The typical open-housing design of an exhaust sensor. Mounting restrictions are similar to those of oxygen and NO_x probes and the sensor tip must be oriented downward to allow condensates to drip out.

RESISTIVE SENSORS FOR DPFS

With on-highway emissions regulations calling for onboard diagnostics, monitoring of aftertreatment systems brings new challenges

BY ROBERTA PRANDI

Onboard diagnostics (OBD) are a critical aspect in making sure that emissions control components in diesel engine systems are operating properly. OBD is performed using sensors that communicate directly with the engine control unit. In diesel particulate filters (DPF), aftertreatment devices broadly used in both on- and off-highway engine applications, the separation efficiency and regeneration processes are usually monitored with pressure sensors that primarily measure exhaust backpressure.

Yet monitoring exhaust backpressure isn't sufficient to truly determine whether or not the DPF is operating properly, said Stefan Carstens, general manager of EngineSens Motorsensor, a German manufacturer of sensor technologies for engines and machines.

"In silicon carbide filters the extruded components tend to tear apart at the connection points," Carstens said. "Also, fractures of individual canals in cordierite filters cannot be discovered with pressure sensors alone."

For these reasons, many manufacturers of on-highway vehicles have been searching for an economic and easy-to-install particulate filter sensor technology. "Lately resistive sensors are being implemented by several suppliers as the best solution to address OBD needs as per LEV-3 and Euro 6-2 regulations," Carstens said.

Particulate matter is formed with a coal nucleus, around which layers of hydrocarbon chains deposit themselves, depending on the combustion process. Higher injection pressures form smaller hydrocarbon fragments that contribute to compose the deposits. Abrasion particles from the engine combustion chamber and engine oil residues can also adhere to the particles.

"The compactness of soot particles from high-pressure systems is tricky, as it is not visible in the raw exhaust gas," Carstens said. "But these very small particles are considered carcinogenic, since they can be breathed and pass directly into the lungs of human beings."

The particles also tend to stick together and collect in larger clots, which can absorb moisture and become heavier. The challenge for particulate filters is to detect both the bigger agglomerates and the nano particles.

"In the presence of oxygen, the coal nucleus of soot particles burns from a temperature of about 550°C," Carstens said. "When an additive is used to trigger the oxidation, the burning temperature is reduced to about 450°C.

"An even better oxidation is achieved with nitric dioxide rather than oxygen — in fact this gas created inside a diesel oxidation catalyst (DOC) can further reduce the oxidation temperature to 260°C.

"This is a very important factor to consider, when the particulate sensor needs to be equipped with a pyrolysis function."

The electrical conductivity of soot particles depends on their structure and on the temperature, he added. "Maintaining temperature between 200° and 450°C brings to reproducible measuring conditions, with a more accurate measuring result," Carstens said. "These conditions can be realized with a low-ohmic resistance heating structure — that is for example, using a platinum thread which, thanks to its properties, allows a precise regulation."

According to Carstens, the construction of such sensors is very similar to that of a thin-film temperature resistor. The basis is an alumina-oxide

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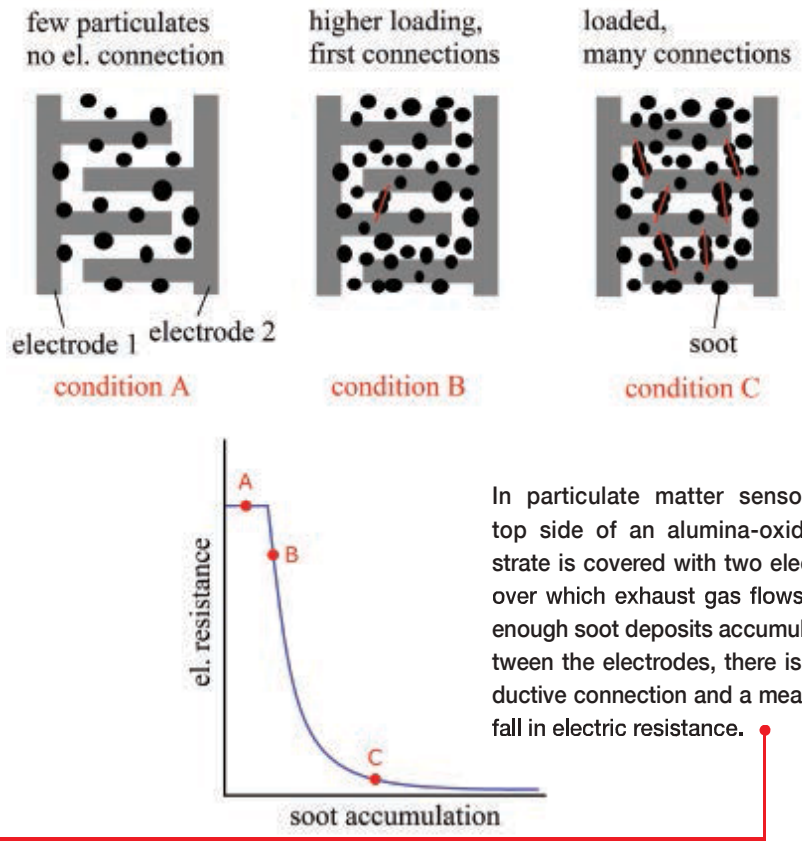

In particulate matter sensors, the top side of an alumina-oxide substrate is covered with two electrodes over which exhaust gas flows. When enough soot deposits accumulate between the electrodes, there is a conductive connection and a measurable fall in electric resistance.

substrate and on the bottom side of the substrate is added a platinum thread that works as a heating element and is passivized by a sealing layer.

The opposite side of the substrate is covered with two electrodes that can have a brush structure or be designed as intertwined threads. "For the electrode material, it is important to consider a good electrical conductivity, but at the same time a high resistance to the peak temperatures reached by the exhaust gas," Carstens said. "Here too, platinum seems to be a good choice."

Exhaust gas passes over the electrode side of the sensor, but there is no conductive connection between the electrodes until soot deposits are formed. "Only when enough particles build up between the electrodes, forming conductivity, the electric resistance falls," Carstens said. "With more particle build-up, the resistance decreases further although not too sharply. The signal is similar to that of a negative temperature coefficient resistor."

A DPF is regenerated when the backpressure in an exhaust gas system increases above a set limit value. To regenerate, the temperature of the exhaust gas is increased above the ignition level of the particles.

"During the regeneration, the emissions of CO_2 increase as well as those of nanoparticles which influences the signal of the particulate matter sensor," Carstens said. "In order to avoid this situation, it is preferable to clean the sensor with pyrolysis during filter regeneration.

"The heating thread at the bottom of the substrate heats up the substrate above the burning temperature for the particles which are then oxidized, leaving a cleaned surface."

Following that pyrolysis, particles will again build up on the electrode side of the sensor. Research has shown that particles adhere better to flat surfaces rather than rough, Carstens said.

"For a better build-up of soot particles on the sensor surface it is also decisive that a laminar flow of the exhaust gas and a catalyst can have a positive effect on that," he said. "Besides that, the temperature profile is also relevant for an ideal mounting location.

"High temperatures above 500°C accelerate the oxidation of soot and the presence of NO_2 accelerates the oxidation process even more at lower temperatures of around 260°C. These oxidation processes are negative for the accumulation of soot on the sensor."

According to Carstens, the optimum mounting location for a particulate sensor can be determined based on the laminar flow, a uniform distribution of soot over the cross-section, low NO_2 concentration and a temperature exposition below 400°C.

"Due to these frame conditions, an ideal location is right behind an SCR (selective catalytic reduction) catalyst," Carstens said. "In this section, the NO_2 has been converted to N_2 and vapor and the urea mixer ensures a good uniform distribution of the complete exhaust flow. Also after the catalyst brick the flow is mostly laminar and temperature is rather moderate."

Carstens said that market introduction of resistive soot sensors first took place in the U.S.A. in clean diesel cars. It can be foreseen, Carstens believes, that the sensors will also become an important part of the exhaust monitoring system for stationary and heavy-duty machinery. Bosch, Conti, Sensata, Delphi, Electricfil and other manufacturers are working on this sensor approach.

A seminar, "Sensors in Exhaust Gas Emission Control," will deal with sensors and present some of the most recent solutions. Organized by SV-Veranstaltungen, it will be held July 2-3, in Frankfurt, Germany.

Several presentations will deal with all sensors used in purification systems of combustion engines such as oxygen sensors, NO_x probes, urea quality and gas temperature sensors.

More details are available at www.sv-veranstaltungen.de/en/international-congress-sensors-in-exhaust-gas-emission-control. dpi

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