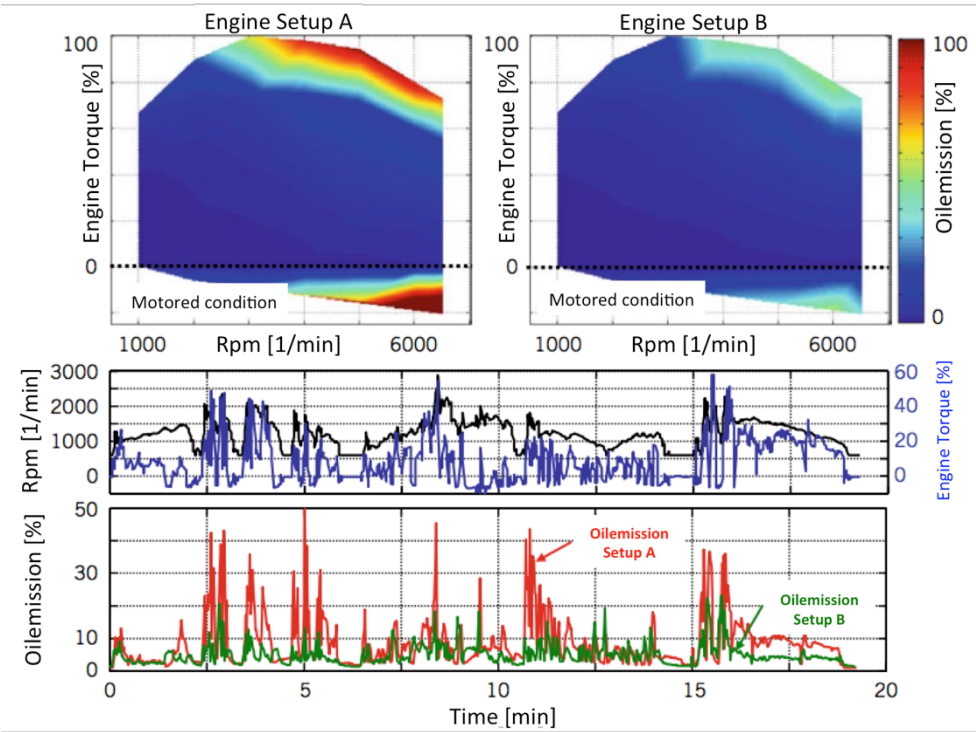

Figure 6 – Stationary and dynamic Oilemission

2013 – System for the measurement of oil emissions in the exhaust gas of Diesel engines

MTZ - Motortechnische Zeitschrift Ausgabe 05/2013 Seite 424-429
Authors: A. Behn, M. Feindt, S. Krause, G. Matz
Source: Springer Automotive Media Wiesbaden GmbH (2013)

Abstract:
The measurement of oil consumption and the investigation of oil consumption mechanisms in combustion engines are subject to various research projects. Methods like drain and weight, or such using tracers like radioactive substances, sulphur dioxide or pyrene are often too slow or insensitive for dynamic engine test cycles.

For this reason within the scope of FVV projects at the Institute of measurement technology at Hamburg University of Technology a mass spectrometer system was developed which can detect and quantify hydrocarbons from engine oil in engine exhaust gases at a high time

resolution and with high sensitivity. While at the beginning the development focused on exhaust gas measurements of Otto engines, the system was also used for investigating the oil vaporization behavior inside the cylinder as well as the fuel mixture generation of direct injection engines. The application of the mass spectrometer system to diesel engines, in particular for in-cylinder measurements, was complicated up to now due to the high particle loading of the gas and the high pressure in the cylinder.

The research project „Development of a direct inlet system for crank angle resolved in-cylinder oil emission measurement in diesel engines“ had the objective to allow in-cylinder and exhaust gas measurements of diesel engines based on the results of previous projects.

Results:

Due to exhaust particles fiber filters or filters from porous materials are not suitable for this purpose, because the precipitated particles are deposited in their gas path. Impactors, cyclone separators and aerodynamic lenses increase the dead volume of the gas path. Based on this knowledge the geometry shown in figure 3 was designed and optimized with the help of the simulation environment ANSYS. It allows at a minimized dead volume the extraction of a small gas flow containing few particles from a main gas flow. Due to their inertia and the high gas speed the particles preferentially follow the main path in horizontal direction. Hence, behind the expansion of the main path a small branch flow can be deducted into the MS path to the analysis device.

Because of its compact design this geometry can be integrated easily into the probe tip near the engine. The gas enters from the combustion chamber through an inlet restriction into the main path, which leads out of the cylinder head. The flow divider sits as a prefabricated part outside of the cylinder head; the transfer line of the main path is connected to a pressure regulation, which supports the pressure at the end of the path at 700 mbar. Behind the expansion point in the main path the extraction of a branch flow is accomplished by means of an additional inlet restriction into the MS path of the analysis device. At the end of the path a pressure regulation adapts to the system pressure of the mass spectrometer of 100 mbar. At this pressure level the gas is extracted for the ion source of the mass spectrometer using a glass capillary.

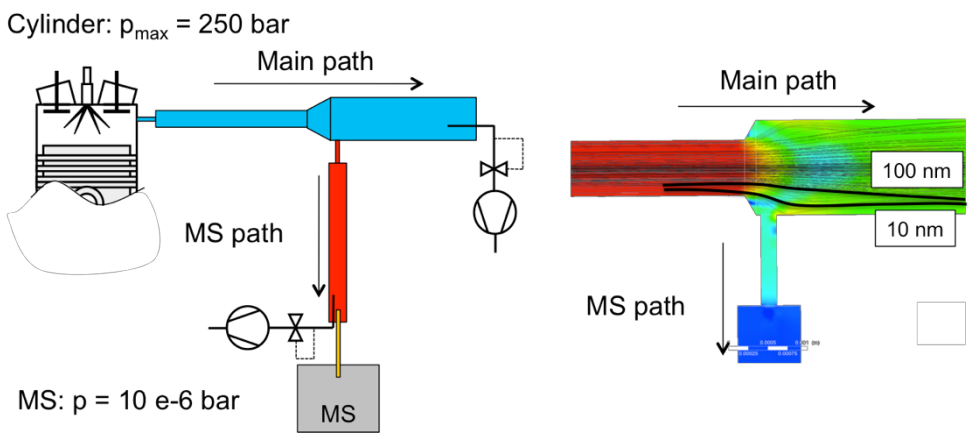

Figure 7 – Construction and path geometry of the direct inlet system with detail image of the simulated particle flow

In figure 8 the result of an in-cylinder measurement of the OM 660 is exemplified in the working point n = 3000 min^{-1}, T = 75 Nm (transfer time correction of the data already implemented). To perform the transfer time correction the transfer time of the inlet system is calculated with the help of the simulated and measured in-cylinder CO2 concentration and is applied in the following to all other measured signals like oil emissions, NOX etc.

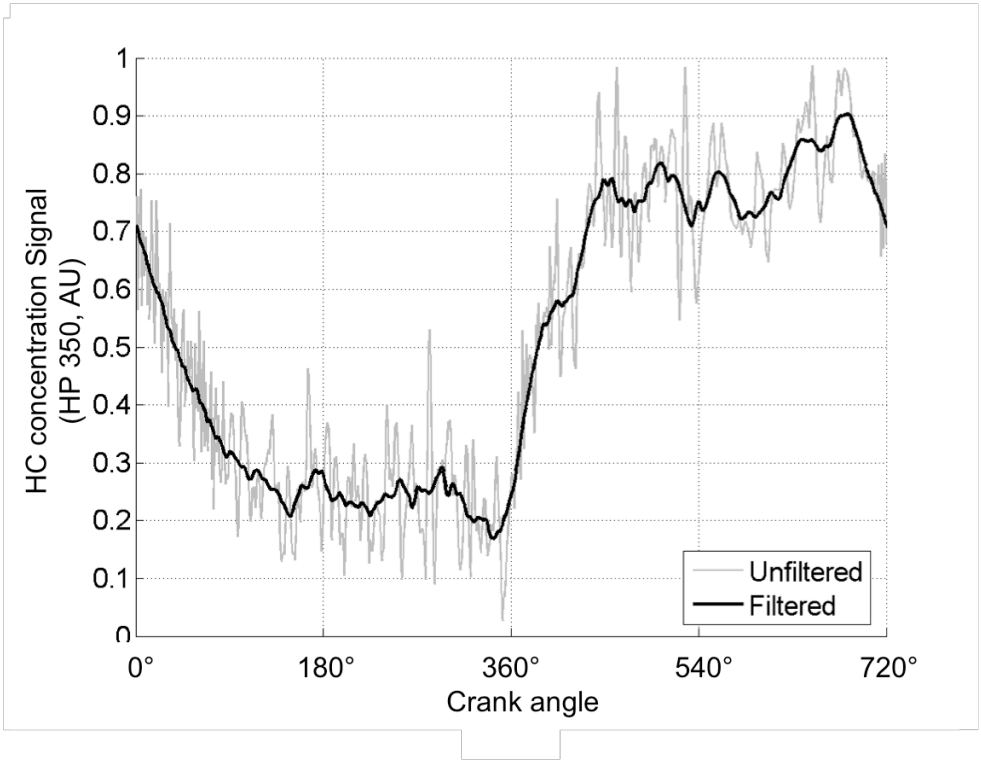

Figure 8 – Oil concentration signal from in-cylinder measurement (normalized)
MB OM 660, n = 3000 min^{-1}, T = 75 Nm

2013 – Analysis of Lube Oil Consumption in Transient Engine Operation

MTZ worldwide, January 2013, Volume 74, Issue 1, pp 26-33
M.Sc. Armin Frommer, Dipl.-Ing. Annette Beeckmann, Dipl.-Ing. Rudolf Freier, Dr.-Ing. Reiner Künzel
http://link.springer.com/article/10.1007/s38313-013-0005-8

Abstract:

Optimisation of lube oil consumption in transient engine operation is gaining increasing attention from engine developers. Engine operation in extended stop-and-go phases can sporadically lead to unexpected oil consumption problems for inner-city driving. In view of this, Mahle has developed a tool that can perform a comprehensive oil consumption analysis for both steady-state and transient operating conditions.

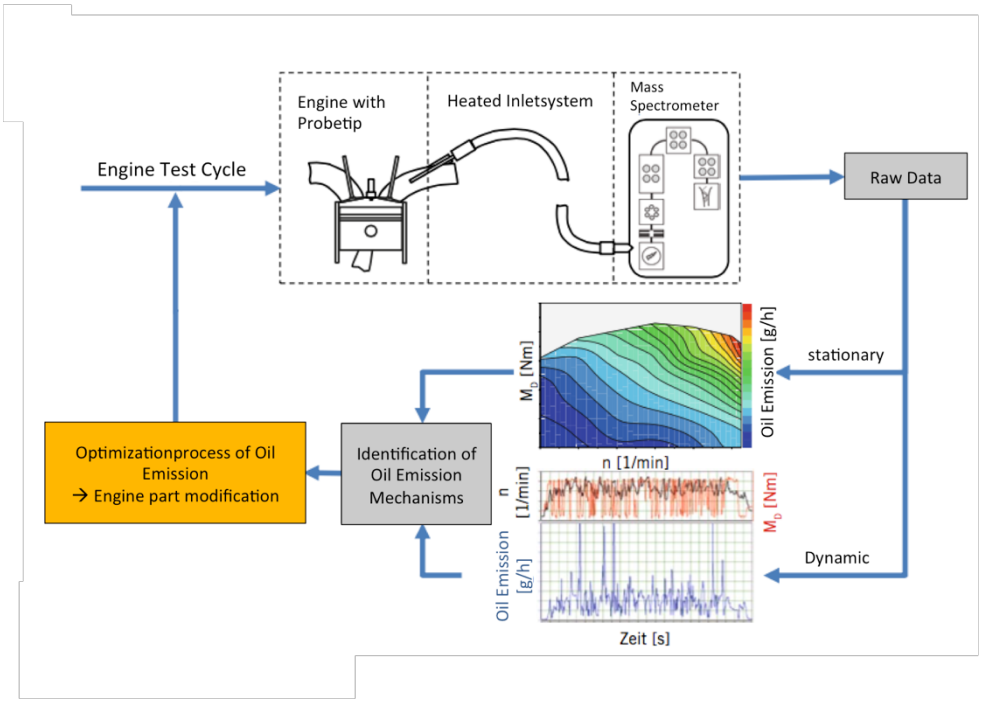

Figure 9 – Schematic Test Setup and Procedure of Oil Emission Analysis

2012 – Online Oil Consumption Measurement – Steady-state vs. Dynamic

SIMEA 2012
M.Sc. Armin Frommer, Dipl.-Ing. Annette Beeckmann, Dipl.-Ing. Rudolf Freier, Roberto Pierotti

Abstract:
Partly competing objectives, as low fuel consumption, low friction, long oil maintenance interval, and at the same time lowest exhaust emissions have to be fulfilled. Diminishing resources, continuously reduced development periods, and shortened product cycles yield detailed knowledge about lube oil consumption mechanisms in combustion engines to be essential. Further reduction of lube oil consumption, however, requires development and continuous optimization of measurement methods allowing precise and reliable analysis of these mechanisms. The Lubrisense mass spectrometric measurement system used at MAHLE allows real-time detection of low-volatile hydrocarbons originating from lube oil in the exhaust. This paper provides an overview about measurement method fundamentals and capabilities. Exemplary results show the general influence of engine speed and load on lube oil consumption of gasoline engines. They also reveal that mechanisms induced by transient engine operation can contribute significantly to overall LOC carrying precious potential for further LOC reduction.

Summary/Conclusion:
Exemplary results in this paper reveal that knowledge about steady-state LOC is one important element but not sufficient for further LOC reduction on modern engines. Besides the general influence of speed and load during steady-state operation LOC behavior is affected by dynamically induced LOC mechanisms, which can contribute significantly to overall LOC. As a result, optimum engine component development includes evaluation of LOC behavior for stedy-state and dynamic engine operation.

The fast LOC measurement method complies with the resulting requirements towards measurement technology. Besides significant measurement time reduction compared to conventional measurement methods, it allows real-time monitoring of lube oil emission and

thus LOC analysis throughout the whole load/speed range of the engine. This offers the opportunity to carry out extensive parameter studies systematically. Suitable measures can be derived from results of these investigations. Finally, the combination of specific test cycles for LOC analysis and catalogues of measures provides a tool that can be used for LOC optimization by target-oriented changes to PCU components, optimizing them as a system in total.

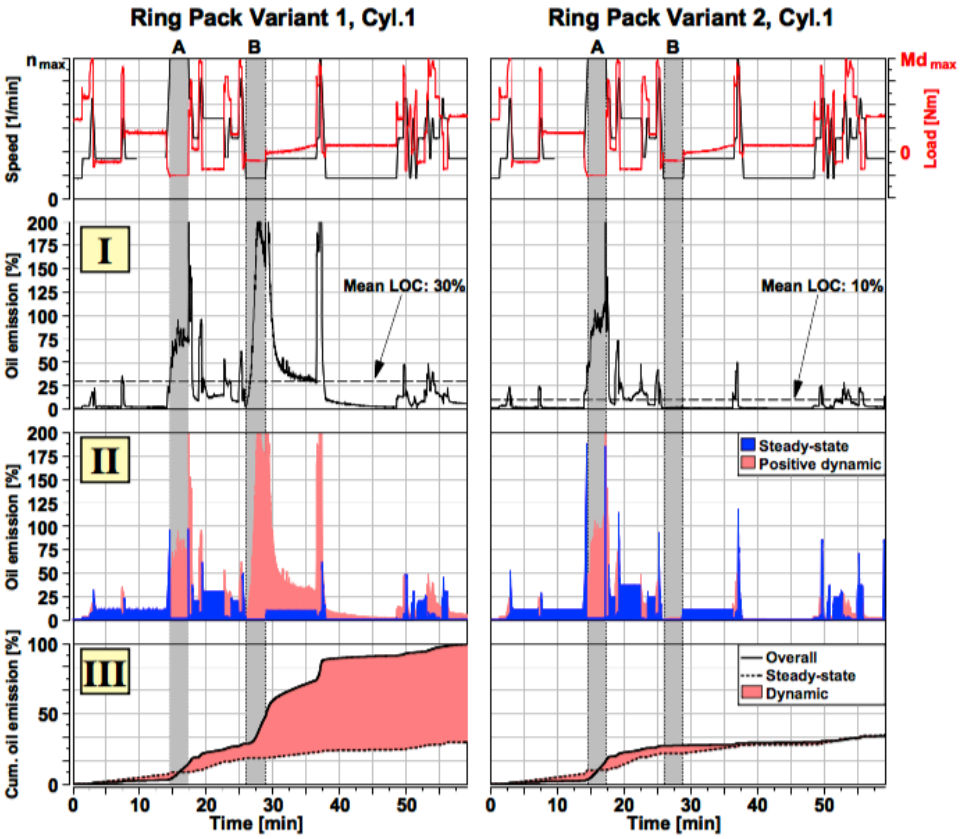

Figure 10 – Comparision of cylinder-selective oil emission vs. Time for ring pack variant 1 and 2 during a transient test cycle

2011 – Diesel-Oilemission

Development of a direct inlet system for crank angle resolved in-cylinder oil emission measurement in diesel engines

Informationstagung Motoren, Herbsttagung 2011, Fulda, Heft R 556

A. Behn, M. Feindt, S. Krause, G. Matz

Abstract:

Within the scope of the project „Development of a direct inlet system for crank angle resolved in-cylinder oil-emission measurement in diesel engines“, a system was developed for high time-resolution in-cylinder and exhaust gas measurements of long-chain hydrocarbon emissions.

For high system sensitivity and stability, a triple quadrupole mass spectrometer was modified with a new ion source. Additional hardware was developed and manufactured for efficient system operation: A dedicated control unit supplies voltages and filament current for ion source operation. An external data acquisition system records the detector signal from the mass spectrometer over the engine’s crankshaft angle and additional analog voltage values. The mass spectrometer is coupled to the inlet system by a heated and pressure controlled

inlet module.

Gas probing from the engine's cylinder is realized using a CFD-optimized, modular direct inlet system. Despite the highly dynamic pressure of up to 250 bar inside the cylinder, the inlet system provides a stable gas flow from the engine to the mass spectrometer. Considering the high particle concentration in diesel exhaust gas, a particle minimizing geometry was integrated into the inlet system.

To investigate the performance of the developed system, in-cylinder and exhaust gas measurements were successfully carried out using two different diesel engines on engine test stands. Additionally, the system was used in a parallel project for analysis of lubrication oil film probes from a diesel engine cylinder.

2010 – Influence of the Mixture Formation on the Lubrication Oil Emission of Combustion Engines

Gohl, M., Brandt, S., Wittler, M., Budde, M. et al., "Influence of the Mixture Formation on the Lubrication Oil Emission of Combustion Engines," *SAE Int. J. Fuels Lubr.* 3(1):733-744, 2010, doi:10.4271/2010-01-1275.
http://papers.sae.org/2010-01-1275/

Abstract:
Partly competing objectives, as low fuel consumption, low friction, long oil maintenance rate, and at the same time lowest exhaust emissions have to be fulfilled. Diminishing resources, continuously reduced development periods, and shortened product cycles yield detailed knowledge about oil consumption mechanisms in combustion engines to be essential. There are different ways for the lubricating oil to enter the combustion chamber: for example as blow-by gas, leakage past valve stem seals, piston rings (reverse blow-by) and evaporation from the cylinder liner wall and the combustion chamber. For a further reduction of oil consumption the investigation of these mechanisms has become more and more important. In this paper the influence of the mixture formation and the resulting fuel content in the cylinder liner wall film on the lubricant oil emission was examined. The oil emission behavior was investigated in a single cylinder spark ignition engine under different mixture formation conditions with Direct Injection (DI) and with Port Fuel Injection (PFI). The oil film thickness and the fuel content in the film were observed using the Light Induced Fluorescence (LIF) technique. The light accessed the cylinder liner through a silica glass window at significant locations which were determined by CFD-simulation. Moreover in-cylinder experiments have been carried out to measure the composition of the oil film and the hydrocarbon emissions by online mass spectrometry. Further numerical simulation results and fundamental laboratory experiments contributed to a more detailed understanding of the interrelation between mixture formation and oil emission.

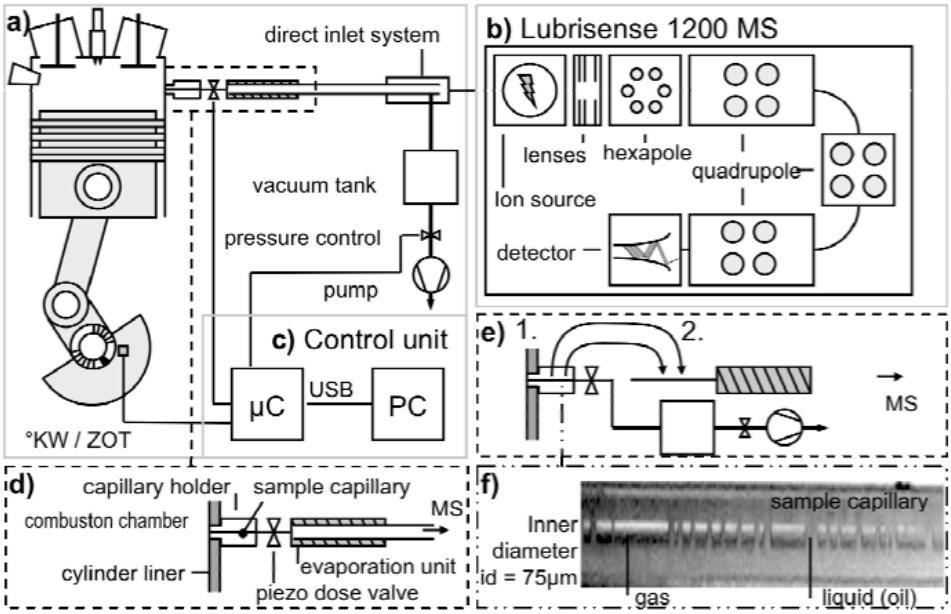

Figure 11 – Schematic diagram of the test process for liner film sampling: a) Engine with sampling and crank angle sensor, b) Mass spectrometer c) Control unit, d) Continuous online sampling, e) Quasi-online sampling, f) Sample capillary after measurement.

2010 – Influence of the Mixture Formation on the Lubrication Oil Emission of Combustion Engines

MTZ worldwide eMagazine, January 2011, Volume 72, Issue 1, pp 46-51
Dipl.-Ing. Matthias Budde, Dipl.-Ing. Sven Brandt, Dr.-Ing. Sven Krause, Dr.-Ing. Marcus Gohl
http://link.springer.com/article/10.1365%2Fs38313-011-0009-1
http://www.atzonline.com/Artikel/3/12550/Influence-of-the-Mixture-Formation-on-the-Lubricating-Oil-Emissions-of-Combustion-Engines.html

Abstract:
Due to diminishing resources, reduced design periods and cycles of life, the knowledge about mechanisms leading to oil emissions plays a major role in today's combustion engine design. During the FVV research project No. 933 "Lubricating Oil Emissions and Mixture Formation" the influence of mixture formation on the fuel wall film formation and the oil emissions of a single-cylinder research engine have been investigated. The research was performed at the Institute for Combustion Engines (VKA) at RWTH Aachen University, at the Institute of Measurement Technology at Technical University Hamburg-Harburg (TUHH) and at the Institute for Machine Elements and Tribology IMK at University of Kassel.

2010 – Analysis of Oil Emission Mechanisms by Simulation and Mass Spectrometry

Gohl, M. and Adams, D., "Analysis of Oil Emission Mechanisms by Simulation and Mass Spectrometry," *SAE Int. J. Fuels Lubr.* 3(2):489-506, 2010, doi:10.4271/2010-01-1562.
http://papers.sae.org/2010-01-1562/

Abstract:

The improvement of engine efficiency, without adversely affecting oil consumption, blowby-gas, wear, or costs are desirable objectives for today's engine manufacturers as they strive to improve engine performance while trying to meet increasingly stringent emissions regulations. In this context the development of piston ring designs as well as optimized surface texturing and lubricating oil formulation is of main interest.
The combination of simulation programs and the application of dynamic online oil emission measurement techniques lead to a target oriented development and a deeper understanding of the mechanisms causing oil consumption. The paper presents the results of the experimental and theoretical investigations of oil consumption mechanisms. A mass spectrometric method developed by the author et al., was used to measure the online oil emission in the exhaust gas by means of direct analysis of the lubricating oil molecules.
Running-in tests were conducted with a four-cylinder gasoline engine to observe the changing tribological performance due to variations in cylinder surface topography and piston ring geometry. In this context the results of the oil emission of a conventional honed surface in comparison with an optimised structure is discussed. Dynamic engine operation, as well as complete engine oil emission maps over different steady state conditions were evaluated.

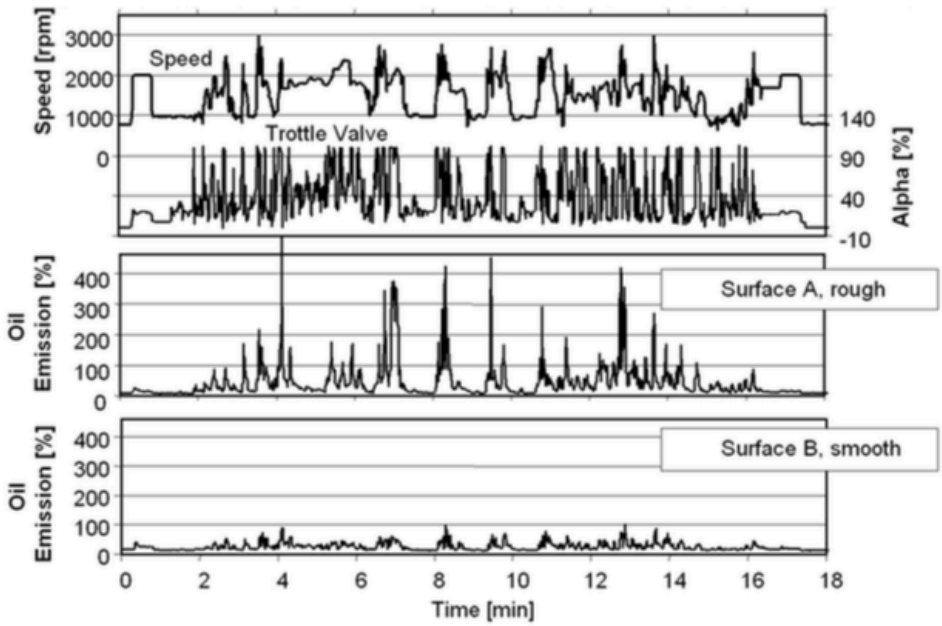

Figure 12 – Measured Oil Emission during Transient Operation in the City Cycle

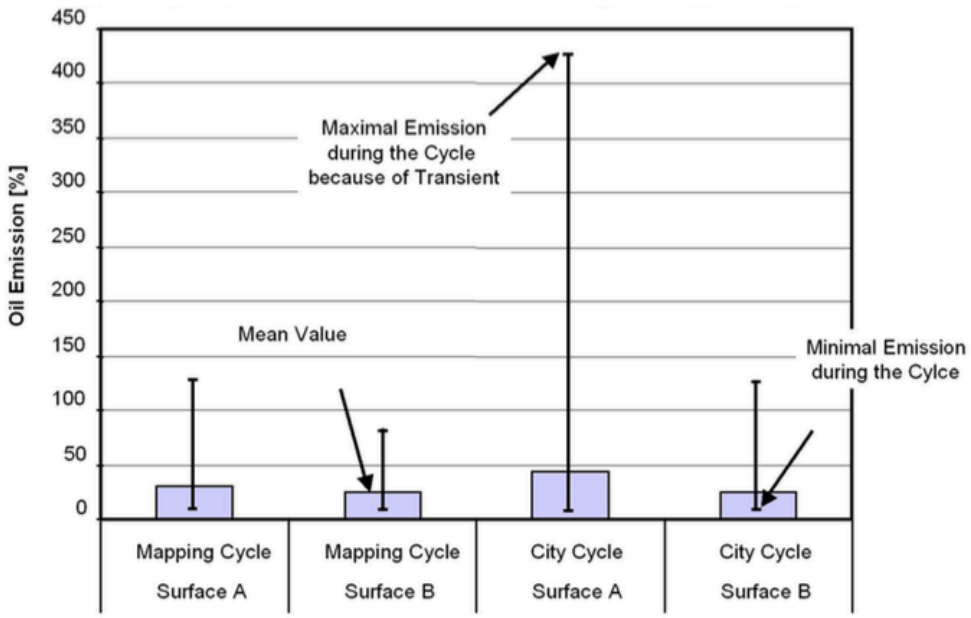

Figure 13 – Comparision of Steady State and Dynamic Oil Emission

2009 – Piston and engine testing

Piston and engine testing, MAHLE GmbH (Ed.), ISBN 978-3-8348.1982-6
MAHLE GmbH (Ed.)

Summary:

"In conventional measurement methods, the consumed lube oil is measured. Particularly at low levels of lube oil consumption, very long running times are needed, which means high costs
The analytical tracer methods, in which the concentration of a tracer (marker) from the engine oil is measured in the exhaust gas, can sometimes provide high accuracy in a relatively short running time. These methods are thus ideal to generate lube oil consumption maps.
…

Direct, fast online measurement, however, is nearly impossible for transient engine operation when using tracer methods.
…

With the analytical measurement method without tracer, the oil emission in the exhaust gas can be determined directly. The underlying measurement principle is based on the condition that the hydrocarbons present in the exhaust gas, which can be associated with the fuel and the engine oil, have different molecular chain lengths. In order o measure oil emission, a mass spectrometer optimized for this application is used, and the long chain and heavy volatile HC components associated with the engine oil are separated out. The HC molecules from the fuel and the engine oil are then measured separately using adjustable mass filters."

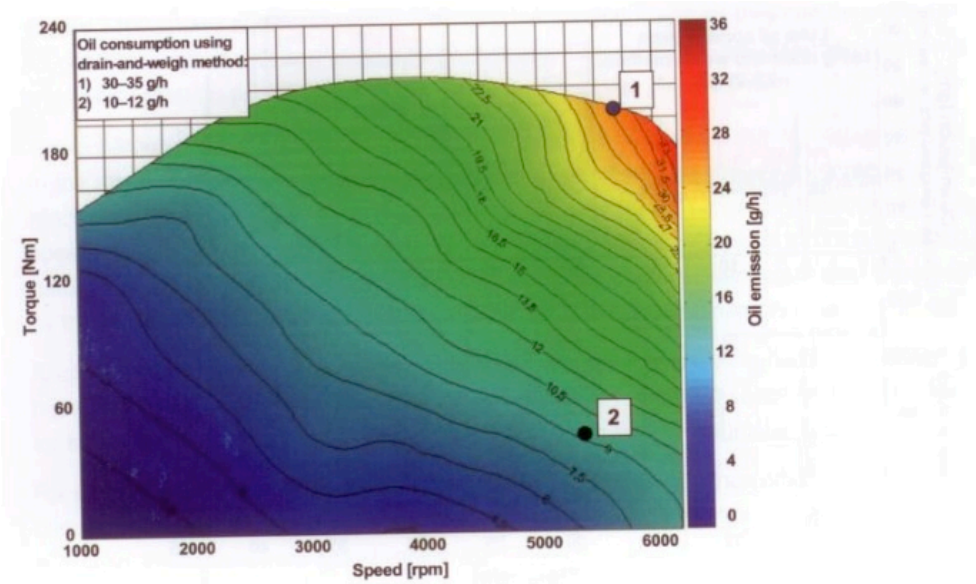

Figure 14 – Lube oil consumption map for a 2.0-liter, four-cylinder gasoline engine, using fast lube oil consumption measurement; measurement points 1 and 2 measured conventionally

2009 – Massspectrometric method to characterize the oil evaporation in the combustion chamber of spark-ignition engines

http://dx.doi.org/10.15480/882.697

To reduce engine emissions caused by evaporation of oil, the investigation of this process in the combustion chamber is necessary. In order to understand the mechanisms of oil emission, the gas composition has to be monitored online for each combustion cycle. A mass spectrometer equipped with a new direct inlet-system optimised by computational fluid dynamics enables crank angle resolved monitoring with a rise time of 2.5 ms over the full speed-/torque-range of a spark-ignition engine. The allocation of the measurement data to the crank angle is calculated by a new software program based on a genetic algorithm using CO_2 measurements and a model of the combustion process.

2006 - Comparative investigations of oil consumption and oil emissions on a spark ignition engine

MTZ worldwide, May 2006, Volume 67, Issue 5, pp 14-17
Norbert Appel, Marcus Gohl, Arnim Robota
http://www.atzonline.com/Artikel/3/3288/Comparative-Investigations-of-Oil-Consumption-and-Oil-Emissions-on-a-Spark-Ignition-Engine.html
http://link.springer.com/article/10.1007%2FBF03227842

Abstract:
Determining the oil consumption of internal combustion engines presents a challenge to every engine test engineer due to the complex interactions. In a joint project set up by Federal Mogul Burscheid GmbH and General Motors Powertrain Europe it was proposed to study the behavior of a gasoline engine with respect to sump oil consumption and oil emissions in the exhaust gas. To measure the emissions a new online measurement system supplied by Automobil-Prüftechnik Landau was used which enables oil emissions to be

measured directly in the exhaust gas of a combustion engine.

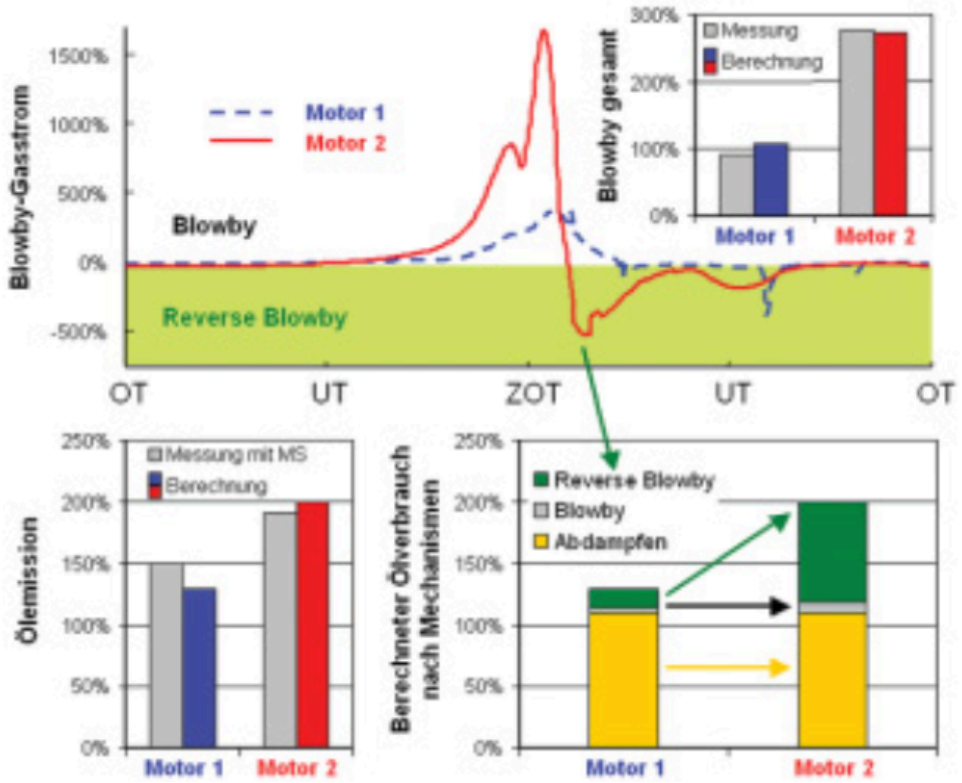

Figure 15 – Comparison of measurement and simulation results at 3000 RPM and full load

2002 - Development and Application of a New Mass Spectrometer Based Measurement System for Fast Online Monitoring of Oil Emission in the Raw Exhaust Gas of Combustion Engines

Powertrain & Fluid Systems Conference & Exhibition San Diego, California USA October 21-24, 2002
Marcus Gohl, Gerhard Matz and Torsten Ollesch

Abstract:

An increasing environmental consciousness as well as the awareness for sustained preservation of natural resources causes new regulations for emissions and great efforts for fuel economy and increasing oil service intervals. For a better understanding of the process generating pollutants, the emissions of every phase of the combustion cycle have to be monitored online. Moreover, it is important to measure the raw exhaust gas during different driving cycles and investigate the influence of different parameters as for example changing engine operating conditions.

The new mass spectrometer (MS) based measurement system allows the direct detection of unburned gaseous oil HC without tracers. The gas inlet system enables crank angle resolved monitoring of different raw exhaust gas compounds in the exhaust manifold or directly in the cylinder. By an integrating method a complete engine map of oil consumption (72 points of operation) is received in one day instead of several weeks with conventional methods.