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Ultrasonic Sensor System for Water Localization in Fuel Cells: Investigation of Operational Conditions

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Summary:
Water management is important for an efficient operation of proton exchange membrane fuel cells (PEMFCs). In particular, accumulation of liquid water in the flow channels must be prevented to ensure uniform distribution of the reactants and consequently high performance of the cell. It has been shown in ex-situ experiments, that liquid water drops on the flow field can be localized using ultrasonic guided waves. In this contribution, we show that temperature is the major influence on the measurement. We also demonstrate that the influence of temperature can be reduced by tracking the signal baseline with the temperature.

Keywords: ultrasound, guided waves, fuel cells, water management, temperature compensation

Introduction

Proton exchange membrane fuel cells (PEMFCs) are a key technology for hydrogen-based power generation. During operation, hydrogen is supplied on the anode side of the cell where it is catalytically split into protons and electrons. Protons permeate through the proton exchange membrane to the cathode side, where they react with oxygen and electrons from the outer electrical circuit to produce water. Due to operating temperature below 100 °C, the water can be liquid. Water management is necessary to prevent flooding of the oxygen flow channels on the bipolar plate as well as drying of the proton exchange membrane. Various techniques have been applied in this context to measure and visualize liquid water in PEMFCs [1]. These techniques typically require a large experimental effort and are limited in terms of integration in operating PEMFC stacks. Sensor systems based on ultrasonic guided waves could be beneficial in this regard. In this study, we investigate the influence of changing environmental and operational conditions on such a sensor system.

Sensor system for water detection based on ultrasonic guided waves

To detect and localize liquid water in a PEMFC, piezoelectric wafer active sensors (PWAS) can be used to excite ultrasonic guided waves within the bipolar plate of the PEMFC. The wave propagation through the bipolar plate and thus, the signals received at the PWAS are sensitive to the presence of liquid water on the bipolar plate. By comparing the received signals with a baseline signal, sessile water drops can be detected on the bipolar plate. Fig. 1 shows a scheme of the measurement principle.

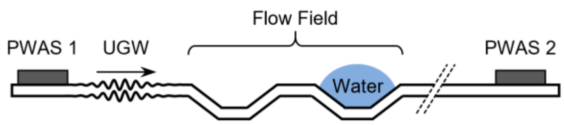

Fig. 1. Scheme of the measurement principle. Ultrasonic guided waves (UGW) are transmitted across the bipolar plate from PWAS 1 to PWAS 2. In the middle is the flow field with a water drop in one of the flow channels.

This measurement principle has been demonstrated in ex-situ experiments on a single bipolar plate in a temperature-controlled lab environment [2]. For an integration of the sensor system in an operating PEMFC, the changing environmental and operational conditions must be considered. Temperature changes affect the guided wave propagation and therefore the measurement signals. Additionally, the surface of the bipolar plate is in direct contact with the gas diffusion layer (GDL) when assembled in a PEMFC, which could potentially influence the measurements.

To investigate these influences, two piezoelectric wafer active sensors (PWAS, disc c255 o5 t0,5 wAg, *PI Ceramic*, Lederhose, Germany) are attached to a bipolar plate (Material No.: 1.4404, gold coating of 1 µm, sheet thickness: 100 µm, outer dimensions: 10 cm by 8 cm). In the center of the bipolar plate is a serpentine

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flow field with eight flow channels (flow field design by *Hydrogen and Fuel Cell Center (ZBT GmbH)*, Duisburg, Germany). For the measurements, the bipolar plate is placed in a temperature-controlled test chamber. One of the PWAS is excited with a square wave signal (2 periods, center frequency: 4 MHz, peak-to-peak Voltage: 10 V). This leads to propagation of ultrasonic guided waves across the bipolar plate, which are received at the other PWAS. The *us4R-lite* platform (*us4us*, Warsaw, Poland) is used for data acquisition and to excite the PWAS.

Investigation of operational conditions

To quantify the change of the guided wave responses, the following signal processing is performed: averaging, selection of a region of interest, forward-backward filtering (4^{th}-order Butterworth bandpass filter with cutoff frequencies of 3 MHz and 7 MHz). The baseline signal (measured at 25 °C without any water on the bipolar plate) is then subtracted from the measured signal. The resulting difference signal is divided into 500 windows before calculating the normalized signal energy E_d for each window. It has been shown that the resulting signal feature vector is suitable to localize single water drops on the bipolar plate using data-driven modelling [2]. Here, the same signal feature is used to quantify the influence of different conditions on the measurement. Measurements were performed under the same conditions, changing only one parameter: a) no change (same conditions as for the baseline signal), b) one water drop placed on the flow field, c) temperature change of 1 K, d) temperature change of 3 K, e) GDL placed on the flow field. Fig. 2 shows the resulting distributions of E_d.

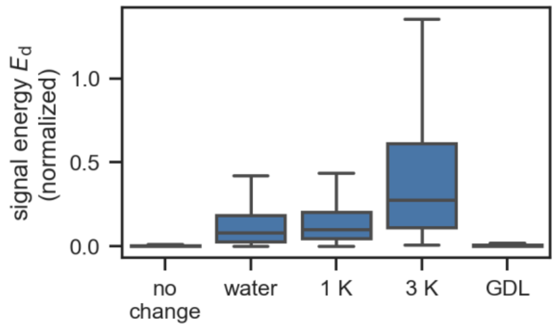

Fig. 2. Distribution of the normalized signal energy E_d for different measurement conditions (no change, added water drop, temperature changes of 1 K and 3 K, GDL placed on flow field). High values indicate a large influence on the guided wave response. Boxes indicate quartiles, whiskers indicate 1.5 interquartile range value.

Even small temperature changes of 1 K and 3 K influence the measurement to a similar or higher extend than the presence of a water drop on the flow field. The GDL on the other hand does not lead to any significant changes of the guided wave response as shown in fig. 2. It can be concluded that temperature changes have to be compensated to ensure accurate liquid water detection in an operating PEMFC. One method for compensation is the optimal baseline subtraction [3]. In fig. 3, the effect of temperature compensation is shown. It can be seen that, after temperature compensation, the effect of a water drop on the normalized signal energy E_d is similar for both temperatures.

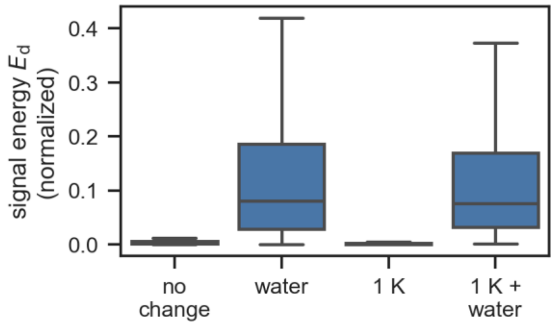

Fig. 3. Distribution of the normalized signal energy E_d with adjusted baseline to compensate for the temperature change of 1 K. Boxes indicate quartiles, whiskers indicate 1.5 interquartile range value.

Conclusion and Outlook

Sensor principles based on ultrasonic guided waves show a high potential for liquid water detection on complex plate-like structures and could provide valuable information on the water management in PEMFCs. The main challenge for the integration into an operating PEMFC stack is the high sensitivity of the sensor system towards temperature changes. It was found that a temperature change of 1 K affects the guided wave responses to a similar extent as the measuring effect used for water detection. Further research is needed to optimize temperature compensation strategies with consideration of the data-driven modelling that enables water localization on complex plate-like structures such as the bipolar plate.

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