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Inline Quality Monitoring of Diesel Exhaust Fluid (AdBlue) by Using the 3ω-Method

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Summary:
Quality monitoring of diesel exhaust fluid is crucial for optimal selective catalytic reduction in diesel combustion processes. This article presents a platinum thin film sensor using the 3ω-method to characterize the diesel exhaust fluid. The results show that this sensor can determine the urea content with in 1 % by weight. An inline measurement is well applicable because the same structure can be used for both concentration and flow measurement.

Keywords: Diesel exhaust fluid, AdBlue, 3ω-method, quality monitoring, platinum thin film

Motivation and Background

The reduction and the control of pollutants produced by burning fossil fuels are a focus of governments and health organizations. The selective catalytic reduction (SCR) is an after-treatment method in diesel combustion processes to convert harmful detrimental nitrous oxides (NO_x) into nitrogen and water. Diesel exhaust fluid (DEF), also known as the registered trademark “AdBlue”, is needed for the SCR process and consists of 32.5 % by weight of urea and 67.5 % by weight of deionized water. The concentration of the urea is crucial for an optimal SCR. Inappropriate DEF brakes the SCR or breaks it down and the emission reduction fails.

Reported DEF quality sensors are based on optical principles [1], electrical [2] and pulsed heating measurements [3]. The sensor presented in this article uses the 3ω-method to determine the concentration of urea in DEF.

Method

The claims of this paper are: (1) The 3ω-method is used to determine the concentration or urea in DEF. (2) The resolution of the sensor is 1 % by weight. (3) The sensor is suitable for inline measurements e.g. in vehicles.

The 3ω-method is a well-known method to measure thermal conductivity and heat capacity [4]. This principle uses a metallic resistor which is driven by an AC-current with angular frequency ω. The resistor heats up by Joule heating and has an AC-component at frequency 2ω which acts as a thermal wave. The propagation of this thermal wave depends on the thermal characteristics of the surrounding. If the resistor has a defined temperature-to-resistance behavior, the resistor is then also modulated with 2ω. Therefore, the voltage across the resistor has a term $V_{3\omega}$ at frequency 3ω and is dependent on the thermal characteristics of the surrounding.

Experiment and Results

The used sensor (shown in figure 1) bases on platinum thin film technology. The platinum thin film element is processed on a zirconia substrate by standard MEMS processes. The resistor is designed as a 45 Ω at 0 °C resistance with a temperature-to-resistance coefficient of 3900 ppm/K.

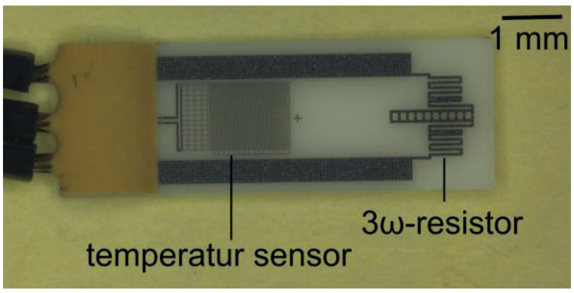

Figure 1: Sensor design: Platinum thin film element on a zirconia substrate. The 3ω-resistor has a resistance of 45 Ohm at 0 °C with a temperature-to-resistance coefficient of 3900 ppm/K. A temperature sensor is also located on the element for further investigations.

The setup of the measurement is designed as a digital lock-in amplifier and allows phase sensitive measurements. A current amplitude of 30 mA is applied for the presented measurements.

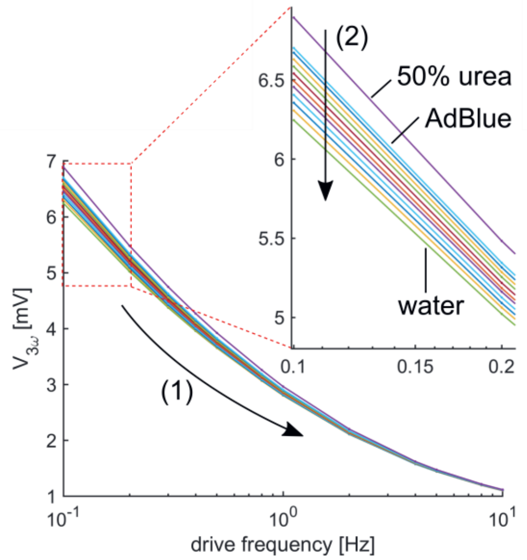

Figure 2: Voltage amplitude $V_{3\omega}$ as function of drive frequency for different urea-water concentrations. (1) The amplitude $V_{3\omega}$ decreases for increasing frequency. (2) The amplitude $V_{3\omega}$ increases for increasing urea amount.

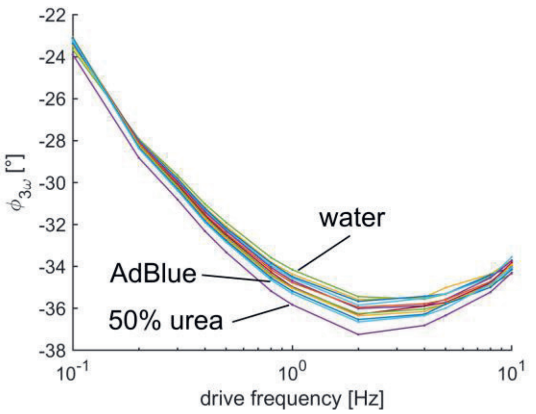

Figure 3: Phase $\Phi_{3\omega}$ as function of drive frequency. The urea concentration is mainly resolvable at a frequency range between 0.2 Hz and 3 Hz.

The 3ω-method is used to characterize mixtures with different urea-water concentration between 0 % by weight and 50 % by weight with respect to urea for frequencies between 0.1 Hz and 10 Hz.

Figure 2 shows the voltage amplitude $V_{3\omega}$ as function of drive frequency. First, the amplitude decreases for increasing frequency. The reason is the smaller penetration depth of the thermal wave (~ $1/\sqrt{\omega}$) [4] and a smaller thermal response result. Second, the amplitude increases for increasing amount of urea. Mixtures of different urea amount are clearly distinguishable for frequencies below 1 Hz. The best resolution is at a drive frequency of 0.1 Hz.

Figure 3 shows the corresponding phase of the 3ω-signal. The urea concentration is best resolvable at frequency of 2 Hz which is different compared to the amplitude. Further investigations have to be done to find the reason. The lock-in amplification may need some adjustments. However, an advantage is that the phase is in first order independent of the current amplitude and the temperature-to-resistance coefficient. This point can be important for applications because it can simplify fabrication processes and calibration procedures.

The amplitude $V_{3\omega}$ as function of urea concentration at 0.1 Hz is shown in figure 4. It is clearly visible that the amplitude increases for increasing urea concertation. Pure deionized water has the smallest amplitude whereas the amplitude at 50 % by weight has the highest amplitude. The reason is in first order the decrease of the thermal conductivity. The concentration resolution is at 1 % by weight. The measurement error is evaluated by multiple measurements. Therefore, the 3ω-method is suitable to monitor the quality of the DEF in a diesel combustion process.

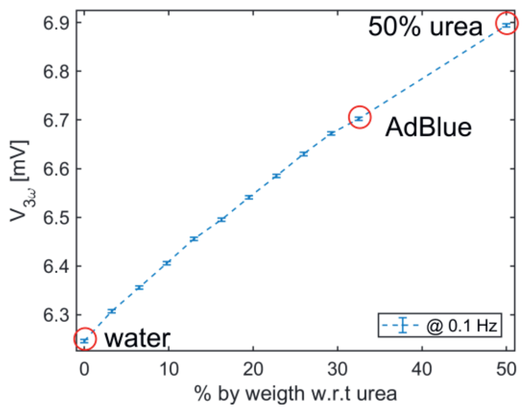

Figure 4: Voltage amplitude $V_{3\omega}$ as function urea with respect to weight.

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