

Edited by **Darlene Fritz**

New GM V6 diesel has cylinder-pressure monitoring

Late next year **General Motors** will launch a new-generation light-duty turbodiesel engine featuring real-time cylinder-pressure monitoring to reduce engine-out emissions.

The 2.9-L V6 will debut in the 2009 **Cadillac** CTS in Europe, and will also power **Opel**, **Saab**, and **Vauxhall** models. It is designed to meet the upcoming Euro 5 regulations, which are expected to require significantly lower oxides of nitrogen (NOx) and particulate matter (PM) emissions.

The engine's closed-loop combustion-control system is a breakthrough technology for diesel engines, which are increas-

ingly under pressure by emissions regulations worldwide, said Charlie Freese, Executive Director of Diesel Engineering at **GM Powertrain**.

"The system uses cylinder-pressure feedback loops to address combustion variation and achieve smooth transitions between combustion modes," he explained. "We call it Pre-mixed-Charge Compression Ignition, or PCCI. The benefit is up to 90% lower NOx compared with Euro 4 engines."

Freese said the system will likely allow GM to avoid the fuel-efficiency penalty that often comes with NOx-reduction techniques. It also is more sympathetic to variations in diesel fuel quality, particularly cetane, he added.

The engine's combustion system features a number of key enabling technologies. Piezo-resistive pressure sensors integrated into the glow plugs monitor cylinder pressure in real time. The **Bosch**-supplied units send real-time data to the engine control unit, which in turn provides precise, closed-loop command of injection timing and cooled exhaust gas recirculation (EGR). The rate of combustion rise is controlled by the variable-geometry turbocharger.

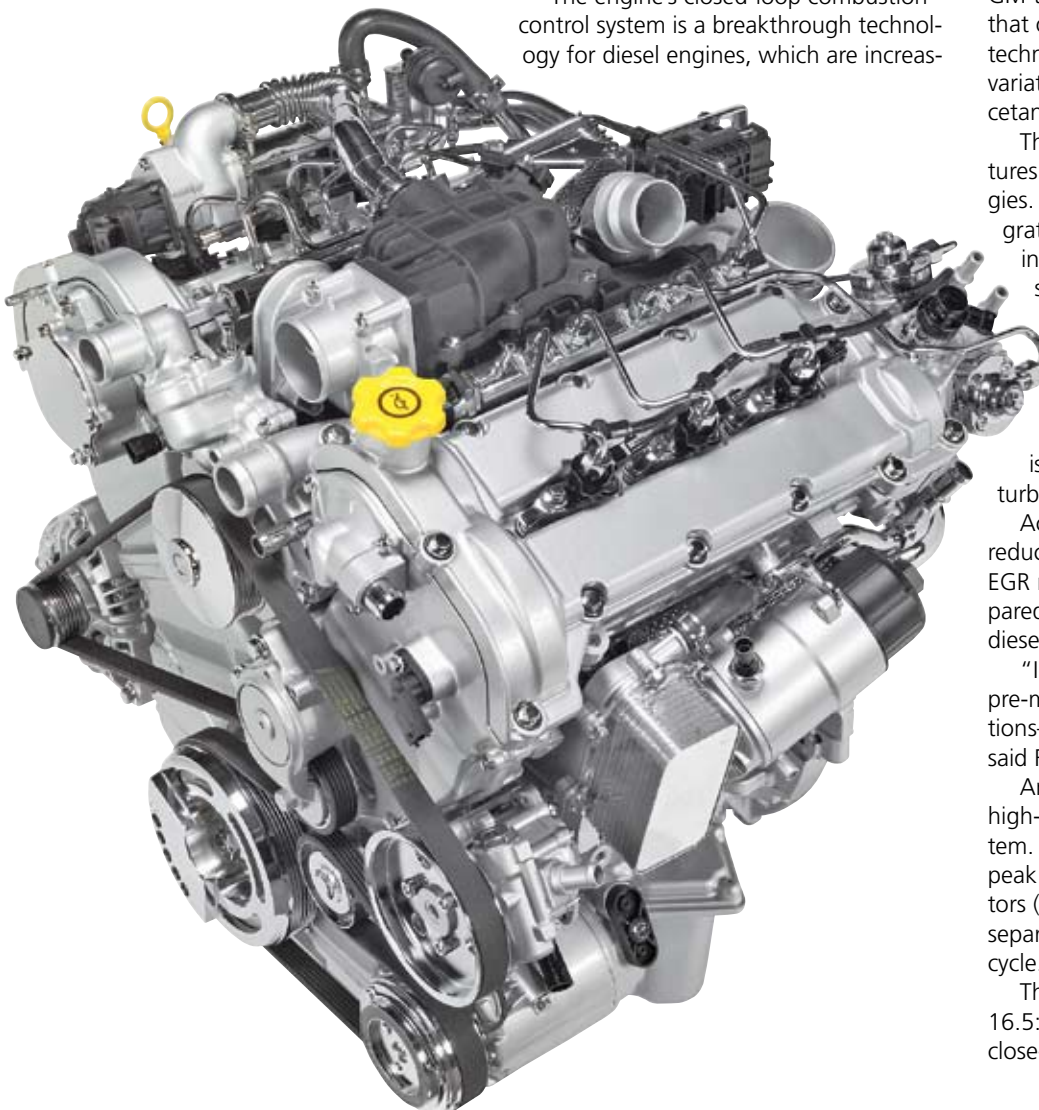
Achieving significant in-cylinder NOx reduction required a substantial boost in EGR rate—65% on the new V6, compared with 40% on GM's Euro-4-spec diesels.

"Increasing EGR helps deliver highly pre-mixed combustion in low-load conditions—a major NOx-reduction driver," said Freese.

Another critical enabler is the Bosch high-pressure, common-rail injection system. Operating at 29,000-psi (2000-bar) peak injection pressure, the piezo injectors (a first for GM) provide up to eight separate injection events per combustion cycle.

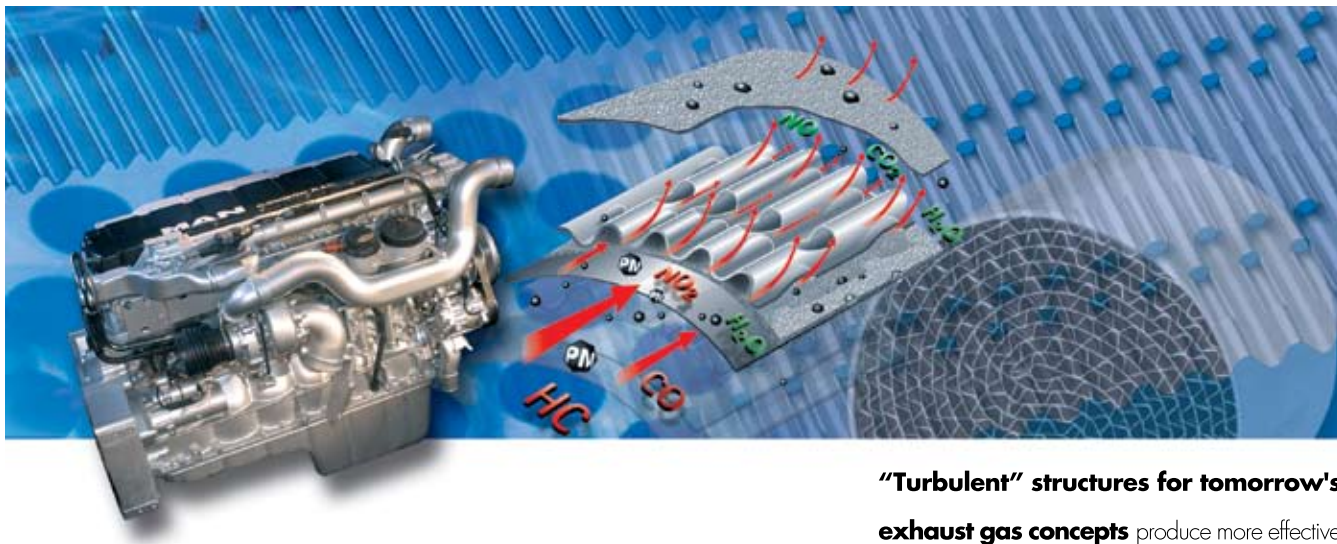
The engine's compression ratio is 16.5:1. The emissions package includes close-coupled oxidation catalyst and par-

Combining innovative piezo-resistive pressure sensors, ultra-high injection pressures, high rates of EGR, and a variable-geometry turbo will allow the 2.9-L DOHC V6 diesel to meet Euro 5 NOx and particulate requirements.

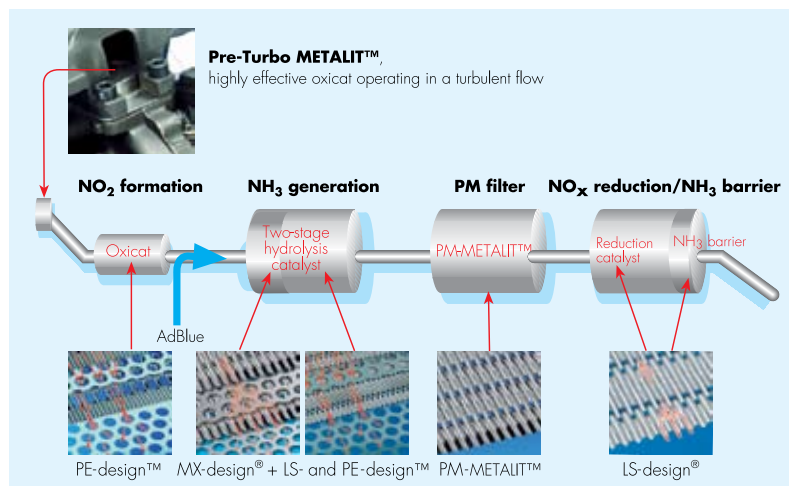


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ticulate filter.

The 60° DOHC V6 will be configured for both longitudinal- and transverse-mount vehicle applications. It features aluminum, four-valve cylinder heads and compacted-graphite iron cylinder block and bedplate. Bore and stroke measure 83 x 90.4 mm (3.27 x 3.56 in).

Output is rated at 250 hp (184 kW) at 4000 rpm, and 406 lb-ft (550 N-m) at 2000 rpm.

GM collaborated with **DaimlerChrysler** subsidiary **VM Motori** on the program, which was formally launched in July 2005. VM Motori designed the engine's base architecture, and will build the engine at its Cento, Italy, facility.

"The relationship leverages VM Motori's existing engine-development capabilities as well as its production capacity," Freese said. Engines for the European-spec Cadillac will be shipped to GM's Lansing Grand River plant, where the CTS is assembled.

GM Powertrain, along with the automaker's Research & Development group, developed the combustion strategy, engine control, and aftertreatment systems.

"R&D developed unique, very powerful simulation software for diesel fuel and combustion systems," noted Freese. "It allows us to model all aspects of the combustion event, thermal characteristics, and emissions." The analysis tools use "genetic algorithms" that optimize all

design parameters, according to Freese.

There are no plans to offer the 2.9-L V6 in GM's North American vehicle portfolio—it is not certified to the ultra-stringent U.S. Tier 2 Bin 5 or California LEV2 standards, which are far tighter on NOx than Euro 5.

However, GM plans to incorporate the advanced combustion process in new families of light-duty diesels, including the new light-truck V8 entering production in late 2008. That DOHC engine, which Freese indicates will displace between 4.0 and 5.0 L, is currently being tested in mule vehicles.

GM's contract with VM Motori permits sales to other manufacturers.

Lindsay Brooke

Diesel goes hybrid?

Having originated in Japan, there is a worldwide trend toward hybrid vehicles with gasoline engines. Hybrid vehicles are expected to account for a 25% share of the U.S. market by 2020. An increase of similar magnitude is also being predicted for the diesel engine, particularly in larger vehicles, such as pickup trucks and SUVs. In Europe, the diesel engine, which already accounts for a share of more than 50%, is gaining ground.

Hybrid technology and diesel technology represent flexible and efficient vehicle drives that are both characterized by low fuel consumption. Within the context of continuing requirements for further reductions in CO₂ emissions, the concept of

combining diesel and hybrid technologies provides an interesting technical option, provided that it can be put into practice cost-effectively.

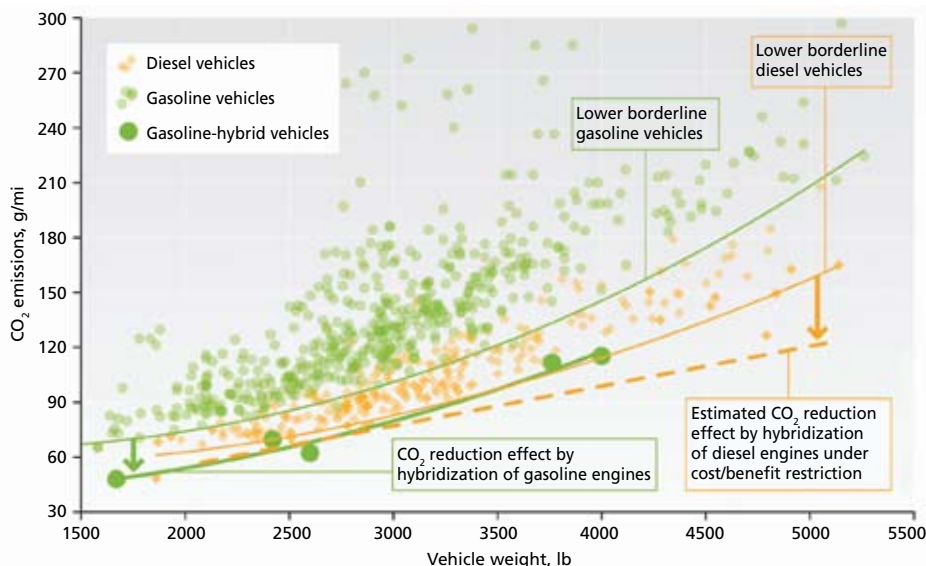
Hybrid technology has resulted in a significant reduction in CO₂ emissions from gasoline vehicles, cutting CO₂ emissions by about 20 to 25%. Taking economic aspects and the level of hybridization into account, a 10 to 30% reduction in CO₂ emissions could be predicted for most diesel-hybrid concepts. Heavy vehicles such as high-end cars, SUVs, and pickups tend to show the greatest potential for reduced emissions without any loss in performance.

Considering the need to balance driv-

ing pleasure, fuel efficiency, and reduction of exhaust emissions and noise, it appears that cost-effective, passenger-car diesel-hybrid concepts can be produced that offer consumers significant added value, aided by future technical innovations.

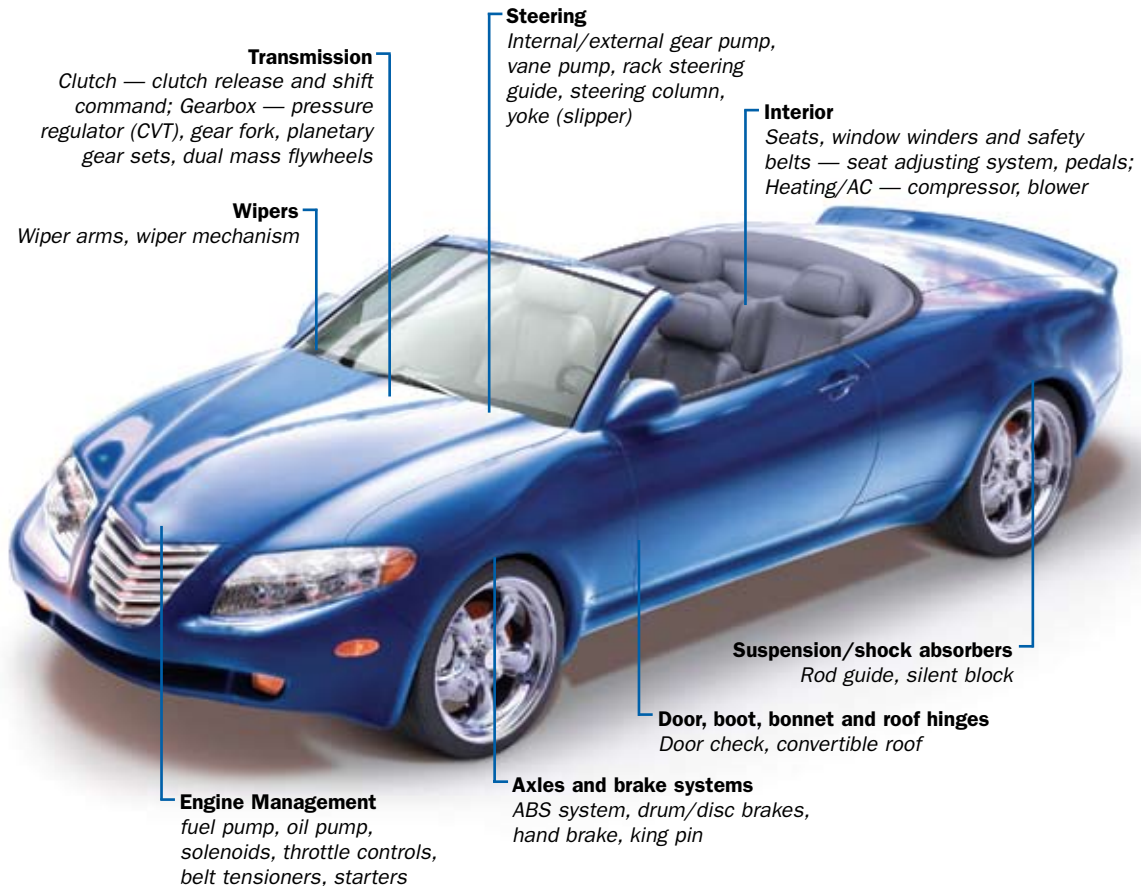
It is possible to create diesel-hybrid concepts that are highly dynamic and clean. These are notable for their characteristically high level of torque at low to high engine speeds, an agile takeoff, and elimination of turbo lag with the use of an electric motor. Costs will be reduced by optimizing (downsizing) system components and the possibility of dispensing with active "de-NOx-ification." Fuel consumption in diesel-hybrid concepts can be reduced by managing energy in line with demand while reducing such losses as braking energy, exhaust-gas energy, and cooling. Innovative engine-control algorithms provide the ability to reduce engine dynamics when changing from one operating mode to another. Systematically shifting the operating mode makes it possible to cut both fuel consumption and exhaust emissions. For the future, there is significant potential for further reduction of emissions by improving the combustion process with partial homogenization. The aim is to meet future U.S. Tier 2 Bin 5 ceilings and Europe's EU5 and EU6 emissions limits.

Integration of the electric-drive components in the familiar powertrain must be optimized in terms of cost. Diesel-engine development will be marked by such



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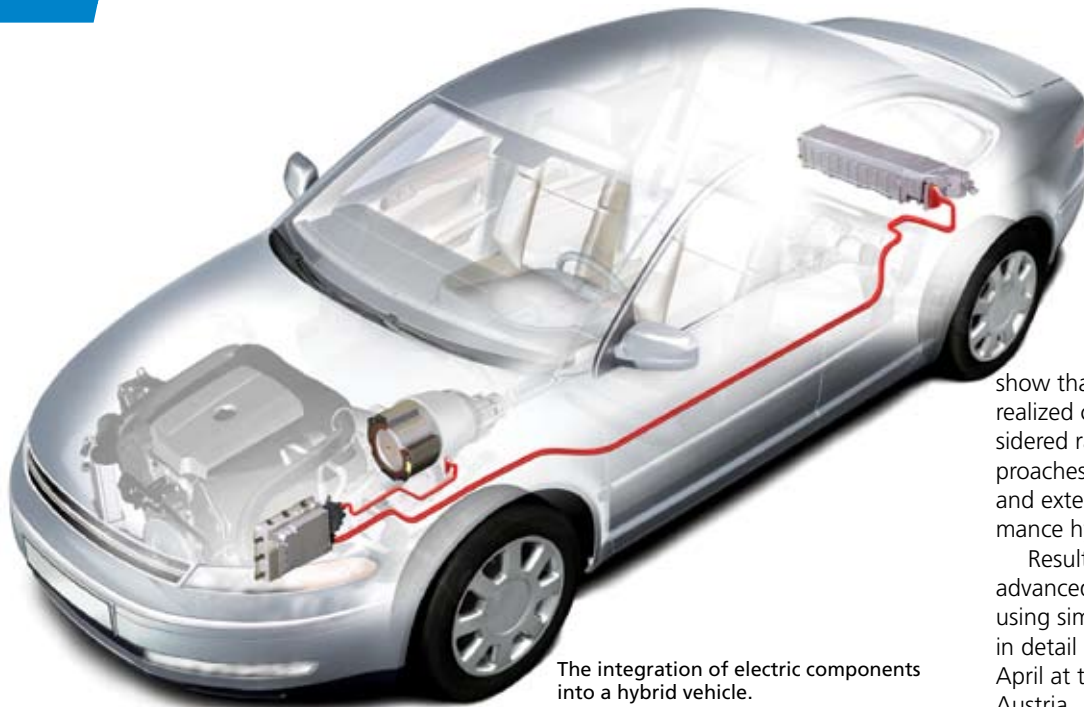
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The integration of electric components into a hybrid vehicle.

simplifications as the removal of hydraulic and pneumatic systems and the integration of functions currently provided by separate components, such as the starter and generator.

In addition to further optimizing the diesel engine and diesel fuel, effectively

controlling the energy flows in the vehicle will be crucial to successfully exploiting further significant improvements.

Despite the many obstacles standing in the way of a diesel-hybrid concept in mass production, results obtained by the **IAV Automotive Engineering** Group

show that the potential benefits can be realized cost-effectively. The options considered range from energy-optimized approaches such as the diesel series hybrid, and extend right through to the performance hybrid.

Results of these studies and additional advanced developments—most validated using simulation tools—will be examined in detail as part of a paper delivered in April at the Vienna Engine Symposium in Austria.

Before then, however, IAV will display specific technical solutions to the focal aspects of diesel and hybrid technologies such as eCVT, SCR, torque vectoring, and overall vehicle simulation at the **SAE** World Congress in Detroit.

Paul Moreton of IAV Automotive Engineering wrote this article for *AEI*.

V6 mainstay gets NVH upgrade

The U.S. automotive market has largely settled on the 60°, aluminum block, OHC V6 engine of about 3.5 L as its mainstay powerplant, used in high-volume midsize sedans, wagons, crossovers, and vans to the tune of millions of vehicles per year.

Today's market sees a convergence of

the competitors with seemingly identical designs, which nevertheless still have very different NVH characteristics. By working on these engines for many years, the earliest practitioners say they have been able to make subtle improvements that contribute to the ability of these mainstream

engines to even serve in luxury vehicles and sports cars.

That ongoing experience evolving engines of similar design has helped **Toyota** reduce manufacturing tolerances and reciprocating mass, for example, said Paul Williamsen, Product Education Manager for Toyota Motor Sales, USA. "I've noticed improvements in machining accuracy and tolerance that in the cumulative must be adding up to some differences," he said.

The block itself is also critically important. Seemingly all new engines follow the expected strategy of using a rigid, deep-skirted block to quell vibration, but nevertheless, differences remain.

Some of those arise from the specific execution of the block's ribs and gussets, and others are due to differences in casting and installation of the cylinder sleeves. For example, Toyota uses a low-pressure casting process that Williamsen says produces a higher-quality block. Toyota, **Honda**, and **General Motors** are among the companies that cast in cylinder liners that have an irregular outside

The General Motors 3.6-L V6 engine features cast-in cylinder liners whose rough outer surface provides an extremely rigid interface with the aluminum block to help match the bore's thermal expansion to that of the piston for consistent clearance.



Don Carmey

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The Mazda CX-9's unique intake tract is the source of the engine's different NVH characteristics in comparison to Ford's version of the engine, according to CX-9 Product Development Engineer Stan Hortinela.

shape to better grip the aluminum block material. Toyota calls the design of its cylinder sleeves "spiny liners."

"The outside of the cylinder, the part that bonds with the casting, is finished with a random-strand finish," Williamsen explained. "It looks a lot like the outside of a bobbin of thread that has been poorly wound."

This irregular finish maximizes the surface area available for bonding the sleeve to the block casting, more than doubling contact area, according to Williamsen. In addition to improving rigidity, this also enhances the engineer's ability to minimize tolerances between piston and cylinder.

Traditionally, thermal expansion rates for the iron cylinder liners have differed significantly from that of the aluminum pistons, forcing engineers to design enough tolerance for both cold starts and hot running conditions.

Bonding the iron of the cylinder liners so thoroughly to the aluminum block gives the cylinders a thermal expansion rate closer to that of the aluminum pistons, according to Williamsen. Toyota then bonds steel inserts to its pistons' skirts, to move the pistons' thermal expansion rate closer to that of the cylinders.

"This allows us to throw out the normal way engineers have been dealing with thermal expansion in engines," Williamsen said. "That was to try to constrain and control and provide enough clearance to assume the worst."

Now, with nearly the same thermal expansion rate for both cylinders and pistons, Toyota can reduce the tolerances built into its engines and use nearly gapless piston rings. The primary benefit of the gapless rings is improved emissions control, he said. "This is a case where the emissions regulations have been a driver for good, which is manifested in the NVH level you are noticing."

Honda uses a similar technique for casting its blocks, and has recently upgraded the design of its V6 engine block for use in the **Acura MDX** crossover SUV. The new block features improved external gussets and braces for increased rigidity, in combination with the cast-in rough liner process. Cold-start NVH is particularly improved by the better thermal control of the cast-in liners, said Dennis Graham, Honda's principal engineer for the engine. "You have a lot less piston slap in warming-up conditions," he said.

At the top end of the engine, Toyota has reduced noise by employing lighter,

thinner-stemmed valves that, in turn, permit use of lighter, softer valve springs. The stems are now 5 mm (0.20 in), down from 6 mm (0.24 in) previously, Williamsen said. "That is a substantial reduction of the overall mass of each valve," he said.

That reduced mass allows the softer springs. "You can actually squeeze the valve spring with your fingers," remarked Williamsen. Softer springs and the use of roller rocker arms mean reduced friction in the valvetrain, as well as a reduction of the associated vibration and noise.

Controlling the valvetrain is a quiet, lightweight chain that has a pitch of only 10 mm (0.30 in). That's 30% smaller than a common bicycle chain, Williamsen pointed out. The chain lets Toyota extend service intervals on the engine, because there is no rubber belt in need of periodic replacement. The use of the smaller, quieter chain is made possible by the other valvetrain advances that reduce mass, friction, and noise, he said.

Upstream of the valvetrain is the intake system, which is a significant contributor to noise. Honda, like all manufacturers, carefully tunes the intake system using resonance chambers to tailor the sound of its engines.

The key to pleasant sound is taking the peaks and valleys out of the sound emitted from the engine over its rev range, said Chris Combs, a senior engineer. "One of the most important things that people don't realize," he said, "is that it can be loud but it can sound okay."

The goal is to shape the sound so that it is enjoyable and not irritating. Lower-frequency sounds tend to emanate from the exhaust, while the intake contributes the higher-frequency sounds, Combs said. "That crossover between intake and exhaust varies depending on the engine," he said.

Adding larger resonance chambers to the intake tract lowers the pitch of the engine's sound, he said. As a final touch for some of its models, Honda adds active engine mounts that reduce the vibration the engine sends to the chassis. The active mounts are particularly effective at reducing noise and vibration at idle and low-rpm driving, Combs said.

Dan Carney

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The presentation matters

Vehicle interiors commonly feature an instrument panel, a gauge cluster, and occasionally a head-up display (HUD), but usually those three items exclude using lasers or transparent materials as part of the manufacturing process or the product presentation.

Visteon engineers intend to change the in-vehicle environment with a number of in-development technologies, including translucent instrument panel (IP) skins, laser-etched gauge clusters, and laser-based HUDs.

Work continues on a see-through IP that uses an 80% opaque-pigmented material, rather than a 100% opaque-pigmented material. "It's enough that you won't see the symbols [warning lamps] until the light behind the symbols is activated," said mechanical engineer Mark Turner, Associate Director of New Business Development and Advanced Technology for Visteon.

Visteon's current IP demonstration buck uses light-emitting diodes to illuminate the vehicle's warning symbols so that the symbols are seen on the IP itself rather than the conventional gauge cluster area. Engineers are now working to enable messaging and navigational aides to be seen from the translucent IP.

"We would need to display different information in the same area of the IP, and that's the tricky aspect," Turner said, expressing the engineering challenge inherent with meeting that requirement. The solution is expected to employ "a configurable light source," according to Turner.

Viper V10 introduces cam-in-cam variable valve timing

The 2007 **Dodge** Viper SRT-10 is attracting headlines for its new V10 engine, which is rated at 600 hp (450 kW) at 6100 rpm, a huge increase from the previous 510 hp (380 kW) at 5600 rpm. Yes, the engine now has twin throttle bodies, a new deep-breathing intake system with larger intake valves, and even-more-aggressive cam lobe profiles.

More significant, however, is that it is also the first production pushrod-valve engine with truly variable valve timing (VVT)—on the exhaust valves. Using a phaser on a camshaft-within-a-camshaft design (**Mahle's** CamInCam), the V10 can

In-vehicle gauge information eventually may be displayed within a laser-etched cluster.



Visteon engineers also are working to fine-tune the graphics presentation of an etched gauge cluster. The manufacturing process uses laser technology to give an enhanced look to instrument-cluster digits and symbols.

"A special material—a plastic polymer that's impregnated with microscopic glass beads—is etched with a laser to create the illusion of 3-D," said electrical engineer Upton Bowden, Electronics Product Marketing for Visteon, adding, "The instrument cluster application is an automotive-industry first."

The laser-etched gauge cluster is expected to reduce the manufacturing requirements by eliminating the need for a bezel-surround to achieve a 3-D look as well as having the potential to reduce costs associated with now-unnecessary materials. Conventional gauge pointers and electronics would remain part of the instrument-cluster package.

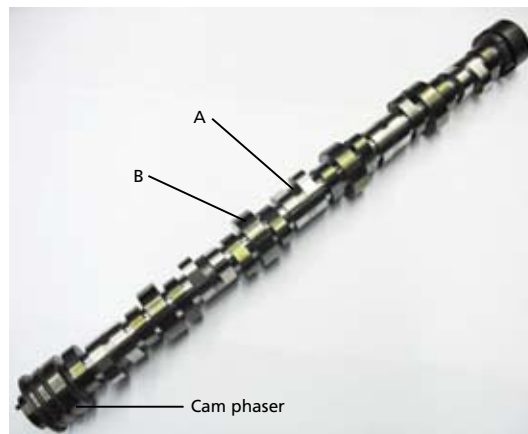
"The laser-etched appliqué layer, approximately 1.5 mm thick, is visible only head-on. By design, it will be nearly impossible for a vehicle's 'co-pilot' to see the information, since the viewing angle is approximately 15° off-axis," said Bowden, adding that production feasibility is likely in early 2008.

Another laser-based technology projects the HUD so that it seems to float beyond the windshield. "A traditional HUD reflects the image off the windshield glass, but this system projects the virtual image about two meters in front of the windshield," said Bowden.

The HUD uses a scanned-beam laser, "so it works well in bright sun because it's a very focused, coherent light. It's unlike white light or light generated from a flat-screen display," said Bowden. In terms of packaging, the laser-based HUD takes up approximately one-third the size of a conventional HUD system. If linked with point-of-interest and mapping technologies, the system could be used to project that information in addition to being a secondary source for vehicle speed, engine rpm, and other conventional gauge-cluster data.

A HUD demonstration buck uses a mono-color laser, but Visteon and **Microvision** engineers are working on a bi-color laser. (Red and green lasers would enable the projection of red, green, and yellow colored images.) "We will have a bi-color laser in a driveable demonstration vehicle this summer," said Bowden.

Kami Buchholz



Although it looks like one camshaft with a phaser at the left end, it's really a hollow tube-type shaft with a second, solid shaft through it, with the phaser connected to both. The intake cam lobe assembly (A) has a pin that goes through a slot in the hollow camshaft and is pressed into the solid cam. The exhaust cam lobe assembly (B) is pressed into position on the hollow camshaft.

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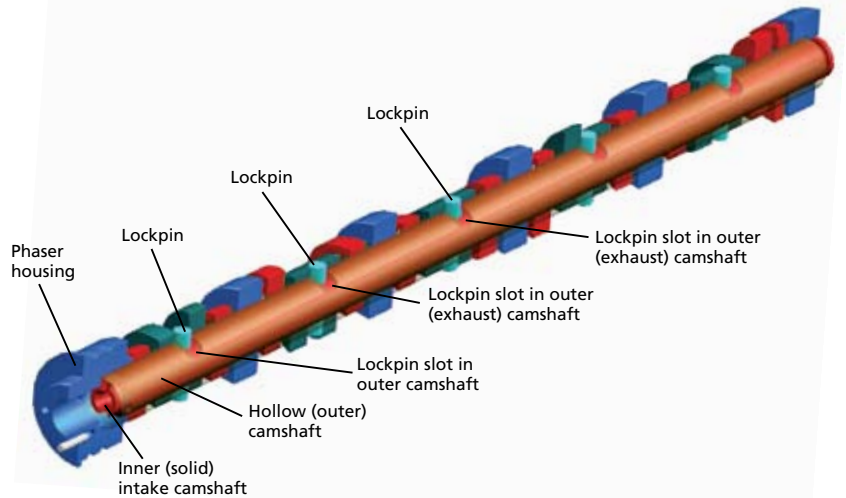


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Exhaust lobes (blue) are pressed onto the (copper-colored) hollow exhaust camshaft. The exhaust camshaft has (light blue) pins that go through the (green) intake lobe assemblies and the exhaust camshaft slots into holes in the (red) solid intake camshaft that sits inside the exhaust camshaft. The blue pins lock the intake lobes to the shaft. The range provided by the pins through the slots permits the exhaust camshaft to change timing vs. the intake camshaft.

The Viper SRT V10 engine has dual throttle bodies that feed an improved intake system with larger-diameter intake valves.

change exhaust valve timing up to 45° vs. intake valve timing, although only 36° actually are used.

This compares with **General Motors'** simpler VCT (variable cam timing) on 3.5- and 3.9-L V6 engines, in which a phaser on a single solid shaft changes timing equally on both intake and exhaust lobes.

The Viper design, developed with **Mechadyne International**, provides the advantage of VVT while retaining the compact size of a pushrod-type, cam-in-block engine. **Chrysler Group** did look at a dual overhead-cam arrangement to advance the Viper V10 performance, but it simply would not fit.

Exhaust-valve control was chosen over intake to provide the valve timing variability needed to improve the idle and part-throttle combustion stability, normally an issue with engines whose camshafts are tailored for high-end horsepower. The performance camshafts produce high exhaust-gas dilution of the intake charge at low rpm/light loads. This results in unstable combustion, which can affect idle quality, emissions, and the ability of the engine computer to detect misfire, which is a federal emissions requirement.

Intake valve control was not chosen because its prime benefit would be improved low-end torque, something the 8.4-L V10 has plenty of, although the

560-lb-ft (760-N-m) peak is at 5000 rpm. Intake control would simply "translate to more tire smoke on a Viper," explained Chrysler SRT engineer Kraig Courtney.

Although technology exists for both intake and exhaust VVT with the pushrod cam-in-block, it would require new designs both for the camshaft and phaser, deemed an unnecessary complexity and cost at this time. The exhaust-only VVT design enables use of a modified Mahle hollow camshaft and a reworked off-the-shelf cam phaser by **INA**.

The cam-within-a-cam consists of a solid intake camshaft within a hollow exhaust camshaft. The solid shaft has holes for cylindrical pins, located at five points that align with axial slots in the hollow outer shaft.

The intake valve cam lobe assemblies are slid onto the hollow exhaust camshaft and positioned above the slots, in a build sequence that permits exhaust lobes to be pressed into position on the hollow shaft. Locking pins are driven through the intake cam lobe assemblies. They pass through the slots in the hollow shaft and are pressed into the pin holes in the solid shaft, locking the intake lobes to the solid shaft. When the solid shaft is turned, the phaser can move the hollow exhaust camshaft between advance and retard positions vs. the solid camshaft, within the range allowed by the slots and the

solid pins that go through them.

The 500-rpm increase for peak horsepower was enabled by a number of changes that reduce valvetrain weight, including new valvetrain geometry. Although the intake valves are larger in diameter for improved breathing, the stems are hollow and shorter. The exhaust valve stems also are shorter.

Although the Viper engine displacement was increased from 8.3 to 8.4 L and the bore was increased from 102.3 to 103 mm (4.03 to 4.06 in), the objective was not the tiny increase in swept volume. The higher engine performance called for stronger reciprocating parts, particularly the connecting rod. With just the small bore change, the SRT V10 could take the already-available rod and piston assembly (with a floating wrist pin) from the 6.1-L SRT Hemi V8.

The V10 cooling system was upgraded with reshaped chambers for better flow, and two new two-speed electric fans that provide more airflow replaced the hydraulic fan.

Although the Viper SRT V10 VVT valvetrain now is the technology leader for cam-in-block engines, it's known that GM has a small-block V8 in development with variable intake- and exhaust-valve timing in a three-valve configuration. We may not see a four-valve pushrod gasoline engine, despite use of that valvetrain in diesel V8s. However, cam-in-block pushrod gasoline engines have a high-tech, high-performance future, and both Chrysler Group and GM keep engineering teams on the job of developing it.

Paul Weissler