

New Particulate Matter Sensor for On Board Diagnosis

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ABSTRACT

The reduction of greenhouse gas is becoming increasingly important for humankind, and vehicles with low CO₂ emissions have a part to play in any reduction initiatives. Diesel engines emit 30% less CO₂ than gasoline engines, so diesel engines will make an important contribution to the overall decrease. Unfortunately diesel exhaust gas contains particulate matter (PM) which may cause health problems, and such PM emissions are regulated by law. In order to reduce PM, especially soot, diesel particulate filters (DPFs) are widely fitted to diesel vehicles. A DPF can remove more than 99% by weight of soot from exhaust gas under normal operating conditions, and they are one of the most important methods to achieve any regulation targets. But if the system malfunctions, the PM emissions may exceed the regulation limit. To detect such PM leakage, on board diagnostics (OBD) are required.

In the real world vehicles are used in a variety of different driving situations and the total amount of PM relates to both the PM concentration and operating time, for example, urban driving with long journey times, and short bursts of high speed driving, both have an important impact on our environment. An OBD needs to perform at not only higher soot concentrations but also at lower soot concentrations.

Therefore, a new direct detection sensor, mainly made of ceramic materials has been developed to detect lower soot concentrations. Particulate collecting electrodes, sensing electrodes and heaters are all built-in and have been designed to give highly effective collecting and sensing of the amount of soot in exhaust gas. As the sensing method is less influenced by particulate conductivity, this sensor can detect lower soot concentrations in the New European Driving

Cycle (NEDC) mode and the Federal Test Procedure (FTP) mode.

INTRODUCTION

Diesel particulate filters made of Si-C ceramics or cordierite have been widely used in diesel vehicles to remove PM from vehicle exhaust gas and to help meet existing legislation. OBD II in US2013 and EURO6 require monitoring of the DPF system for malfunctions that may cause the tailpipe PM emission to exceed the regulated levels. This monitoring and diagnosis has to be performed on board. In accordance with EURO5, the delta pressure sensor has been used not only for DPF regeneration control but also for OBD purposes because the detection limit for EURO5 is ten times the regulation limit. At this level, precise sensors which can measure low-concentrations of PM directly in the exhaust pipe are not necessary for OBD purposes.

But the proposed EURO6 requires the monitoring of two times the PM regulation threshold, and 1.75 times the PM regulation threshold for OBD II in US2013. This means that the EU and the US commission will enforce strengthened OBD regulations. [Figure 1](#) shows the legislation of the OBD thresholds in the EU and the US.

Several kinds of PM or soot sensor have been proposed to detect PM or soot directly, e.g. the resistive type which measures soot conductivity [1] [2], the single pole type which measures transient electrical signals in the exhaust flow, and the two pole type which have a similar structure to a spark plug, etc.

The proposed sensor in this paper is still in the development stage but presents the possibility of measuring low PM

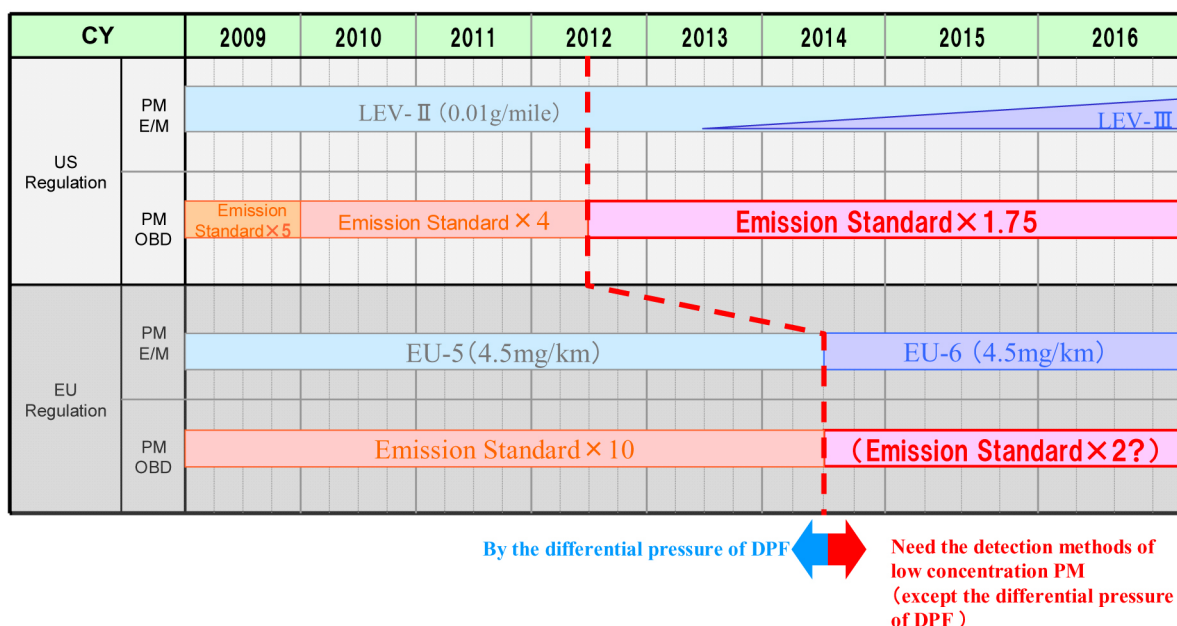


Figure 1. US and EU legislation of OBD thresholds

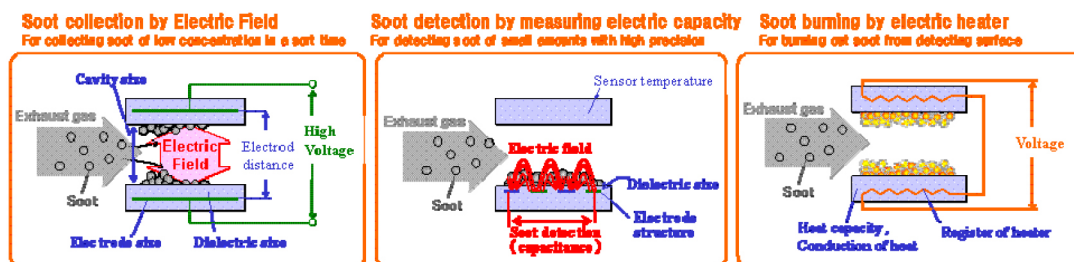


Figure 2. Sensor operation stages

concentrations in both the NEDC and FTP modes. Firstly, this paper explains the basic mechanism of PM forcible collection by means of an electric field, a sensor structure, a sensor electric circuit, and the correlation between PM concentration and capacitance values of the sensing electrode. Then the OBD performance in NEDC and FTP modes with a prototype sensor is presented. Secondly, the approach to improve the sensitivity of this prototype sensor, and its sensitivity improvement in the NEDC mode is explained. Finally, in conclusion, the summarized performance of this proposed sensor is given.

BASIC CONCEPTS OF THE PM SENSOR

This is the basic concept of the proposed PM sensor. The head of the sensing element is inserted into the exhaust pipe in the same way as an oxygen or temperature sensor.

The proposed sensor detects the accumulation of soot. To detect the amount of soot, the sensor operates cyclically and

in three sequential stages (Figure 2). In the first measurement stage, soot is forcibly collected using an electric field and a thin soot layer is formed on the surface of the detecting electrode. In the second stage, soot is naturally accumulated and detected by measuring electrostatic capacitance changes. In the third stage, the accumulated soot is burned using a heater and the sensor returns to the first stage of the measurement.

FEASIBILITY STUDY OF PM AMOUNT DETECTION

The following figure shows the test conditions for a feasibility study of soot detection. Exhaust gas containing PM was generated by a 2.2L 4-cylinder turbocharged diesel engine. The PM concentration was changed by equipping the engine with a DPF with plugs removed to control the PM amount at the bottom of the DPF (Figure 3). The sensing unit is the white box-shaped ceramic block inserted into the downstream side of the DPF. It has removable sensing electrodes. The amount of PM adhesion by weight can be

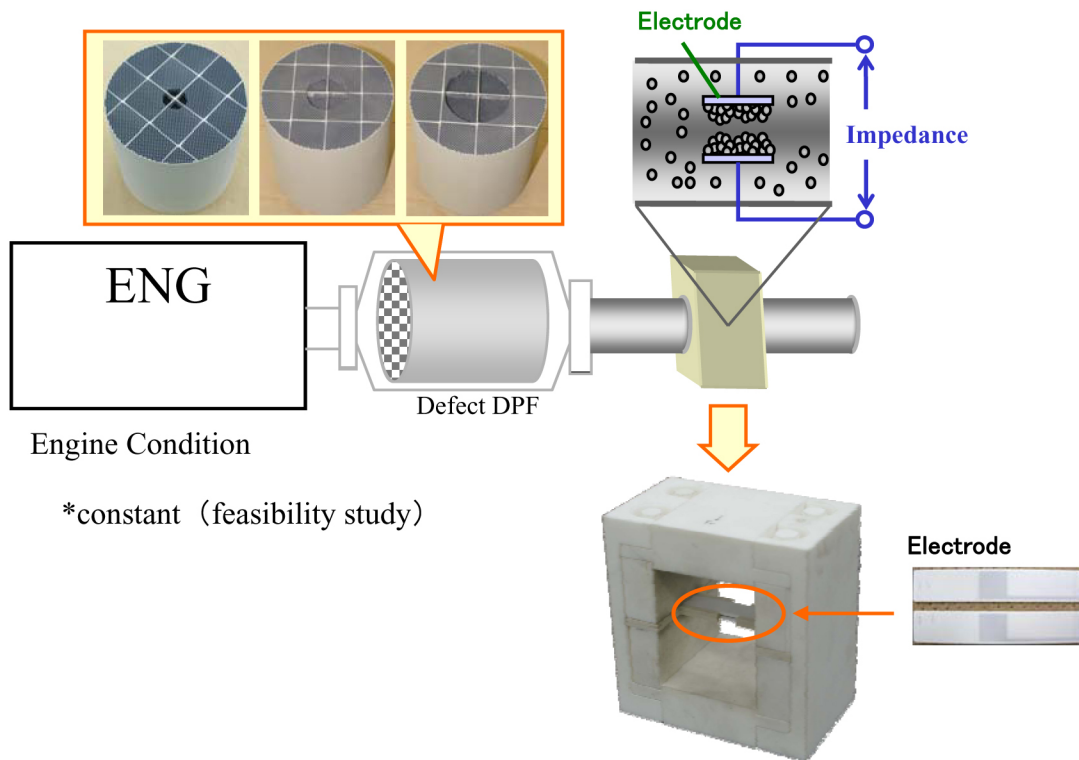


Figure 3. Feasibility test conditions of the detection method

precisely measured by removing these electrodes from the block and measuring their total weight.

This method is useful for the fundamental study of soot detection, but the same method is not applicable to the actual OBD process. Therefore, measuring the impedance between the electrodes was considered as an alternative method of measuring the amount of deposited PM. The deposited PM can be simulated by the capacitance and the resistance in the equivalent circuit (Figure 4).

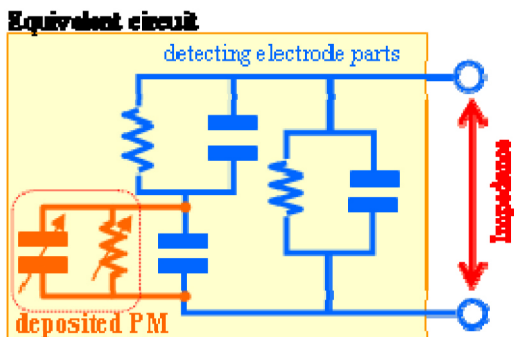


Figure 4. Equivalent circuit of measuring electrodes

A preferred detection method would be independent of temperature because the exhaust gas temperature varies widely throughout the driving cycle or according to driving modes. For a PM accumulation type sensor like this, changes

in measured values have a strong influence because they indicate two possibilities: that the total volume has changed or that the total volume has not changed, but conditions have changed. Figure 5 shows the temperature dependency of the capacitance and resistance measurement of the PM adhered to the electrode. The PM was already deposited on the detecting electrode and the temperature of the detecting electrode was changed using an electric heater. The capacitance measurement shows weaker temperature dependency than the resistance measurement. The capacitance measurement is therefore suitable for measuring the PM amount. Furthermore, the capacitance measurement has a potential for the self-diagnosis of sensor electrode's snapping.

FORCIBLE SOOT COLLECTION EFFECT

Tests were performed at 1500 rpm / 80 Nm engine with defected DPF at a high PM concentration of about 20 mg per cubic meter. To establish comparison with other methods, the forcible soot collecting method was not initially used. Figure 6 shows typical time series data of capacitance changes due to natural soot adhesion.