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News from Research and Development | Number 02 | 2005

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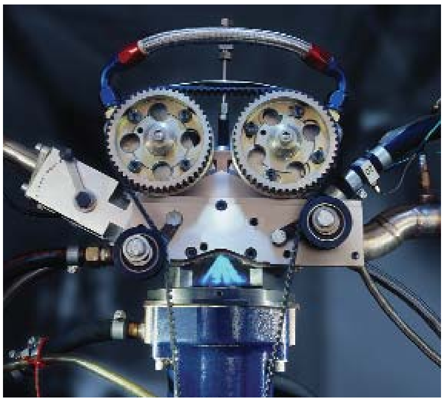
Perfect Combustion, Minimal Emissions

HCCI is the acronym that is expected to revolutionize the automotive industry. It stands for Homogeneous Charge Compression Ignition, a technology with which Bosch researchers intend to combine the advantages of gasoline and diesel engines in a single system: Lower emissions and lower fuel consumption.



The transparent engine is used to study fuel distribution within the combustion chamber.

An engine's fuel consumption and emissions are directly influenced by the combustion process. A fuel that burns incompletely is obviously being utilized imperfectly, and unburnt hydrocarbons remain as pollutants. In the direct injection of gasoline or diesel, the fuel is atomized very finely to ensure good combustion. But that's just one part of the story. The other is that the nature of the combustion process also influences pollutant emissions. If the fuel jet burns like a flare, nitrogen oxides are formed in the hot peripheral zones while soot is formed in the cooler areas. It's this kind of inhomogeneous combustion that creates problems.

Therefore Bosch researchers are looking for ways of making combustion more homogeneous. One possible method goes like this: The injection system injects a metered dose of gasoline or diesel fuel into the cylinder. During the ensuing moment, fuel and air throughout the combustion chamber have time to mix, forming a nearly uniform mixture. The piston then compresses the mixture, causing the temperature and pressure to rise until the mixture ignites almost uniformly – with no flame front, no nitrogen oxides and no soot.

That is the theory. The trick is to make it work like that in practice. The total system, including injection, engine and engine management, is highly complex. That is why the scientists at Bosch have to fine-tune all the variables to optimize both fuel consumption and emissions. They are using experiments as well as simulations to design combustion chamber geometries that optimize the processes of homogenization and combustion. And they are investigating the best ignition timing during a cylinder cycle. Another factor that can improve the rate of combustion and reduce exhaust emissions is air management, i.e. the metering and mixing of cold intake air and hot exhaust gases.

Researchers hope that this approach will meet the more stringent future emission limits without the need for costly exhaust after-treatment, such as catalytic converters to reduce nitrogen oxides. After all, the more complex the treatment of raw emissions from the engine, the greater the risk that fuel consumption will also increase.

Editorial

New Combustion Methods

Dr. Martin Knopf
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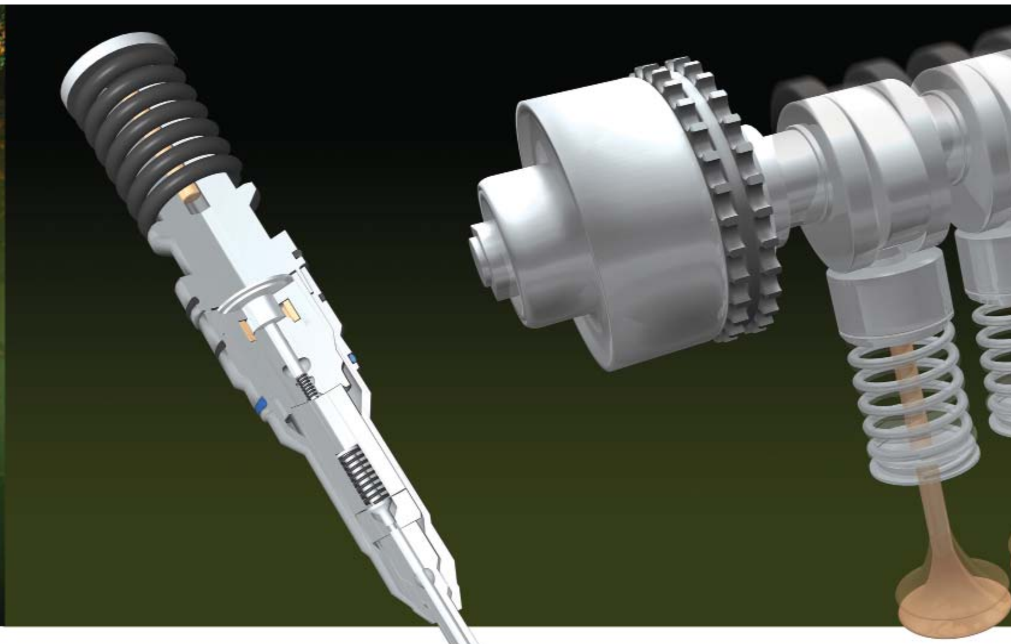
Everyone will agree that emissions of exhaust pollutants and CO_2 from motor vehicles must be reduced further. In practice, these objectives conflict with each other. If one of these is reduced, the other inevitably rises. With the more stringent regulations expected in 2010 (Euro 5), this conflict can no longer be resolved simply by increasing the proportion of diesel engines on the road. In fact, sophisticated exhaust gas purification may result in higher CO_2 emissions and increased fuel consumption.

The main thrust in anticipation of Euro 5 must be to maintain the CO_2 values already achieved with diesel combustion and to fully exploit all available internal combustion techniques. Thus, the latter would lessen the conflict between these goals and reduce the need for costly exhaust after-treatment.

Homogeneous Charge Compression Ignition (HCCI) increases efficiency and thereby lowers CO_2 emissions and fuel consumption in the gasoline engine. In the diesel engine, on the other hand, it reduces raw emissions. This new combustion process makes it possible to meet future nitrogen oxide limits in the engine's partial-load range without costly exhaust after-treatment systems.



Fuels
The potential advantage: The fuel quality and composition influence the emissions. An optimized mix reduces pollutant emissions.
The challenge: The compatibility of new fuels with other materials must be tested. The physical characteristics of the combustion process, such as the boiling point curve, must be optimized.

Injection
The potential advantage: The more precise the control of the injector, and the finer the atomization that can be achieved with the injector nozzle, the better the mixture formation, and the lower the emissions resulting from combustion.
The challenge: Higher pressures produce finer and more homogeneous atomization. The materials must withstand such pressures (in the future, 2,300 bar in diesel direct injection, 200 bar in gasoline injection).

Air Management
The potential advantage: The air supply can be actively regulated with a flexible valve control. And the thermodynamic processes in the combustion chamber can be optimally adjusted with the right amount of fresh air or by using exhaust gas recirculation, for instance to reduce nitrogen oxide emissions.
The challenge: In the mixture formation process optimal proportions of air and exhaust gases must be regulated using information from simplified calorimetric models.

Controlling an Engine’s Emission Levels

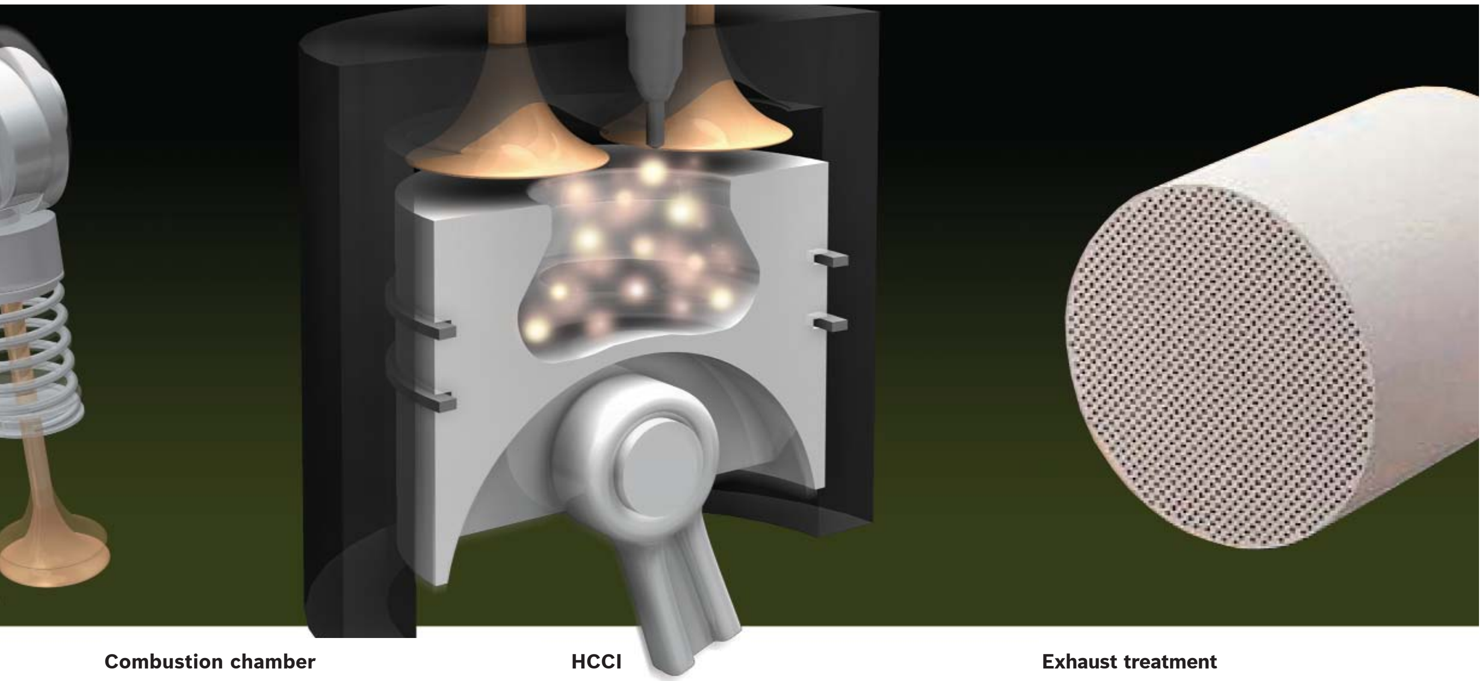
Combustion in existing engines involves flame fronts: When the air-fuel mixture in a gasoline or diesel engine ignites, a flame front swiftly expands throughout the combustion chamber. Unfortunately, this uneven combustion produces high levels of exhaust gases that must be purified. Bosch researchers intend to use the HCCI technology to replace this wasteful combustion method, at least in the partial engine load range.

The entire combustion process should take place as uniformly as possible throughout the combustion chamber. In future engines, fuel combustion will create no visible flame, and combustion will occur simultaneously throughout the entire combustion chamber. As a result, emissions of soot and nitrogen oxides will be reduced. The principle is analogous to the blue flame of a gas range, which burns with fewer emissions than does a smoky candlewick. Bosch researchers intend to approach this ideal state from two directions: From the diesel side and from the gasoline side.

In both engine designs, it’s important to optimize the system as a whole. To date, the operating states of a diesel or gasoline engine have been mapped in a large number of characteristic curve fields. If the driver steps on the gas, the engine management software scans these diagrams and tables, and adjusts the ignition, intake air charge and injection metering to meet the required operating state of the engine.

The HCCI method goes a step further: The engine regulates itself and its emissions by means of a pressure sensor in the combustion chamber. Such feedback control is required because homogeneous fuel combustion cannot simply be set to the right level, since HCCI combustion cycle differs statistically from the preceding one. With a sensor in the combustion chamber, for instance on the glow plug or on the spark plug, the instantaneous operating conditions within the combustion chamber can be measured. The in-cylinder pressure signal has proven to be the best variable to be tracked for this purpose. The measured pressure in the combustion chamber is used to control the air management.

The proper mixture of fresh air and recirculated exhaust gas is of key importance. This can be achieved with external exhaust gas recirculation alone or in combination with internal exhaust gas recirculation by means of variable valve timing. This approach lowers the combustion temperature and thereby pre-



Combustion chamber
The potential advantage: The geometry of the combustion chamber must ensure that air and vaporized fuel are perfectly mixed to suit the respective combustion strategy.
The challenge: Finding a single geometry that represents a good compromise for every conceivable operating condition (from partial load all the way to full load).

HCCI
The potential advantage: Homogeneous Charge Compression Ignition lowers emissions in the diesel engine and reduces fuel consumption in the gasoline engine. The two engine designs are converging.
The challenge: HCCI operation of the engine is only possible in specific portions of the engine map. Engineering solutions that will make it possible to increase this area as much as possible must be found.

Exhaust treatment
The potential advantage: Particulate filters and catalytic converters reduce pollutants. In an optimally tuned system, the exhaust air can be cleaner than the intake air.
The challenge: Any exhaust treatment process will influence engine management as a whole. For instance, by requiring dosing strategies that will ensure the optimal settings for the regeneration of the exhaust treatment system.

vents nitrous oxide formation. But to optimize fuel consumption, final compression temperatures must be high. Feedback from the sensor ensures an optimal compromise for the driving situation at a given moment.

In addition to pressure sensing, temperature or knock sensors can also contribute to the overall timing of each cylinder cycle. In the gasoline engine in particular, it's essential to prevent a drift toward uncontrolled knocking that might damage the engine.

In principle, the HCCI method can be used only at moderate engine speed in the partial-load range. This is due to the short time windows – between 50 and 120 milliseconds per cycle – available for achieving a homogenized mixture. As the engine speed increases, the time window shrinks until homogenization is no longer possible. Since exhaust emissions are regulated based on the extent of vehicle operation within representative driving cycles, the goal for HCCI is to cover as large of an area as possible in theses cycles.

If the driver operates outside this ideal cycle – for instance by fast acceleration in a low gear – the HCCI engine reverts to the conventional operating mode of the gasoline engine. This is why future engine designs will have to be able to work in both operating modes: HCCI at low and intermediate loads, and conventional combustion at full load.

Bosch researchers are striving to maximize the load range in which the HCCI method can be used. The development of this design is still a work in progress. It addresses charge composition and charge dynamics, injection timing and supercharging strategy, combustion chamber geometry and active combustion control. An example to control the charge dynamics is an electrohydraulic valve-train system (EHVS) which enables the operation of HCCI, as well as improves the performance of the conventional operation mode. Initial prototypes are already being tested, but there are still many technical hurdles to overcome before a market launch will be possible.

The large number of mutually interactive variables and sub-systems is a major engineering challenge, but it also provides the flexibility essential for converging to an optimal solution. After all, a properly matched combination of fuel, injection system, air management and exhaust treatment should always make it possible to create sufficiently stable operating conditions to meet prevailing regulatory or self-imposed emission and fuel economy targets. Bosch expects that appropriate engine design and engine management can already reduce raw emissions sufficiently to render additional exhaust treatment methods very economical, among other benefits.

Since particulate filters will, in the future, be standard equipment with diesel engines, the combustion method, for instance, can be adjusted to minimize nitrogen oxide emissions.

Filling Up with Synthetic Fuels?

Synthetic diesel fuels can reduce soot and hydrocarbon emissions from automobiles by about 40 percent, and carbon monoxide is reduced by as much as 90 percent. Tests conducted by Bosch researchers have revealed that all other emission levels remain about the same.

Fuel analysis: Optimizing fuels for state-of-the-art engines and injection systems

In this study, researchers fueled up a production diesel car with GTL, a synthetic fuel. GTL stands for Gas-to-Liquid, which denotes that natural gas has been made into diesel fuel by means of a synthesis process. And this product doesn't contain any sulfur or aromatics!

It's also possible to produce synthetic diesel fuel from biomass (Biomass-to-Liquid, BTL) or coal (Coal-to-Liquid, CTL) by using analogous methods. The raw material is converted into a synthesis gas — a mixture of H_2 and CO — which in turn is converted into engine fuel by a process known as Fischer-Tropsch synthesis. The end products from those different source materials should be indistinguishable.

A GTL road test has shown that the soot/nitrous oxide (NOx) trade-off is more favorable than with standard diesel fuel. This is a term that refers to the fact that when soot emissions are reduced by the engine management, NOx emissions are increased, and vice versa — which presents developers with a dilemma. The maximum benefit can be achieved by using a GTL fuel in combination with a particulate filter.

Long-term outlook

Researchers are investigating to what extent alternative fuels are compatible with existing engine designs, whether gasoline or diesel, what emissions they produce, and whether long-term effects occur, such as engine wear. Their research includes the full range of options, from bioethanol for gasoline engines to biodiesel and BTL.

No doubt, bio-fuels will become increasingly important. Not only because of petroleum reserves are finite, but also because European legislators favor them. According to European guidelines, biogenic fuels will have to account for approximately six percent of total fuel consumption by 2010, and even further increases can be expected.

Bosch scientists are investigating what effects the new fuels will have on the materials, functions and service life of engine components. Biodiesel from rape oil, for instance, exhibits aging effects that make it more suitable for fleet vehicles, which are always on the move, than for a second family car that may sit in the garage for days on end.

Deposit formation

Depending on their composition, fuels may cause deposits to accumulate on internal component surfaces. Bosch scientist are investigating exactly where these deposits occur and how deleterious they can be. More precise study of the thermal and energetic properties of the synthetic fuels will have to be carried out in the future. This is because these properties play a major role in the complex injection systems.

And even state-of-the-art combustion methods can benefit from the use of synthetic fuels. In applications such as these, a long ignition delay combined with a high burn rate is desirable. This combination would, for instance, allow the HCCI method, which can be used only in a limited portion of the load range, to operate for a wider range.

In Brief

Direct Start Wins Award

Stopping and starting engines at traffic signals or in a traffic jam might be even easier in the future without a starter. Bosch researcher André Kulzer has demonstrated that precision-tuning of the engine management, injection and ignition makes a direct start possible without a starter motor in gasoline injection engines. In a no-load condition, the engine shuts off automatically. And it can be started up again in a fraction of a second. This capability could reduce fuel consumption by four percent under normal driving conditions, according to *Technology Review* (4/2005). In July, the "Stuttgarter Forum Auto und Umwelt" honored Kulzer with the Research Award 2004 for his work.

Events

January 31 to February 2, 2006
Dr. Frank Weberbauer will give a presentation on "Homogeneous Diesel Combustion – Thermodynamic Potentials" at the meeting on „Exhaust Gas After-Treatment“ of the Car Training Institute in Neckarsulm, Germany.

Published by
Robert Bosch GmbH, Stuttgart

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