Eye On Electronics

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Diesel engines offer a clear fuel economy advantage, but reducing their emissions has been a significant challenge. Even the smallest parts can play an important role. In this case it's the glow plugs.

Rudolf Diesel invented his engine in the 1890s as a way to help independent craftsmen compete with large industries. Its very high compression gave it a very high thermal efficiency. Steam engines in use at the time converted about 10% of their fuel into usable energy. The high-compression, slow-burning diesel engine was as much as 50% efficient in the conversion of fuel into energy.

Efficiency is still the ace card for today's modern clean diesel engine technology. The diesel process in use now can be as much as 30% more efficient than comparable gasoline engines. More importantly, advanced technology has made them just as clean-burning as their gasoline-fueled counterparts. Diesels still cost more to build, but the energy savings will pay for that.

The downsides to the diesel engine are well known. To handle all that compression creates a need for stronger and heavier blocks and crankshafts that cost more to build. The timed injection of the fuel into the high heat and high pressures of the diesel combustion chamber is also costly. The original diesel engines were mostly stationary engines for factories or shipboard/locomotive engines where size and weight didn't matter much. The early diesels were known to be noisy, smelly, hard to start and a significant source of pollution.


Illustration courtesy Beru, Inc.

The pressure sensor glow plug shown here does more than just add heat to the mixture. It monitors the pressure in the combustion chamber in real time as an input to the engine control computer.

In the last 20 years, significant development in electronic controls has turned the ugly duckling diesel into something of a swan. At the heart of this are starting and emissions systems based on electronic controls, actuators and software.

The Beru Corp. is a German company that specializes in diesel cold starting systems. Its website (*www.Beru.com*) includes a number of technical papers that talk about glow plugs, instant starting systems with glow plugs and the effects glow plugs can have on engines in terms of emissions and fuel consumption.

Glow plugs get their heat from the battery in the form of electricity. This added demand on the battery comes at just about the worst time. At the same time the engine needs glow plug heat, the battery also has to supply power to crank the engine. Like all DC motors, the starter's speed is voltage-dependent. As the battery voltage sags under the load, the cranking speed slows down, giving the compressed air even more opportunity to cool off, hindering combustion.

There are a number of things the glow plug needs to do. Since most people expect instant starting like with gasoline, the faster the glow plug can light up and provide the needed heat, the better. Glow plugs also need to have sufficient glow volume. The glow plug must have enough mass so that moving air and turbulence cannot cool it off. A system of thermal regulation is needed to keep the temperature constant even though the forces trying to pull heat from the glow plug are variable.

The glow plug must be properly positioned. Beru says that the plug tip should be located precisely at the edge of the mixture turbulence. It has to be positioned deeply enough into the chamber to do its job, but not interfere with the flow and turbulence of the air and/or the fuel injection.

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There are challenges that come with this precise glow plug positioning. The area of the combustion chamber is already crowded with valves, piston crowns, injector nozzles and the like. When the engine design has four valves per cylinder, there's not much room left for the glow plug. This adds the requirement that the glow plug be long and skinny.

Controlling the power to the glow plugs can be handled in at least two ways. The current draw to each plug could be in the range of 7 to 15 amps. This can be switched by individual solid-state drivers such as MOSFETs. These devices can be directly controlled from the computer's logic level signals in response to the software that's trying to manage and minimize the current draw from the battery.

Relays are used when all of the glow plugs are to be turned on at the same time. The total draw in some systems can be hundreds of amps, and the solid-state drivers needed to handle that much current would be too expensive to be practical. The relays are not so happy with these currents either, and can become high replacement and/or wear-prone items.

The goal of the software management of the glow plugs is to make sure the heat is delivered where it's needed, at the time it's needed, for the shortest possible time. Beru says its glow plug tips can heat to 1000°C so quickly that the engine can reliably start within 2 to 5 seconds at –30°C. And it's not only the glow plugs involved here. To make its Instant Start System (ISS) work correctly requires optimization of the fuel injection point and the fuel injection quantity. The glow plug must also have the correct heating capability for the application and be located in exactly the right spot.

The job of the glow plug is not complete once the engine starts. During the warm-up phase of the engine start cycle, emissions performance (carbon particulates) can be improved by as much as 40% by keeping the glow plugs in action. The management of the heating added during this phase is under computer control. For typical applications, the glow plugs will still be adding heat as long as 3 to 4 minutes after start-up. Generally, the glow plugs are off by the time the coolant temperature hits 70°C.

Beru says that when the engine is running, the glow plugs can be cooled by the charge cycles and the air movement that occurs during the compression phase. The temperature of the glow plug will go down with increased speed (given a constant applied voltage). As more fuel is added, the glow plug temperature will rise (assuming a constant voltage and speed). The electronic control unit can compensate for these effects. Under electronic control, the glow plugs are always supplied with just the right power for the engine operating circumstance.

The added operational time on start-up for the glow plugs is particularly effective against the white or bluish smoke that often occurs during the start-up and warm-up phases. These noticeable emissions are caused by incomplete combustion of the fuel due to the temperature being too low. The post-heating helps the fuel burn more completely, resulting in a 40% or more reduction in the smoke. This post-heating also helps reduce diesel rattle and knocking—noises due to uneven burning of the diesel fuel that results in sudden pressure pulses. Post-heating of the combustion chamber by the glow plugs is a major factor in solving longtime diesel problems.

According to Beru, the basic principle of how the glow plugs works is based on two coils hooked in series and located inside the ceramic of the glow plug body. The smaller heating coil is made of a high-temperature-resistant wire. The resistance of this coil is largely independent of its temperature. It's this wire and the ceramic or metal that holds it that actually light up and create the "heating" zone at the tip of the glow plug.

The second, longer regulator coil is very temperature-dependent in terms of its resistance. Current fed to the heating coil first has to pass through the regulating coil, which also is warmed by the heating coil. As the two sources of heat warm the regulating coil, its resistance increases, lowering or reducing the current flow to keep the heating coil from getting too hot and burning out.

The glow plugs live in a hazardous neighborhood. Having electronic controls in charge of the plugs means that individual glow plug diagnostics are possible. In the ISS system, the current in each glow plug can be monitored. If there's trouble, the computer can tell you about it.

There's one more feature worth mentioning. What would help the engine control system do its job is to know the actual pressure, in real time, in the cylinder. This would allow the computer to make more accurate injections in terms of quantity, EGR rates and the injection point.

The glow plugs are in exactly the right spot to make that measurement. Beru's developers have integrated a piezoresistive pressure sensor in the glow plug body. The heating rod is not rigidly pressed into the glow plug housing, but rather is allowed to move against the pressure sensor element located safely at the rear of the glow plug. The net result is that the glow plug becomes a sensor that greatly improves the computer's ability to control the combustion process. M