automotion

EDITION 1 | 2006 | IAV – AUTOMOTIVE ENGINEERING

Optimizing Combustion with Hydrogen

A promising concept for ultra-lean homogeneous combustion in spark-ignition engines

by Utz-Jens Beister and Oliver Dingel

Working in collaboration with the Massachusetts Institute of Technology (MIT), ArvinMeritor has developed a concept that aims to enhance combustion by adding hydrogen. The development brief for the project commissioned by ArvinMeritor and described below is to develop and construct a concept vehicle with the purpose of investigating the possibility of implementing the research results into practice with a near-production engine on the test bench and in the vehicle. The project was conducted on a cross-site basis at IAV Inc. in Ann Arbor, USA and at IAV GmbH in Chemnitz.

Principle of Hydrogen-Enriched Combustion

Ultra-lean combustion of the engine charge is viewed by many as a necessary step in the evolution of the spark-ignition engine. Enriching the mixture with even just small quantities of hydrogen improves mixture ignitability, increases flame velocity and enhances combustion stability during the combustion process. Running the engine at lambda values in excess of 1.8 could reduce NO_X emissions to a level that eliminates the need to treat NO_X emissions altogether. By adding reformed gases to the cylinder charge, it is also possible to lower the knock tendency and thus substantially increase the compression ratio.

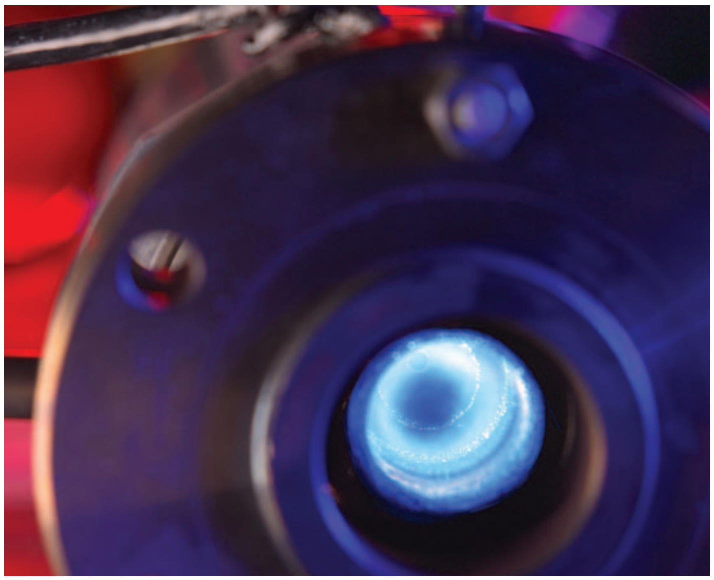


Fig. 1: Plasma region in the reformer

Having developed a compact and fast response fuel reformer, ArvinMeritor offers a technology that provides the means to reform a fraction of the fuel on board, thereby permitting ultra-lean homogeneous combustion in spark-ignition engines. The reformer gas generated in the reformer is estimated to contain 21 % hydrogen, 22 % carbon monoxide and 5-6 % hydrocarbons, carbon dioxide and water components. The remainder is nitrogen.

Concept Realization

In an initial step, the test vehicle is supplied with synthetic gas from a high-pressure tank. The gas is blown into a balanc-

Continued on page 2

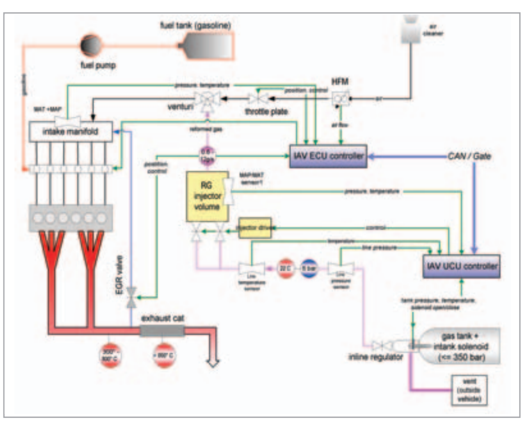


Fig. 2: System overview (reformer gas stored in the pressure tank)

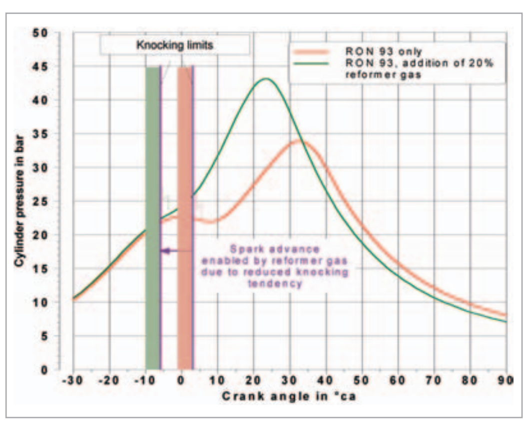


Fig. 3: Reduction in knock tendency at full load and after adding 20 % reformer gas (n = 1500 rpm)

Editorial

Dear Readers,

Welcome to IAV's new publication automotion for North America. It tells you who we are and what we do. I hope you find this new newsletter from IAV Inc. informative and please let me know what you would like to see featured in future editions.

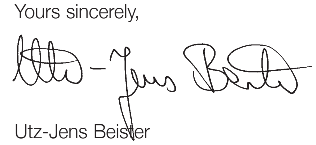
IAV has covered several topics of particular interest to the automotive community from hydrogen-enhanced combustion to exhaust aftertreatment for diesels. Much of this has a central theme: reducing atmospheric pollution and the need to carefully manage limited fuel reserves.

At IAV Inc., we have not just a new newsletter but also a new website. This will give you a much better overview of IAV Group worldwide as well as information on our Ann Arbor, MI operations. Check out the article on page 4.

I also would like to use this opportunity to introduce myself as the new President of IAV Inc. I am a native of Berlin and joined IAV in Germany after completing my degree studies in Mechanical Engineering.
Five years ago I transferred to the US.
I have had several positions in the company, last being VP of Engineering.
My vision for IAV Inc. is to establish the company as a full service provider for powertrain engineering by expanding our capabilities. Watch for developments in future editions.

Finally, do check out the article on our SAE exhibit on page 2. There is going to be some very interesting material there. Most of all be sure to visit us at Booth #2100.

Yours sincerely,



Utz-Jens Beister
President of IAV Inc.

ing volume by means of injectors. This achieves pressure and mass flow level conditions that correspond to those of a real reformer. By simulating the entire unit using IAV's THEMOS® engine process simulation tool during the course of development, all of the components required for the concept were designed immediately in such a way that no further development loops were necessary later on. Figure 2 shows the components in their systematic layout.

As hydrogen and carbon monoxide are both constituents of the reformer gas and regarded as being critical to safety, an FMEA-based safety system was developed and implemented in the vehicle. The engine is controlled by an IAV prototype engine control unit that completely replaces the vehicle's production control unit, thereby making it possible to integrate additional software functions and calibrate all engine-related parameters during the development process.

Project Results

The aim of the investigations was to verify the above-mentioned effects reformer gas containing hydrogen has on combustion.

IAV has an engine test bench that provides the capability of producing the mixture from three gas components in varying concentrations directly in situ, thus permitting investigations into the effect of gas composition on engine performance. It can be seen that the addition of reformer gas clearly reduces the tendency to knock (Fig. 3). In the part-load range, the hydrogen component is seen in particular to stabilize combustion. As a result, it is possible to ensure ignition even with mixtures that are highly diluted by residual gas or charge and achieve an improvement in efficiency on the basis of dethrottling effects.

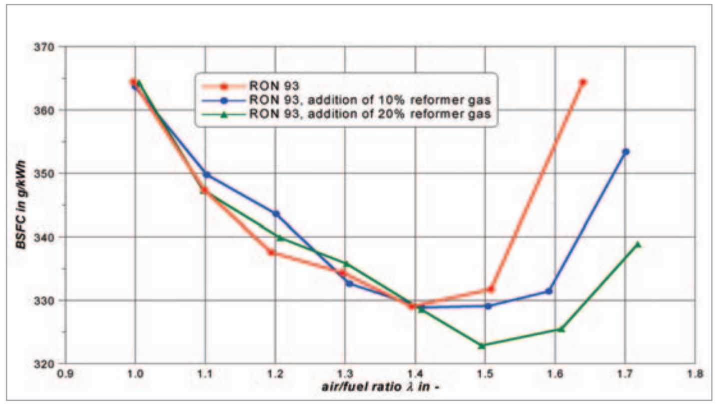


Fig. 4: Shift in the lean misfire limit on adding different reformer gas percentages (n = 2000 rpm; pme = 2 bar)

Figure 4 shows a shift in the lean misfire limit towards mixtures leaner than stoichiometric in response to adding a portion of reformer gas. Furthermore, it is possible, in the near-idle range as well as during the cold-start phase where over 90 % of emissions are produced in the exhaust emission test, to achieve significant improvements in the field of untreated emissions when the engine is running solely on the reformer product (see Fig. 5).

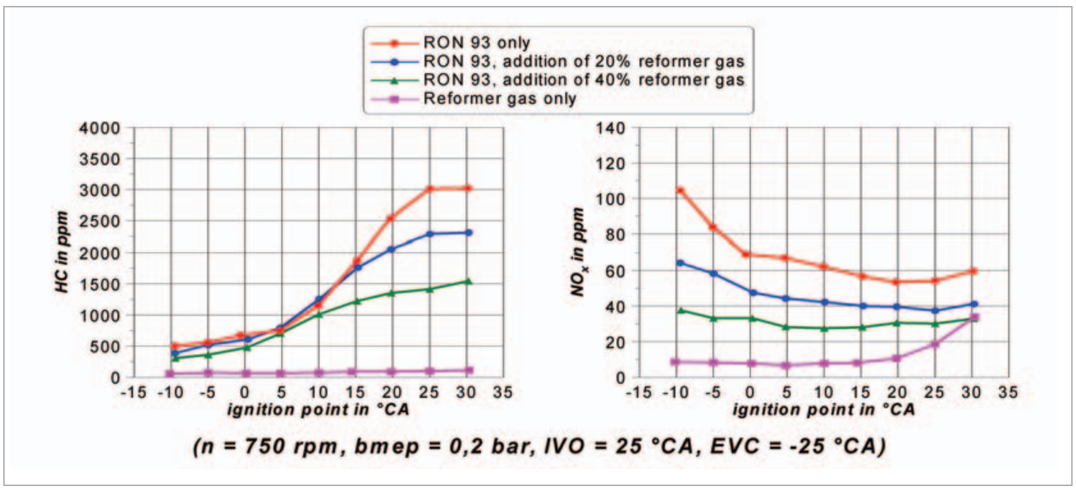


Fig. 5: Untreated emissions in the near-idle range while running on different percentages of reformer gas (n = 750 rpm; pme = 0.2 bar)

The test results confirm the positive influence of hydrogen enrichment on the combustion process. In order to exploit this potential to the full, it is planned to use a supercharged engine in the coming development phase. There are also plans to use an "on-board" reformer in the vehicle.

A detailed report on the project was published in last year's October edition of MTZ.

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SAE 2006 World Congress

IAV at SAE 2006

by Paul Moreton

Don't miss IAV at the SAE Congress and Exhibition April 3-6 at Cobo Hall in Detroit. This year we will have exciting new exhibits demonstrating some of our recent projects, and the tools and techniques that we will use to bring your job in on time to the highest quality.

We will be showing a Mini Cooper "S" for which IAV did the entire powertrain integration. Next to it will be a complete powertrain and, of course, IAV engineers on hand to discuss what we did and how. Our Drive Recorder, fast becoming the industry standard in fleet data recording will be on display. The various models of Drive Recorder NG and Drive Recorder Compact are in service with OEM test fleets in Europe, North America and Asia – in heavy duty trucks as well!

IAV is expanding its vehicle integration and NVH activities around the world including North America. A great demonstration of IAV's capability in this area is our NVH exhibit showing the extensive sound encapsulation of a European diesel engine that makes that diesel just purr!

Occasionally, IAV engineers have a little fun and our automated double clutch motorcycle transmission display is a good example. The concept is used in cars also: come and discuss how IAV can improve your transmission line-up.

An all-new calibration tool, IAV's Cal Guide, is a process oriented tool for managing calibration datasets throughout their life cycle. It's not just a storing and organizing set up but assigns completion status, access rights, RASIC definitions and other attribute information to your calibration data. We will be pleased to give you a demonstration so you can experience the well-designed user interface that supports the natural workflow that lets you make the perfect calibration.

The BMW 4 cylinder NG4 exhibit shows how involved IAV is in major programs with the world's performance carmakers. IAV did base engine calibration for the NG4 engine family that powered the 1 series, 3 series, the X3 and Z4 and the performance and emission optimization to EURO 4 and LEV 1. We also did in-vehicle calibration for drivability, start behavior, EOBD etc. Let's talk about how IAV engineers and Cal Guide can help you get your engine – diesel or gas calibrated on time and to budget.

Drop by for a chat with our experts in hybrid and alternate drives - we will have experts in most areas so try us!

And don't forget we serve the best coffee at the show!

Our Booth is # 2100 in the Wayne Hall.

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SAE 2006 World Congress
April 3-6
Cobo Center • Detroit, Michigan • USA
Driving Innovation through Partnerships

Exhaust Gas After-Treatment for Diesel Passenger Cars and Light Commercial Vehicles

IAV: development and calibration partner for exhaust treatment systems

by Frank Heimlich and Kai Behnk

In recent years, tighter emission limits have led to the introduction of active exhaust gas after-treatment systems in the diesel passenger car. In the course of this development, the integration of exhaust treatment systems in existing or future vehicle concepts has become increasingly prominent in the work of a development service provider. The associated development process demands interdisciplinary collaboration in the fields of design, computation, electronics, as well as engine, component and vehicle testing. With its diverse range of services, IAV is able to cover every aspect of this process.

At the moment, the focus in mass-production development is clearly on diesel particulate filters (DPF). Although, in the light of future emission legislation, an increasing amount of work is also being done on systems to reduce nitrogen oxide, such as NO_X adsorption catalyst technology or the SCR process.

Development Process

Early in the advanced engineering phase of new emission concepts, IAV supports the development work of OEMs and system suppliers by constructing prototypes (e.g. injection systems, exhaust systems, modified EGR systems), as well as by providing test control units tailored specifically to the applications at hand. Here, it is possible to provide bypass solutions that use the existing engine control unit or also employ universal control units that act completely independently, such as IAV's FI2RE. The software is developed to meet the client's specific requirements. New systems are implemented and tested on the engine test bench. One focal aspect of advance engineering in this context is combustion process development for generating special regeneration modes.

In the later phase of concept development, the focus centers on implementing a system for a vehicle platform (or also engine family). As far as exhaust treatment is concerned, this means it is necessary to develop an exhaust treatment concept tailored to the relevant engine, to the installation conditions and to the emission ceilings that are to be met.

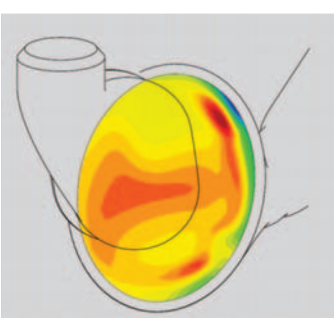

Fig. 1: Temperature distribution computed for a catalytic converter face

Proceeding from a specification, the first step involves selecting the system. This process begins by estimating raw emissions, exhaust-gas temperature and mass flows. To do this, IAV uses roller dynamometer test simulation in order to obtain the requisite data, irrespective of the prototype availability. Based on these virtual driving cycles, further simulation tools are used for comparing and assessing different exhaust treatment concepts.

Design and Computation

Once the system has been defined in principle, work starts on the exhaust system's layout. In the vehicle package, the exhaust gas after-treatment system, the vehicle underbody and the powertrain form a group of components that significantly influence each other's design, as a result of their physical proximity. The design must therefore take into account package conditions, the producibility of component geometries, as well as the operating principle of the exhaust treatment system. In this field, the range of services provided by IAV includes designing the actual exhaust system, as well as assessing the exhaust system's package-related suitability and extends through to the digital mock-up.

In terms of pressure loss, thermodynamics and strength, the initial design of the exhaust system is optimized on the basis of 3D-CFD simulation, a process that is also used in a whole host of other applications at IAV (Fig. 1). From the aspect of exhaust treatment, it is particularly important in this context to ensure that the flow of emissions to catalytic converters and particulate filters is as even as possible. A further important application is the computation of spray preparation and mixture of media in secondary injection systems, such as urea metering for SCR catalysis or fuel injection for the regeneration of particulate filter or NO_X adsorption catalysts.

Designing the exhaust system also involves defining the sensors and their positioning in the powertrain. Here too, consideration must not only be given to the package but also to optimizing flow across the sensors because only then can they deliver representative measurement values to the engine's electronics. This is also an area in which 3D-CFD makes an important contribution. IAV has its own synthetic gas test bench for testing the function of exhaust-gas sensors.

Development of Electronics and Algorithms

The engine electronics themselves are key to the operation of the overall exhaust gas after-treatment system. In the case of DPF calibration, electronics monitor the filter's saturation level, calculate the best time for initiating regeneration, control exhaust-gas temperature during regeneration and define the

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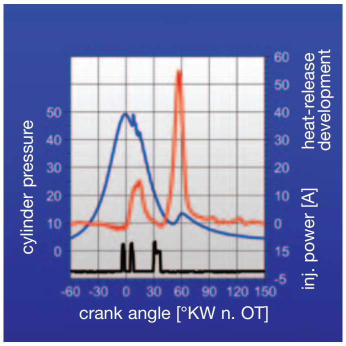

Fig. 2: Indication diagram showing DPF regeneration mode with post injection following shortly after the main injection

point of return to normal operating mode. Calibrating these algorithms, as well as developing the algorithms themselves, form part of IAV's main fields of work in exhaust gas after-treatment. One of IAV's particular strengths lies in the close cooperation between Electronics and Engine Testing.

Engine Test Bench and Component Testing

Engines are calibrated for the various operating statuses on IAV's engine test benches. Whereas for conventional engine operation the aim is to reduce consumption and pollutant emission as far as possible, the emphasis in particulate filter regeneration (Fig. 2), for example, is on raising the exhaust-gas temperature while providing a sufficient supply of oxygen and minimizing oil dilution resulting from post injected fuel. Calibration is performed on highly dynamic engine test benches which, among other facilities, are equipped with two-line exhaust-gas analysers, particulate mass measuring systems, opacimeter, as well as cylinder pressure indicators. A mass spectrometer is also available for analyzing further exhaust-gas components. Test bench time is utilized particularly effectively through the application of DoE (Design of Experiments). Proceeding from the models obtained from the test data, the IAV Model Analyzer determines the optimum settings.

In addition to calibrating engines, many different function and component tests are conducted on the engine test bench. For instance, determining the maximum permissible soot level represents an important test from the aspect of verifying reliable DPF operation because if too much soot is allowed to accumulate, damage may be caused to the filter's ceramics or to the catalytic coating while the soot is being burned off. In addition to conventional temperature measurement with thermoelements, IAV uses High-Speed Surface Temperature Visualization (IAV®HSTV) as a means of visualizing the curve of component temperatures on the monolith faces in high time resolution (Fig. 3).

IAV has special component test benches for conducting other analyses, such as the newly installed synthetic gas test bench for catalytic converters or a pressure-chamber test bench for optical spray analysis. This is where injection systems of all types can be assessed in relation to spray preparation (Fig. 4).

Vehicle Calibration

Precision calibration of engine and exhaust-system operating behavior takes place in the vehicle test. Important aspects here include examining engine calibration and adjusting it to real driving conditions. In particular, this process involves monitoring and adjusting emission calibration, exhaust-gas temperature control and soot level computation, as well as corrective functions, such as ash correction, which responds to the accumulation of ash in the filter over its service life. Further activities include calibration work on dynamic and acoustic behavior, behavior at the point of transition between normal operation and the regeneration stages, calibration of on-board diagnosis (OBD) and testing under extreme conditions, such as heat, cold, altitude as well as urban or motorway driving. In this context, IAV's services also include endurance testing and the supervision of fleet tests.

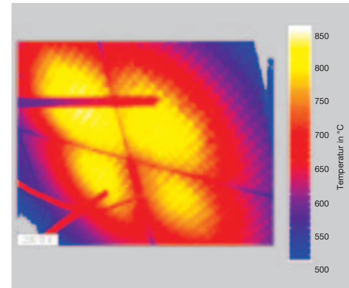

Fig. 3: IAV®HSTV shot of diesel particulate filter regeneration

Fig. 4: Spray pattern of a multiple-hole injector, taken in IAV's pressure chamber using the Mie / Schlieren method for the simultaneous visualization of vapour and liquid distribution

Finally, at the end of the development process, this leaves the vehicle emission certification procedure which, thanks to the company's own emission roller dynamometer, can also be performed directly at IAV, as can certification in relation to engine power and OBD.

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Coming soon

Coming soon, IAV's New Website

by Cheryl Boland

On Mach 31, IAV will launch its new, exciting, information packed website!

The website is a complete redesign and represents the IAV Group's worldwide capabilities. Information regarding the complete IAV Group portfolio of services and products, as well as location specific information will be provided. You can also find up to date information on conferences, papers, and even career openings.

We encourage you to visit www.iav-usa.com to find out more!

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automotion
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Design:
ZITRUSBLAU
www.zitrusblau.de

Frequency:
three times a year

Thermodynamic Real-Time Analysis

FI2RE now with integrated cylinder pressure sensing

by Wulf Schmidt

For IAV's FI2RE flexible development control unit, there now is a new module for sensing cylinder pressure and for evaluating pressure curves from the aspect of thermodynamics. The motivation for developing this new tool came from the demands of IAV's ADCS (Advanced Diesel Combustion System) homogeneous combustion process. In the meantime, the system is also being used externally for developing new HCCI combustion systems.

Conventional combustion processes are initiated by spark ignition or injection. HCCI processes are characterized by very early injection, followed by controlled compression ignition of the hot mixture heavily diluted by residual gas. Ignition occurs almost simultaneously throughout the combustion chamber which leads to a sharp reduction in NO_X and soot emissions. This, however, eliminates the capability of directly controlling the time at which energy is released. In order to control compression ignition, it is necessary to adjust the thermodynamic state of the cylinder charge with extreme precision and the many different engine parameters affecting the course of combustion must be controlled in synchrony with the cycle. Thermodynamic real-time analysis of the cylinder pressure curve is the key to stabilizing the sensitive HCCI combustion process.

The new TRA module (Thermodynamic Real-Time Analysis) is an extension to the FI2RE system for the angle-synchronous sensing and evaluation of cylinder pressures in real time. Cylinder pressure sensing starts by recording the signals from the cylinder pressure sensors. The module provides eight differential, electrically isolated analog inputs from –10 V to +10 V. 8th-order input filters with a cut-off frequency of 40 kHz keep back unwanted signal components. Eight 16-bit A/D converters, each operating at 500 kS/s, convert the pressures into digital signals. The pressure curves from eight cylinders can be recorded at a resolution of 0.1° crank angle up to 8000 rpm. An FPGA pre-processes and sorts the pressure data into a fast dual-port RAM. A 400-MHz floating point DSP processes the data at up to 2.4 GFLOPS.

The DSP analyzes the pressure curves measured and reduces the data to characteristic combustion values, such as p_{miHD}, Q_{max}, α_{Q10}, α_{Q50}, α_{Q90}, $dp/d\alpha_{max}$ and p_{max}. The functions for real-time analysis are produced in Matlab/Simulink. Code generation, compilation and downloading the DSP program via USB2.0 are started at the press of a key. This process takes just a few seconds.

In addition to two CAN buses, a fast synchronous serial RS422 interface with a transmission rate of 10 Mbit/s is provided for feeding back the results at high speed. The USB2.0 port provides the optional capability of streaming the raw pressure data to the hard disk of a PC at up to 8 Mbytes/s.

TRA module

For the 720° work cycle of each cylinder, it is possible to define any segments in which pressures are sampled at different angle resolutions. The segments may even overlap, providing flexibility in the way data recording can be matched to different algorithms. The segments are managed entirely by the FPGA without necessitating additional computing time from the DSP.

To develop its ADCS process, IAV is using the FI2RE with the new TRA module in the closed-loop mode with a MicroAutoBox from dSPACE: the FI2RE takes over the injection system analysis and carries out thermodynamic real-time analysis of the combustion curves. The MicroAutoBox with IAV's HOCCOS (Homogenous Combustion Control Software) controls the higher-order engine functions for homogeneous combustion.

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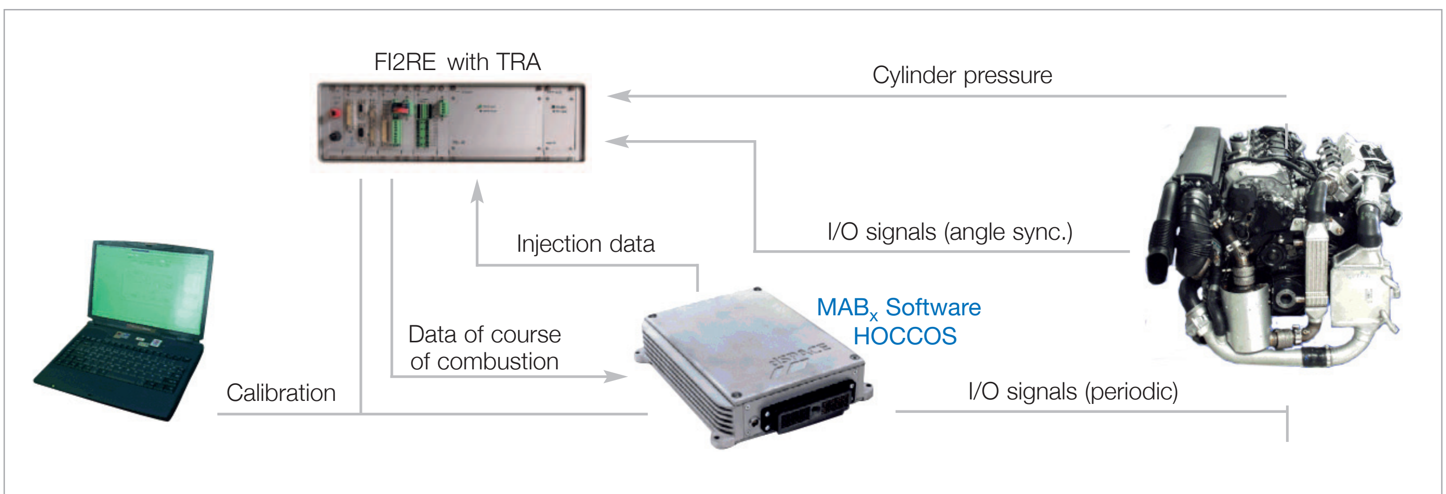

Public Appearances & Publications

Congresses

Come and see IAV at the accompanying trade shows and exhibitions!

20-23 Mar 2006
DAGA 2006
Braunschweig, Germany

22-23 March 2006
VDA Congress
Munich, Germany

3-6 Apr 2006
SAE World Congress
Detroit, USA

20-23 Apr 2006
Engine China 2006
Bejing, China

27-28 Apr 2006
27th International Vienna Engine Symposium
Vienna, Austria

2-4 May 2006
dSpace User Conference,
Plymouth, MI, USA

9-11 May 2006
Testing Expo
Stuttgart, Germany

10-12 May 2006
SQS-Conference
Düsseldorf, Germany

30 May – 1 Jun 2006
Sensor + Test
Nuremberg, Germany

31 May – 1 Jun 2006
The Diesel Engine
Lyon, France

14-15 Jun 2006
International Congress Bodywork and Plastic Materials: "Light-Weight Vehicle Bodies and Maintenance of Vehicle Performance"
Sochaux, France

20-22 Jun 2006
Component Suppliers' Show
Leipzig, Germany

27-28 Jun 2006
26th HDT Conference "Electronics in the Motor Vehicle"
Dresden, Germany

27-28 Jun 2006
VDI Conference "Vehicle Transmission"
Friedrichshafen, Germany

IAV/HDT Conferences

22-23 Jun 2006
IAV/HDT Conference "Gas-Powered Vehicles - Moving out of the Niche?"
Dresden, Germany

18-19 Sept 2006
2nd IAV/HDT Conference "Knock Control for Spark-Ignition Engines"

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Technical Publications

MTZ 03/2006
"IAV's Single-Cylinder Engine as a Tool for Developing New Combustion Processes"
Lutz Stiegler, Frank Menzel, Julius Pape, Wulf Schmidt, Thomas Kracke, Dr. Thomas Seidel

MTZ 04/2006
"Potential of Cold Flame Technology for Implementing Pre-Mixed, Homogeneous Combustion in a Diesel Engine"
Heike Puschmann, Ansgar Sommer, Heide Pohland vom Schloß, Dr. Klaus Lucka, Prof. Dr. Heinrich Köhne (Öl-Wärme-Institut gGmbH)

MTZ 5/2006
"Flow Measurement During Compression Using Doppler Global Velocimetry (DGV)"
Oliver Dingel, Dr. Thomas Seidel, Henry Steuker

ATZ 6/2006
"Development of Hybrid Electric Vehicles for Mass Production, Part 1"
Dr. Burghard Voss, Oliver Mehler, Steffen Lintz

MTZ 6/2006
"Measurement and Analysis of Engine Start Using the Example of the Spark-Ignition Engine"
Olaf Kannapin, Juergen Schroeder, Peter Strauss

ATZ 7-8/2006
"Development of Hybrid Electric Vehicles for Mass Production, Part 2"
Dr. Burghard Voss, Oliver Mehler, Steffen Lintz

MTZ 7-8/2006
"Model-Based Pilot Control of a Turbocharger for Future Emission Targets in Diesel Engines"
Oliver Predelli

MTZ 9/2006
"Knowledge-Based Engineering in Engine Development"
Dr. Ernst Beutner

ATZ 10/2006
"Reproducibility of Driving States and Automated Calibration Using IAV-SUCCESS"
Bjoern Steffen

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Papers

3-6 Apr 2006
SAE World Congress 2006, Detroit, USA
"A New Approach for Process-Oriented and Tool-Based Calibration Tasks for Engine Management Systems"
Sven Meyer, Sven Klingspon, Oliver Predelli

"Boost and EGR System for the Highly Premixed Diesel Combustion"
Ralf Buchwald, Guido Lautrich, Oliver Maiwald, Ansgar Sommer

"Calibration of Torque Structure and Charge Control System for SI Engines Based on Physical Simulation Models"
Elmar Millich, Dr. Wolfram Gottschalk, Malte Koeller, Holger Braun, Matthias Schultalbers

"Model-Based Friction and Limp Home Compensation in Electronic Throttle Control"
Salem Al-Assadi, Jens Breitinger, Nathan Murphy

"Electronic Throttle Simulation Using an Nonlinear Hammerstein Model"
Salem Al-Assadi, Jens Breitinger, Michael Traver

"Tuning an Electronic Throttle Controllers Using Computer-Aided Calibration Method"
Salem Al-Assadi, Jens Breitinger, Nathan Murphy

26-28 Apr 2006
ITG Symposium "Voice Communication" 2006, Kiel, Germany
"Evaluation of Speech Quality in Hands-Free Systems in Vehicles"
Gudrun Klasmeyer, Martin Herrenkind, Karl Kreft

27-28 Apr 2006
27th International Vienna Engine Symposium, Vienna, Austria
"Variable Valve Trains in Passenger-Car Diesel-Engines - Potentials, Limits and Opportunities of Realization"
Kurt Blumenroeder, Gerhard Buschmann, Joern Kahrstedt, Ansgar Sommer, Oliver Maiwald

10-12 May 2006
11. Software & Systems Quality Conferences 2006 / 7. ICS Test, Düsseldorf
"Automated Closed-Loop Testing of Embedded Engine Control Software"
Sven Rebeschiess, T. Liebezeit, U. Bazarsuren (TU Berlin)

"XML Format for Automated Software-in-the-Loop Tests"
Sven Rebeschiess, H. Schumann (DLR), T. Liebezeit, Prof. Dr. Clemens Gühmann, U. Bazarsuren (TU Berlin)

17 May 2006
8th International Conference on Turbochargers and Turbocharging, London, UK
"Part-Load Performance Prediction of Turbocharged Engines"
Rene Berndt, Prof. Dr. Jörg Seume (University of Hanover), Prof. Dr. Helmut Pucher (TU Berlin)

31 May - 1 Jun 2006
The Diesel Engine, Lyon
"Injection Rate Shaping with the Twin Common Rail System: a Coupled Experimental and Modeling Investigation"
O. Pajot, S. Houille, F. Vidal, F. Dabireau (PSA Peugeot Citroen), Jens Stegemann, Maximilian Brauer, Thomas Roelle, Axel Seiffert

"Assessing the Maximum Soot Mass Loading of Catalyzed Diesel Particulate Filters by Advanced Modeling and Regeneration Control"
Lutz Kraemer, Frank Heimlich, Bernhard Kleiter, Ralf Gratzke, Kai Behnk

14-16 Jun 2006
ACC - American Control Conference, Minneapolis, USA
"A Nonlinear Model for Design and Simulation of Automotive Idle Speed Control Strategies"
Christian Bohn, Dr. Thomas Boehme, Aik Staate, Petra Manemann

27-28 Jun 2006
26th HDT Conference "Electronics in the Motor Vehicle", Dresden
"Automated Closed-Loop Testing of Embedded Engine Control Software"
Sven Rebeschiess, T. Liebezeit, U. Bazarsuren (TU Berlin)

"XML Format for Automated Software-in-the-Loop Tests"
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