automotion
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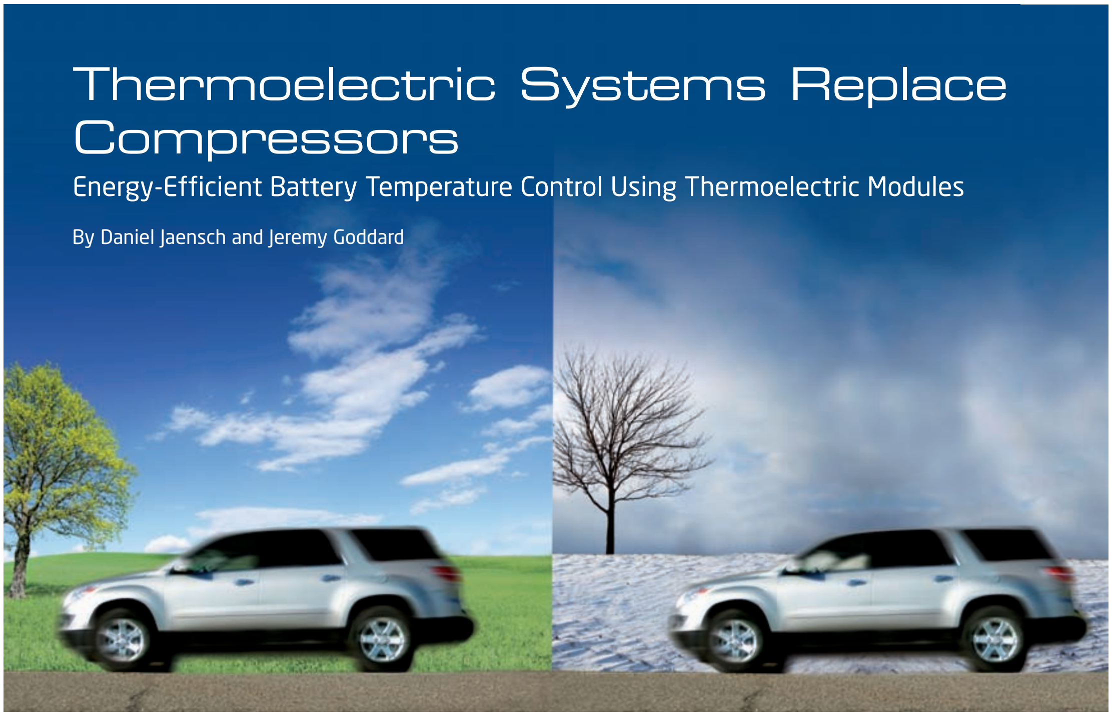
Thermoelectric Systems Replace Compressors

Energy-Efficient Battery Temperature Control Using Thermoelectric Modules

By Daniel Jaensch and Jeremy Goddard



Various combinations of conventional methods of temperature control are being used for cooling and heating the battery in electric vehicles. Thermoelectric modules are an interesting alternative: they work particularly quickly and use comparatively little energy – these and other outstanding properties could simplify future vehicle systems significantly.

Lithium-ion batteries work best when operating within a narrow temperature range: 25 to 30 degrees Celsius. If the battery temperature falls below this band, capacity and the power output available from the energy storage system suffer. If the batteries get too hot, their useful life is drastically shortened. "A permanently excessive operating temperature can even cause the li-ion battery to ignite or explode," says Daniel Jänsch from IAV's Technology Monitoring division. "Plus we also need to keep the temperature gradients within individual cells, as well as the temperature differential between the cells, as low as possible so the electrochemical reactions take place at the same speed throughout the system." In practice, this means having to heat the battery in winter, and efficiently discharge excess heat in summer. "With the systems we have now or which are soon to be available, cooling for the li-ion battery in electric vehicles is mainly provided by the air-conditioning system." Jänsch explains. "An auxiliary electric heater is used when necessary to heat the battery."

The developers at IAV are taking a different approach: thermoelectric modules (TEMs) are employed to keep the battery within the right temperature range. An electric current in them produces a transfer of heat (Peltier effect). Heating and cooling are the domain of heat pumps, and the outstanding properties of TEMs make them an extremely attractive option for electric vehicles. "When it comes to heating, heat pumps are particularly well suited to getting waste heat from the powertrain to the battery," Jänsch says. "Their energy-transfer efficiency is far higher than that of an auxiliary electric heater, and on the cooling side, TEMs are in a position to compete with conventional systems too." To analyze the system's potential and its limits, Jänsch and his colleagues have configured an overall system, for electric or hybrid vehicles, on the basis of analytical computations and an FEM simulation of heat transfer in the battery cell, and have modeled it in MATLAB/Simulink. The model contains sub-models for vehicle, TEM system, controllers, battery cooler and an electric, as well as a thermal, battery model. Mileage for the given driving cycle was computed using the vehicle model, with the assumption that this requirement can be covered completely by the battery. Experts tested the TEM system's cooling function in the highly dynamic SFTP-US06 driving cycle at an ambient and initial battery temperature of 35 degrees Celsius. For the heating function, they used the moderate NEDC driving cycle at an ambient temperature of minus 20 degrees Celsius and an initial battery temperature of minus ten degrees Celsius.

Quickly Taking the Battery to the Right Temperature with a TEM System

Simulation showed that a TEM system is capable of quickly cooling the battery: its mean temperature reached the specified range after approximately 600 seconds to allow for optimum performance while keeping battery aging low.

The TEM system was also able to score on the heating side: here, too, the mean battery temperature of 25 degrees Celsius was attained after approximately 600 seconds (from this temperature, the battery is able to reach the optimum temperature range using its own heat). In contrast, such a warm-up will take around 1,900 seconds using an auxiliary electric heater (with a rated output of two kilowatts) and up to 3,600 seconds using coolant heat from the vehicle's cooling circulation system. "The simulation model provided us with the means to compare the energy required by the TEM system with that of a conventional refrigerant circuit system," Jänsch reports. "Although performance is extensively governed by the operating point and cannot be judged wholesale, we did establish that TEM systems are

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Editorial

Dear Readers,

My first EV experiences were in the late 70s supporting Dr. Ernst Stuhlinger's research in Huntsville, AL, but when I drove GM's EV1 at an EV conference in February 1998, the sophistication and potential of electric drive was truly brought home. It was an epiphany for me, and returning later that morning to my rental car with its seemingly primitive use of fire and explosions felt like going back to the dark ages.

The initial responses to the pressures of global warming and the tightening supply of petroleum have been quite different on each side of the Atlantic. European taxation promoted the increased adoption of diesels. With a greater sensitivity at the time to particulate emissions, and a once-bitten concern about light-duty diesels, North America moved towards hybrid vehicles. However, the much stricter CO_2 and CAFE regulations now implemented have aligned the approaches globally to develop HEVs and BEVs for our world of diminishing petroleum supplies.

The automotive industry continues to make remarkable progress in increasing powertrain efficiencies with IC engines. However, the sea change within powertrain engineering and the driving need for expertise in HV controls, signal distribution, batteries and motors is truly being felt throughout the automotive and adjacent industries.

I recently attended the GACCOM e-Mobility Forum in Birmingham, MI, which IAV helped sponsor, and where many interesting presentations addressed not only such powertrain developments, but also the connected vehicle and charging infrastructures needed. There is much enthusiastic attention being paid to these "peripherals," and this issue of automotion includes a relevant discussion between IAV's Willi Nietschke and Thomas Neumann, former CEO of Continental and now responsible for all electric vehicle programs at VW Group.

It is truly a very exciting time to be in our industry, and IAV continues to work in the vanguard of advanced IC development and to bring related engineering expertise to HEV and BEV controls, mechanical design and vehicle integration. I hope you enjoy the articles we have prepared on IAV's work in all these areas.

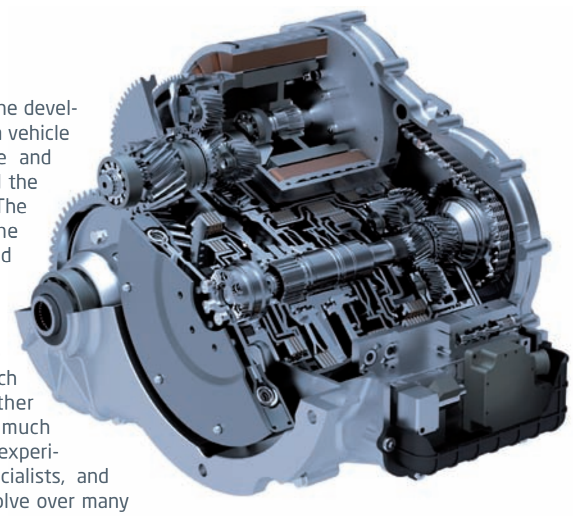
Wishing you and yours a great holiday season, and looking forward to working with you in the New Year,

Jeremy Goddard
Vice President Sales & Marketing IAV Inc.

A More Systematic Approach To Transmission Design

New IAV Tool-Based Design System Saves Time and Weight

By Erik Schneider, Joerg Mueller and Wayne Petzke



A new software package from IAV finds the optimum layout for transmission systems. Avoiding unnecessary costs, reducing weight and saving space are just a few of the benefits. This system also takes into account load regimes and their influences on mating parts using a methodical approach to provide reliable and repeatable results.

What does the optimum transmission look like? It must work reliably throughout the entire life of a vehicle, which can be up to several hundred thousand miles. It must be lightweight, compact and manufacturable at the lowest cost. The transmission specialists from IAV are currently developing software to find the best compromise in configuring components to meet these requirements. "To date, experts have dimensioned individual components separately using specifically tailored software in each case," says Erik Schneider, head of the Transmission and Hybrid Systems department at IAV. "Although we have bearing and shaft specialists, for example, hardly any systematic approach exists that covers all disciplines for the overall transmission system at this early phase of development." This leads to many components being configured for a lifespan which is not relevant in practice. Components are often not optimally designed which results in transmissions with excess weight, size and cost.

The Basic Idea: To Simulate Driving Profiles

A more intelligent approach is to simulate potential failures in advance using driving profiles based on load calculations or empirical values from testing. The objective is to establish a virtual method of determining if components embedded in the overall system can meet complex durability requirements.

IAV experts have been working on such software since 2009. "We want to develop a methodical approach to optimizing the configuration of the powertrain's components to take into account actual load and thus a predicted failure profile", explains Schneider's colleague Jörg Müller, team manager of Concepts / Synthesis. In practice, the developers input the program vehicle usage through mileage and relevant cycle data, and the powertrain structure. The software simulates the load distribution and delivers the main component dimensions, such as optimum gearing topology. The computer-aided approach also provides further advantages: "Today, much still depends on the experience of individual specialists, and transmissions often evolve over many decades. What we want to achieve is far more certainty and flexibility for the increasing number of new powertrain configurations, technologies and market requirements." says Schneider. The new software now provides a basis for objectively monitoring and understanding the criteria underlying the decisions taken in designing a transmission and its components. Load profiles and the estimation of durability are foundations for the simulation. "This enhances development certainty and can shorten development time," Müller comments. "The methodology gives us tremendous transparency, and the results can be reproduced at any time."

Ideal for Model Ranges

The program is also an ideal basis for shared component studies, and can quickly and reliably answer the question of whether a specific component is suitable for use under other boundary conditions, such as with a more powerful engine in another vehicle application. In such a case, only a few elements may need to be adapted. "Detecting precisely these without a large number of costly and work-intensive tests on actual components is the challenge. Ultimately, the method allows manufacturers to employ modular systems and thus use more share parts; it also enables them to develop inexpensive product families," says Schneider. Since the program was developed by IAV itself, it can be matched to customers' wishes with a high degree of flexibility, including specific hybrid applications.

"There are no proven commercial tools for this task on the market at present; and if there were, we might not have the possibility to make modifications in the way we want," Müller says. "This is why we decided to develop the methodology ourselves." The software has already been successfully tested in designing specific powertrains, and is currently being provided with an easy-to-operate user interface. A professional version is scheduled to be made available in early 2011. The new tool also works with other IAV software, such as transmission synthesis. This is important because development work is becoming ever more complex. After using the transmission-synthesis software to determine the optimum transmission layout, the next step is to feed the results into the new transmission design software to create a fully optimized system.

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no longer far behind conventional air-conditioning systems in terms of power consumption. So it's worthwhile to keep an eye on them." Today, thermoelectric materials exist in the laboratory with a ZT value (which indicates the efficiency with which heat is converted into electric energy) > 1.0, compared to ZT values of 0.6 to 0.8 for the commercially-available thermoelectric material.

When the more-efficient materials come onto the market in a few years, TEMs will have finally caught up with the classic air-conditioning technology. In addition, TEMs provide flexibility in the way they can be matched to operating conditions, are scalable in every respect, and can be controlled with ease and precision. Compared with other technologies, their low level of complexity makes TE heat pump systems robust, maintenance-free and durable.

They come with advantages in the space they require, weight, integration effort and cost, and they rely neither on chemical nor mechanical processes; they use no moving parts nor fluids. They are completely silent in operation and are non-polluting. "My vision is the fluidfree electric car," Jänsch says. "With TEMs, we won't need any fuel or coolant, and the closed, high-pressure circulation system will be unnecessary." As a result, vehicles will become far simpler with less servicing requirements. There will also be fewer problems in the event of a collision, and the impact fluids have on the environment will no longer be an issue." Jänsch concludes: "Thermoelectric modules have fantastic properties: they will reach extremely high levels of efficiency in just a few years. In relation to the sum of their qualities, compressor systems will find them hard to beat."

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"Electromobility Is Not Only a Technical Challenge"

Wilfried Nietschke Interviews Dr. Karl-Thomas Neumann during the Second German Electric-Vehicle Congress

By Wilfried Nietscke and Paul Moreton

Wilfried Nietschke, Senior Vice President of Technology Monitoring at IAV, and Dr. Karl-Thomas Neumann, the Volkswagen Group's General Representative for Electric Traction, speak in this automotion interview about the challenges presented by electromobility, the state of the art and the part that is played by development partners such as IAV.

Nietschke: Dr. Neumann, you have just delivered a fascinating opening presentation on the opportunities and challenges of electromobility at the second German Electric Vehicle Congress in Bonn. Where do you see the biggest challenge in electromobility at the moment?

Neumann: We are now at a stage where we want to get e-vehicles into mass production. The key challenge here is cost.

Nietschke: Are the OEMs ready for this?

Neumann: I feel that we realize what's at stake. I'm also convinced our suppliers and ourselves are now doing everything we can to bring costs down. If anyone can master the electromobility challenge, then basically it is up to us. Greater emphasis must be given to the system-based approach. Structurally speaking, there's still some work to be done. What is needed are specialized, dedicated teams to focus solely on electromobility. After all, you can't develop a combustion-engine vehicle in the morning and hope to bring an electric car out in the afternoon.

Nietschke: How do you see Asia? Is Asia setting the pace?

Neumann: In technology, I'm not so sure, even though it is the main market for electromobility, largely because of the incentives they give there for electric cars.

Having just broached technology, is it ready to go into mass production, or are we still in what you might call a secondary prototype phase?

Neumann: No, the way I see it, the technology is ready. But again, there's the question of affordability.

Nietschke: What are your expectations in this context for a conference like the second German Electric Vehicle Congress?

Neumann: Electromobility is not only a technical challenge, and this is a very important point. Looking at the congress program, it covers the entire spectrum of electromobility: the engineering aspects, of course, but also the political side which sets the basic parameters, the overall infrastructure with the energy suppliers, and also the aspect of economic efficiency through new business models. Given all this, the conference provides the ideal opportunity for networking on an interdisciplinary scale in the way that is absolutely necessary.

Nietschke: I'd be interested in hearing your opinion on the role that development providers, like IAV, play in electromobility. What contribution can we make?

Neumann: They are already making a huge contribution, not only through the many different development activities in which they're involved, but also through the fleet-related support they are providing for e-vehicles. Alongside these business operations, IAV can also slip into the role of a strategic partner because of the profound automotive and systems-related expertise it brings. Electromobility is a gigantic opportunity for all development partners.

Nietschke: What are your visions on the subject of electromobility – looking somewhat further into the future.

Neumann: Looking way into the future, I do believe a significant segment of our vehicles will be electric. Yet I don't believe the combustion engine – at least within my lifetime – will disappear. What will change, though, is the way people see the car.

Electromobility is likely to put an end to the classic model of owning a car for five years and then buying a new one. There will be a greater number of mobility-business models that will allow us to use other vehicles in addition to our electric cars – consider micro-leasing, for instance.

Thank you for giving us this interview, Dr. Neumann.

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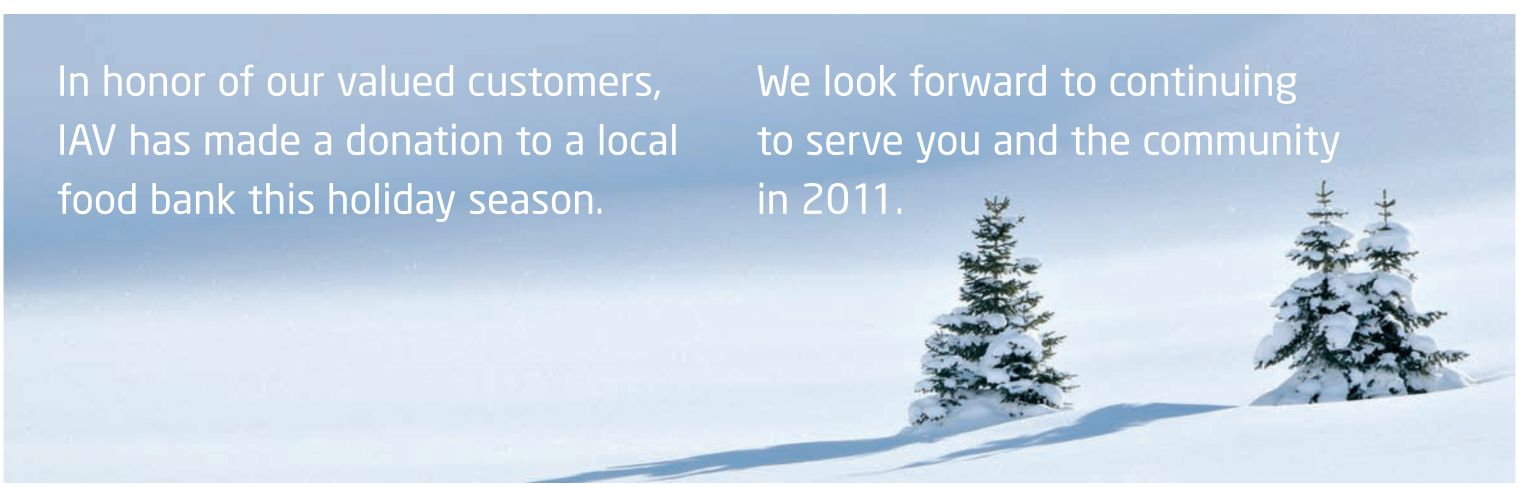
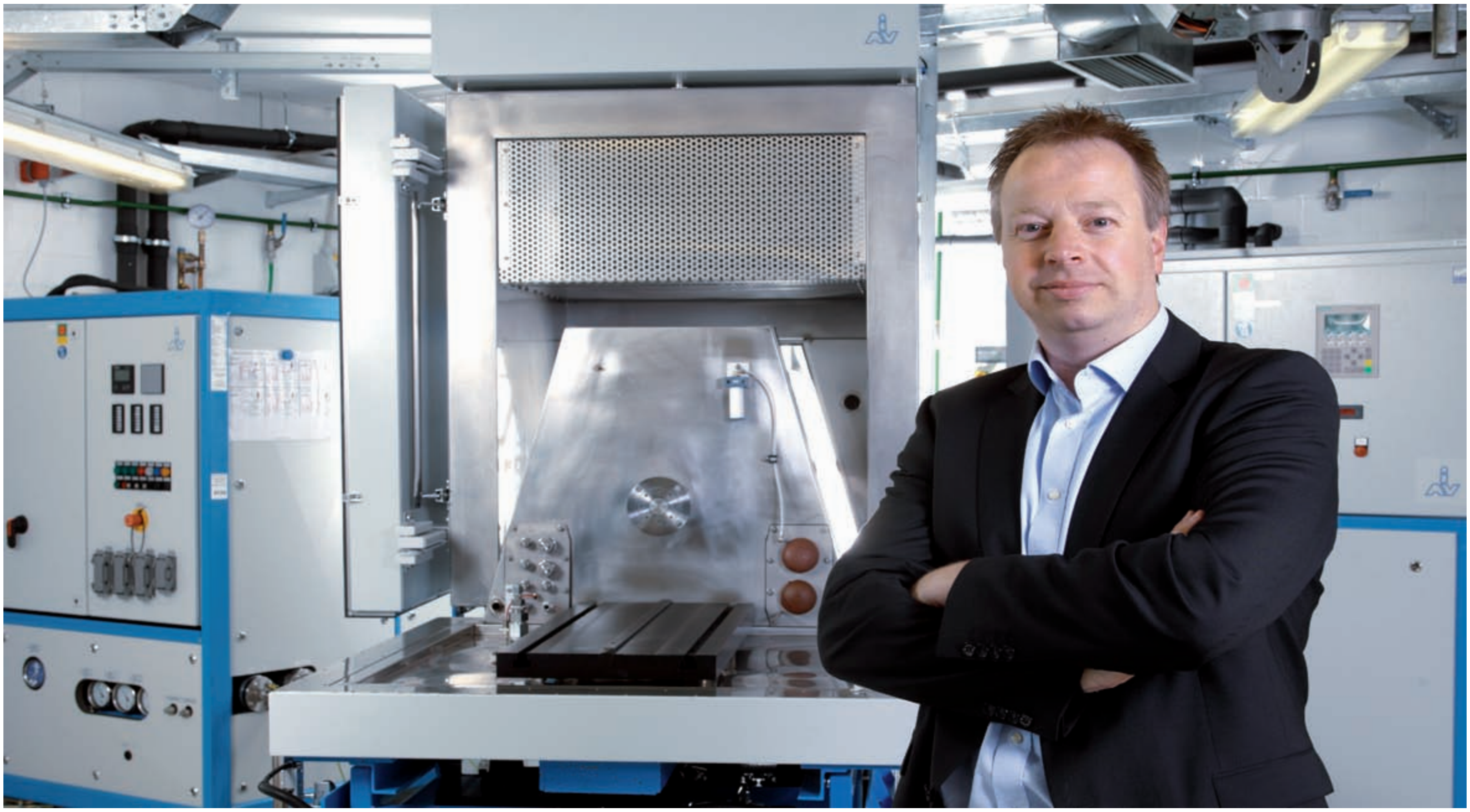


A Close Look into Injection System Development

IAV's New, Innovative Test Bench for Developing Future Injection Systems

By Ralf Marohn and Mike Traver



IAV now has a new injection system test bench capable of dynamically controlling temperature, while analyzing injection systems. The system can control the temperature of single injectors quickly and with extreme precision and permits the use of all liquid fuels currently in use.

IAV's experts have been developing new concepts for diesel and gasoline injection systems for over two decades. The focus of these activities has been on providing design solutions and developing innovative functions for production systems. A new high performance test bench for injection systems has been set up to provide even better real world investigations into worst case application conditions such as bad quality fuels.

Following a six month planning phase and a twelve month construction period, IAV's specialists are proud to show the results of their development work. "We are now able to condition the fuel and its surrounding air with extreme precision, particularly for transient test conditions," says Ralf Marohn, head of the Fuel and Injection Systems department. "The temperature range of the new test bench extends from –40°C to +140°C; the conditioning for fluid flow and for the surrounding air can be controlled separately."

Capability of Running through Entire Temperature Profiles

Also new is the system's ability to run entire temperature profiles in a very short period of time. Until now, IAV's test rigs have been limited to static measurements. The functional studies at different temperatures are showing highly informative results.

"Most measurements in the past were at 40°C," Ralf Marohn explains. "and some effects couldn't be identified." He names the disturbed behavior of injectors asked to inject small quantities: fluctuating temperatures may result in the possible failure of the pre-injection. "With the new system, we can now detect these effects at a medium rate of temperature change of 5 °C /min even more precisely and, above all, more quickly," Marohn is pleased to note. "There are only a few test benches of this type in the world."

A Test Bench for All Fuels

With the new test bench, IAV experts can work with diesel and gasoline, and now with kerosene, ethanol or contaminated fuels of the type often encountered in developing markets. An electric motor drives the high pressure pump while the fuel is collected after injection and returned to the tank. A new innovation is the fuel cooling and filtering system which reduces evaporation of the highly volatile fuel components and significantly decreases the frequency of fuel-changing intervals, especially in durability testing. Testing presents no fire risk, for inert gases are used to surround the entire injection system in the test chamber. The injected fuel quantity can be determined at any temperature through the shot-to-shot measurement function in IAV's Injection Analyzer.

As an integral part of IAV's tool chain, the Injection Analyzer allows the injection rate to be recorded as a function of temperature over the engine's entire operating map. "We can conduct shot-to-shot measurements in the critical operating states, such as at cold start or at the re-start of a hot engine," Ralf Marohn says. "In doing so, we investigate the individual partial injection events with a high level of precision and use the results to enhance the injection system design or to calibrate the engine controls."

Modern injection systems can shape the rate of the injected fuel in multiple ways to help optimize combustion, and continuous rate shaping goes a step further. The test bench can now be used to establish the stability of the rate shaping depending on temperature. IAV is developing algorithms and functions for the reliable handling of rate shaping for use in many customer applications.

Fit for Start-Stop and Hybrid Applications

The new high performance test bench is being applied in the development of engines for hybrid vehicles. The influence that start-stop systems have on the high pressure injection pumps is becoming significant. High pressure pumps may now start frequently from a standstill which leads to increased wear because, during the start function, the bearing is not yet properly lubricated.

IAV is now using the temperature-controlled injection system test benches to provide optimum support in addressing such critical development issues. IAV has been building expertise in this area for many years and is providing automobile manufacturers, as well as component suppliers, with assistance in their projects. The new system complements the test benches already in use at IAV: optical spray analysis in pressure chambers; modern nozzle flow rate measurement technology; and extensive special techniques for measuring fuel and injectionsystems.

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Injection in Great Shape

Injection Rate Shaping Resolves the Trade-Off between Reducing Emissions and Saving Fuel

By Oliver Predelli and Mike Traver

Modern diesel injectors offer the ability to shape the rate of injection and to help resolve the trade-off between lower NO_X and soot emissions on the one hand, and better fuel economy and quiet engine operation on the other. IAV presented this potential in April 2010 at the 31st International Vienna Engine Symposium.

Diesel engine developers are facing a dilemma. To improve the compression-ignition engine's NO_X, soot and noise emissions, the main center of heat release has been shifted toward less favorable thermodynamic conditions. This development direction has lead to higher fuel consumption and CO_2 emissions. "Legislation has imposed stringent limits on permissible carbon dioxide emissions," says Oliver Predelli, Vice-President of Diesel Engine Development at IAV, in describing the challenge. "We must succeed in making the diesel engine more economical without increasing combustion noise or pushing up nitrogen-oxide and soot emissions."

Developers are finding a solution in continuously shaping the rate of injection. In current diesel engines, a small quantity of fuel is injected into the cylinder before the main injection event. These pilot injections influence the ignition-delay phase in such a way that the injected diesel fuel combusts directly in the spray wherever possible. "The pre-injection avoids a sudden rise in pressure in the cylinder and prevents harsh knocking," Predelli explains. Although this is a step in the right direction, it is still not perfect: multiple pilot injections cannot follow as closely in succession as the engine truly demands. Ideally, they should merge into one another and then with the main injection.

Timing of the Injected Fuel Quantity Can Be Shaped in Any Way

The problem is solved by continuous rate shaping. Modern injectors, such as the PCR NG injector from Continental, allow the positioning of the nozzle needle at any chosen point in the nozzle hole and to constrict the needle seat and adjust the timing of the injection rate in virtually any way. Working in collaboration with Continental Automotive GmbH, IAV has examined the potential of continuous rate shaping and was invited to present its findings at the 31st International Vienna Motor Symposium.

The test set-up comprised a single cylinder passenger car engine with a displacement of 0.5L. IAV's Modular Prototyping Engine Controller (MPEC), with an advanced piezo output stage, was used for controlling the engine. IAV's universal FI2RE control unit delivered the signal for actuating the injector, and IAV's Injection Analyzer analyzed the actual rate of injection.

Using the test set-up, the team learned that the two conventional pilot injections could be replaced with a ramp shaped curve ("continuous rate shaping"). "The main injected fuel quantity is converted to produce the desired consistent rise in pressure while keeping combustion quiet," Predelli says.

Compared with conventional multiple injections, engine noise was 3 dB(A) lower, and the level of sound power halved. This effect was not only able to compensate for the acoustic drawbacks, but also to reduce the raw emissions inside the engine from Euro 5 to Euro 6. Proceeding from a Euro 5 calibration, the increase in injection and boost pressure halved the nitrogen-oxide emissions while leaving particulate emissions and combustion noise unchanged. The drop in fuel consumption also brought lower CO_2 emissions: Predelli is expecting more "significant improvements" and puts the potential saving in using the technology at about five percent.

Application Possible in Production Vehicles

IAV has evaluated the system and is ready to act as a neutral consultant with parties interested in the new aqpproach. Next developments will involve testing continuous rate shaping on full-sized engines with four or more cylinders, and production readiness seems possible in the next few years.

It is another step closer to resolving the trade-off between better fuel economy and quiet combustion and lower NO_X and soot emissions.

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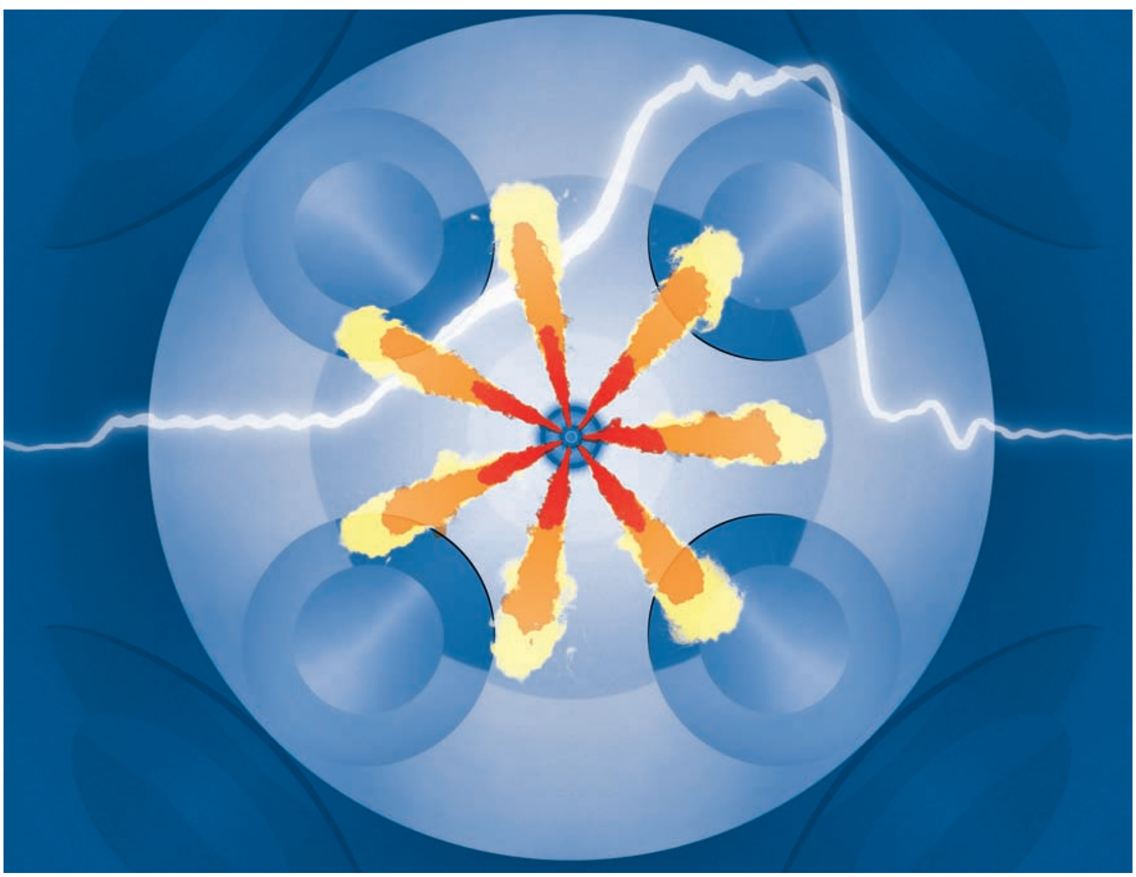

IAV presented the potential offered by continuously shaping the injection rate in April at the 31st International Vienna Engine Symposium

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Public Appearances & Publications

December

December 9 - 12, 2010
2nd IAV Conference on "Thermoelectrics goes Automotive"
Berlin, Germany

ATZ 12/2010
"Computer-Assisted Optimization of Transmission Structures Based on the Example of an 8-Speed Hybrid Automatic Transmission"
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February

February 9 - 11, 2011
SAE Hybrid Vehicle Technologies Symposium
Anaheim, CA

February 15 - 16, 2011
8th Braunschweig Symposium "Hybrid Vehicles, Electric Vehicles and Energy Management"
Braunschweig, Gifhorn

The symposium intends to focus on and promote the development of efficient vehicle drive systems by combining the use of combustion engines, electric drives, systems for storing and generating electrical energy, necessary torque and speed converters, including open and closed-loop control electronics.

April

April 12 - 14, 2011
SAE World Congress
Detroit, MI

May

May 17 - 18, 2011
CTI Symposium
Detroit, MI

September

September 21 - 23, 2011
SAE North American International Powertrain Conference
Chicago, IL