E-Diesels Come of Age

Pending environmental regulations have triggered an avalanche of advanced diesel engine technology that promises far more than just clean-air benefits.

By Sven Donaldson

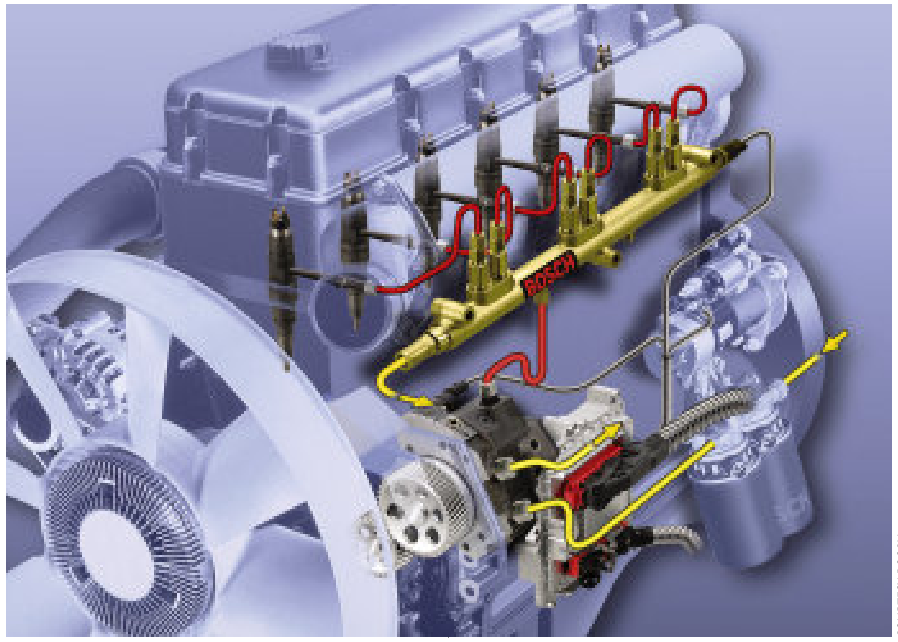
DESPITE THE GLOBAL REVOLUTION in electronics and computerization, many boaters still believe that a basic, naturally aspirating diesel engine with all-mechanical fuel injection remains the most reliable way to propel a vessel. After all, as the familiar arguments go, electricity and salt water are never a wholesome combination, and the more complex the machine, the more likely it is to fail.

No question, these are persuasive points, but they don't address the actual causes behind most diesel breakdowns. Problems with fuel and fuel delivery top the list, followed by mechanical failures caused by overheating, inadequate lubrication, salt intrusion and, in some cases, suboptimal combustion.

COURTESY VOLVO-PENTA

Electronically controlled diesels are becoming the standard for new builds. Qualms about reliability are a thing of the past, thanks to better production methods and quality testing (left).

COURTESY NORDIC TUG



COURTESY BOSCH

Common rail systems use one tube to feed fuel, pressurized to at least 18,000 psi, to all the injectors. This method provides excellent fuel atomization.

THE WAVE OF THE FUTURE IN diesel fuel delivery is the so-called common rail system.

Although the new generation of electronically managed fuel delivery and engine monitoring systems can't guarantee against every potential headache, it can certainly help in many critical areas. At the same time, electronic diesels are significantly cleaner, quieter and more fuel-efficient than their predecessors.

Naturally, marine diesel manufacturers are keenly aware of customers' misgivings about owning an engine that cannot run without its electronics, so they are going to great lengths to develop nearly "bulletproof" circuitry, often with built-in redundancy for key functions. Soon, the only new engines available will feature "clean diesel" technology that relies completely on electronic controls.

Of course, if boaters embrace this new technology as enthusiastically as they did the four-stroke and advanced two-stroke clean outboards, the industry has nothing to worry about. Since concerns most often stem from the unknown, a knowledge of the basics of electronic diesel management of today's advanced marine engines is essential.

Coming Clean Air Targets

Last May, the EPA announced a new Clean Diesel initiative for marine applications (visit www.epa.gov/). This future round of standards — while not yet cast in stone — will go considerably beyond the Tier II emissions requirements for new recreational marine diesels, slated to take effect between 2006 and 2009.

Boaters need not worry about the Tier II EPA standards with their next marine diesel because most engine manufacturers appear to be meeting them easily, and well ahead of deadline. This is happening because comparable on-road diesel emission standards have, in many cases, already kicked in, and because the Tier II standards can usually be met using in-engine technologies that transfer easily to the marine sector. These include refinements in engine design such as optimized combustion chamber design and variable valve timing, but, more significant, sophisticated electronic fuel delivery and engine monitoring systems.

Down the road, achieving tougher Tier III standards will depend first and foremost on a nationwide transition to ultralow sulfur diesel fuel — a crucial initiative that the Bush administration has, to date, staunchly favored. Low sulfur fuel not only reduces pollution directly, but also enables a variety of catalyzed, afterburn technologies that can virtually eliminate diesel particulate and nitrous oxide emissions.

The marine industry is concerned about bringing catalytic converters aboard because many of these devices operate at very high temperatures and are not easily reconciled with wet exhausts. On the other hand, a new generation of "low-temperature" catalytic soot filters is becoming available, as well as the distinct possibility that in-engine technology alone may progress enough to meet Tier III standards by 2011 — the earliest possible implementation date for the marine sector.

Some Diesel Fundamentals

Reciprocating diesels offer the best thermal efficiency and torque characteristics of any marine engines available, making them ideal for serious cruising under power. Their inherent efficiency results largely from a very high compression — typically an 18:1 ratio — which superheats the induction air charge and causes fuel to spontaneously ignite the moment it's sprayed into a combustion chamber. High torque results primarily because the relatively slow-burning diesel fuel sustains high piston force for the duration of each power stroke.

The chief downside of an engine that operates at very high pressures is that it makes much greater demands on mechanical components, such as pistons, connecting rods, crankshaft, piston rings and so forth. Heavy construction used to be the only answer, but in recent years enormous engineering effort has gone into developing "high-speed" diesels featuring lightweight moving parts to minimize inertial forces and vibration. Sophisticated engine designs and high-tech materials have not only created a new class of high-performance diesels, but also simultaneously have improved engine longevity for low- and midspeed boats.

True, most modern diesels are still considerably more costly than their gasoline counterparts, but given enough operating hours, they will easily pay off. And in many cases, issues of fuel economy and range make diesel the only viable choice.

Advanced Fuel Systems

The wave of the future in diesel fuel delivery is the so-called common rail system, which features a single tubular reservoir supplying all the injectors with fuel pressurized to at least 18,000 psi. A rotary gear pump feeds fuel into the common rail; the injectors are, in essence, simply fast-acting needle valves which open momentarily to support combustion as required.

Very high injection pressure is a prerequisite for any good diesel fuel delivery system because forcing fuel through a tiny nozzle at extreme velocity achieves superior fuel atomization and, ultimately, a more complete burn.

By contrast, the unit injectors still found on most contemporary diesels are compact, high-pressure piston pumps that must not only meter the fuel, but also boost it to the required high injection pressure within a very brief time interval. Like an engine's intake and exhaust valves, most mechanical injectors are actuated by a straightforward cam system.

More recently, howerver, a new generation of hydraulically or solenoid-actuated injectors featuring computerized controls has been introduced. These so-called electronic unit injectors allow more accurate control of fuel delivery as well as allow high injection pressures to be maintained at low engine revs.

The most sophisticated versions have a "double action" feature, which delivers an initial pilot injection to start the burn and induce turbulence within the combustion chamber. The main fuel charge, coming a split second later, can then burn more completely.

The common rail diesels go a step further because their injectors need only meter the fuel and, hence, can cycle much faster than unit injectors. Indeed, with a common rail system, it's feasible to have anywhere from three to 10 injection events during each power stroke. Both the staccato sound of the injectors themselves and the familiar

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In common rail systems, fuel injectors are little more than electronically controlled, fast-acting needle valves.

rattle associated with percussive diesel ignition are virtually absent in today's common rail engines.

The extended burn improves torque and fuel efficiency, yet reduces nitrous oxide emissions by preventing peak combustion temperatures from spiking too high. In addition, common rail diesels are automatically self-bleeding because any air bubbles in the fuel are pushed harmlessly out through the injectors.

Feedback and Monitoring

Diesels with electronic fuel injection, whether unit type or common rail, can fine-tune fuel delivery parameters far better than the all-mechanical systems ever could. With today's clean diesel technology, a broad range of engine operating parameters now figures into the fueling equation, including fuel and ambient air temperature, turbo boost pressure, rpm, cylinder head tempera-

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Tier II-compliant diesels optimize burn by incorporating data such as temperature, rpm and turbo pressure to the fueling equation and adjusting as needed.

ture and, in some cases, combustion chamber pressure. The latter can be monitored by installing a new type of glow plugs, which become pressure probes once their usual role as cold-starting aids is finished.

Most Tier II-compliant diesels are turbocharged, usually as much to cut down emissions and fuel consumption as to increase maximum power. Pre-compressing the induction air before it enters the cylinders is the simplest way to ensure that enough oxygen is always available to achieve as close to a 100-percent fuel burn as possible.

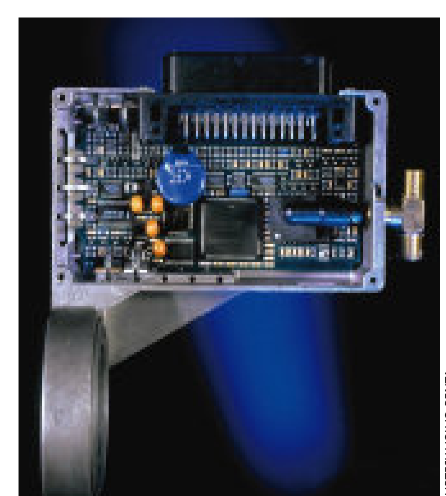
Unlike gas engines, which require about a 15:1 mixture of air and fuel to ensure reliable spark ignition, diesels run just fine on extremely lean mixtures. This means that diesels' turbocharging is effective across the entire rpm range, not just at the higher speeds normally associated with car engine turbos.

To deliver more uniform boost pressure at all engine speeds, a growing number of diesels are equipped with two-stage turbochargers or units with variable-geometry vanes. Turbo function can be monitored and, in some cases, controlled electronically. The same applies to charge air cooling (intercooling), typically used in conjunction with turbocharging to maximize the density of the induction air supply.

Besides providing feedback for optimizing normal engine functions, having an array of electronic sensors linked up to a computer control module is an invaluable aid for diagnosing problems, hopefully in time to avoid engine damage. In some cases, diesel manufacturers and electronics engineering firms have developed universal computerized diesel control systems capable of managing any electronic engine, whether unit injected or common rail. Detroit Diesel pioneered this in-field, introducing their first generation DDEC systems nearly 20 years ago. Today, all the major international players offer comparable electronics platforms.

Just as in the automotive field, there's a growing trend for marine manufacturers to adapt what is known as CAN-bus technology, because it saves money and greatly simplifies installations. The acronym stands for Control Area Network, and the term "bus" is used to describe a straightforward, single-cable arrangement that permits not only engine-related equipment, but also all onboard electronics to be daisy-chained into a comprehensive, integrated system.

Examples of marine CAN-bus technology are Volvo Penta's EVC™ (Electronic Vessel Control) and the generic MagicBus™ system by marine control specialist Teleflex Morse. Cummins MerCruiser diesels use the SmartCraft™ integrated control system developed by Mercury Marine. To



COURTESY VOLVO-PENTA

Electronic control modules are being built tougher to withstand the rigors of marine applications, and more often than not have redundant backups.

counter the widespread perception that engine electronics represents a weak link, most manufacturers have developed rugged systems that will shrug off submersion, salt spray, temperature extremes, shock, vibration and intense magnetic fields.

A Win-Win Scenario

The latest electronic diesels, particularly the common rail models, are incredible performers on the water. For starters, visible smoke is either minimal or completely eliminated, even when a heavily loaded boat is given full throttle from a dead stop. The new engines are also significantly quieter and smoother than their predecessors. Better yet, their power, torque and throttle response are as good as if not better than ever.

Not surprisingly, the more sophisticated technology does have an impact on engine price, even though the manufacturers have obviously absorbed the lion's share of their research and development expenses in an effort to field cost-competitive products.

On balance, however, buyers who select EPA Tier II diesels before the upcoming deadlines can take heart that they are not only doing a good turn for the environment, but also getting superior engines.

New Developments in E-Diesels

Caterpillar began producing marine diesels with full-authority electronics in 1994, and is now on its third generation of computerized engine controls. The company champions proprietary unit injectors known as HEUI (hydraulically actuated electronically controlled) as a superior alternative to common rail fueling. Cat diesels are highly respected and popular with the big-boat crowd, but lately the company has also tackled the small-to-medium diesel market with some sophisticated new models. Latest is the C7 series, a 7.2-liter in-line six that can churn out up to 460 hp.

Cummins Mercruiser is a recent 50-50 joint venture for building and marketing marine diesels, but Cummins has long offered electronically controlled marine engines based on its advanced truck diesel technology.

Under the Cummins Mercruiser banner, it has debuted two common rail marine diesels: the QSC8.3, which delivers up to 540 hp, and the QSC5.9 for up to 380 hp, depending on application. The company is bullish about

Cummins Mercruiser QSC

common rail technology, so look for more new product announcements before long.

Detroit/MTU is now a U.S./German partnership under the umbrella of parent company DaimlerChrysler. Its well-known DDEC electronic diesel management system has gone through numerous iterations and now delivers comprehensive engine controls and diagnostics, along with direct, fly-by-wire-style control of the entire drive train.

The Detroit/MTU Series 60 and Series 2000 engines (350 hp and up) utilize electronically controlled unit injectors, but the big Series 2000 engines are common rail designs. With either approach, the company is comfortably meeting EPA Tier II emission standards.

John Deere, best known for its farm machinery, recently gained a significant foothold in the marine diesel market, particularly among small commercial boats and trawler yachts. The company now offers, under its PowerTech trademark, four lines that achieve Tier II ratings, covering a broad power band from 80 to 526 hp. Their 8.1-liter 6081 model is a common rail design; the other PowerTech lines utilize either electronically controlled rotary fuel injection or electronic unit injectors.

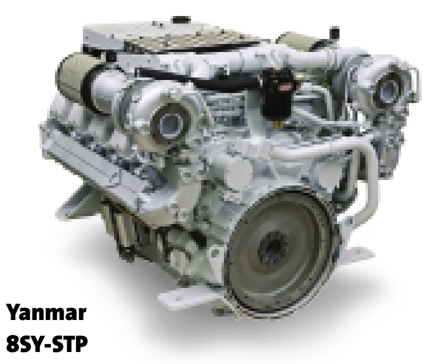
Lugger Alaska Diesel Electric introduced its first electronic diesel in 2004, the L1276A, in power classes from 340 to 425 hp. Like its other engines, this model is a conservative design that delivers its rated output at modest speeds of 1,800 to 2,100 rpm. The electronic control system, two-stage unit injectors, four-valves-per-cylinder head and other features enable it to reach EPA Tier II standards. However, most buyers will continue to choose this brand primarily for its easy-maintenance designs and rugged reputation.

Volvo Penta leads the marine industry in bringing common rail diesel technology to market, having launched three new engine lines in 2003. The D4 (3.7 liters, up to 260 hp) and D6 (5.5 liters, up to 370 hp) were engineered from the ground up specifically for seagoing applications. The hottest versions of both now feature supercharging and turbocharging to maximize low-end torque. The lightweight aluminum D3 (2.4 liters, up to 160 hp) is based on an advanced five-cylinder automotive design.

Volvo Penta also offers numerous electronic diesels featuring electronic unit injection, the most recent being the D9 (9 liters, up to 545 hp). All Volvo Penta electronic models employ the company's proprietary EVC computerized control, monitoring and diagnostic system.

Steyr, while still a bit player in the North American market, is an innovative Austrian company that produces some of the lightest, most technologically advanced small diesels available. Its diesels feature a unique monoblock architecture, meaning the cylinder head and block are fabricated as a single unit to reduce weight, improve cooling and eliminate head gaskets. An electronic engine management system controls fuel delivery via two-stage, ultrahigh-pressure injectors. Engine performance data can be streamed to a laptop computer if desired. Steyr diesels are available in four- and six-cylinder models from 85 to 265 hp.

Yanmar marine diesels are still mostly the all-mechanical type, although a number are refined enough to achieve Tier II emissions standards. A recent partnership arrangement with Scania of Sweden has augmented the product line, giving Yanmar a foot in the electronic-diesel door with its big 6SY-STP720 (11.7-liter, 720-hp) and 8SY-STP (16-liter, 900-hp) engines. Both feature comprehensive electronic engine management systems and electronic unit injectors. Like other Yanmars, they are among the lightest diesels in their respective power brackets.



Yanmar 8SY-STP