Uncertainty Analysis for Low-Cost Transformer Type Inductive Conductivity Sensors

Yiğithan Kandur[1] , Julius Harms[1,*], Thorsten A. Kern[1]

[1]Institute for Mechatronics in Mechanics, Hamburg University of Technology; imek@tuhh.de
[*]Correspondence: julius.harms@tuhh.de

Abstract: Transformer-type inductive conductivity sensors (TICS) are the industry standard for long-term conductivity measurement in fluids. This paper analyses the potential of TICS as a low-cost alternative to the more cost-efficient type of conductivity cells by an implementation with reduced complexity. Sensor characteristics and performance in comparison to high precision sensor are described in the study. Linearity and hysteresis error in measurement, reproducibility and permeability influence by the temperature change are quantified through the experiments. The results were interpreted in regards to core material, geometric properties and noise shielding. Study presented in this paper provides a better understanding of performance and uncertainty characteristics in order to improve the design of low-cost transformer type inductive conductivity sensors.

Keywords: Salinity; Conductivity; Inductive; Transformer; Low-Cost; Uncertainty;

1. Introduction

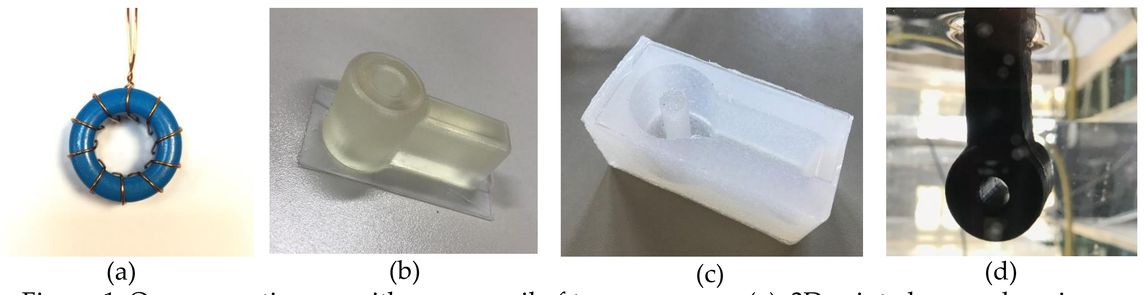
Transformer-type inductive conductivity sensors (TICS):

- Consist of two or more toroidal coils with ferrite cores
- Have advantage of being protected from corrosion and biofouling
- Are expensive than conductivity sensors due to the complexity

This study aims to implement low-cost TICS alternative with reduced compelixty, and provides better understanding on the uncertainties.

2. Materials and Methods

Developed low-cost TICS has two identical Mn-Zn (Fig. 1a). 3D model of end product sensor (Fig. 1b) is used to create casting mold by silicon rubber compund (Fig. 1c). Coils are placed in mold and casted by polyurethane based resin that resulted in end product (Fig. 1d).



(a) (b) (c) (d)

Figure 1: One magnetic core with copper coil of two per sensor (a); 3D printed sensor housing (b); Silicon based casting mould (c); End product sensor is under the conductive solution (d).

Experiment setup is defined between 12°C to 31°C and 0 to 55 mS/cm. Operational drive frequency was tested and selected as 30 kHz at 600 mV.

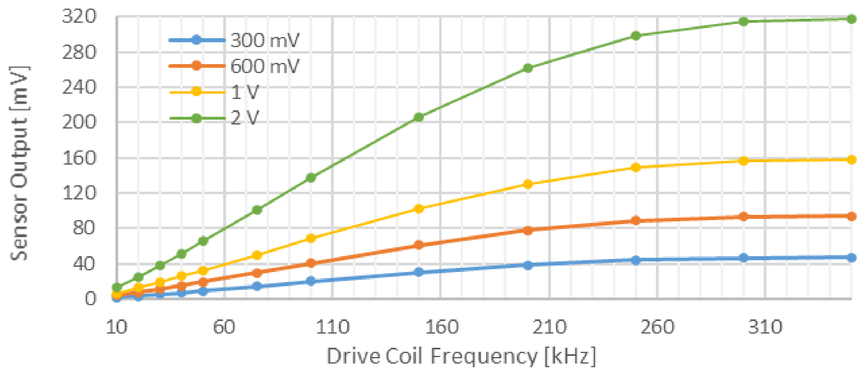
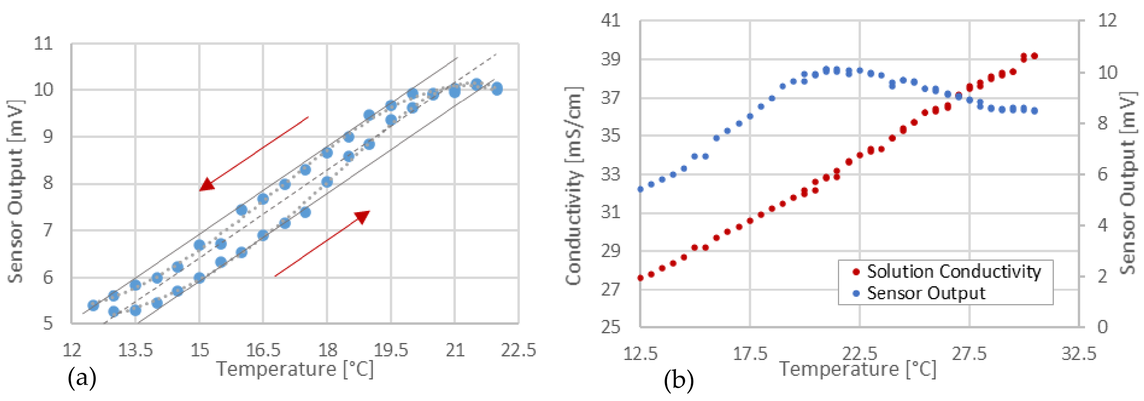


Figure 2: Sensor output with respect to increasing operating frequency for drive voltages.

3. Experiments and Results

Permeability of magnetic core is influenced by the temperature change and may result in hysteresis phenomenon (Fig. 3a). Measurement characteristic was observed for linear change in temperature (Fig. 3b).



(a) (b)

Figure 3: TICS with hysteresis phenomenon (a); TICS response with respect to temperature (b).

To observe the linear conductivity measurement behaviour of TICS sensor, water tank filled with fresh water initially and temperature of the solution was fixed along the experiment. While conductivity of the solution increased gradually, TICS output and linearity error was recorded.

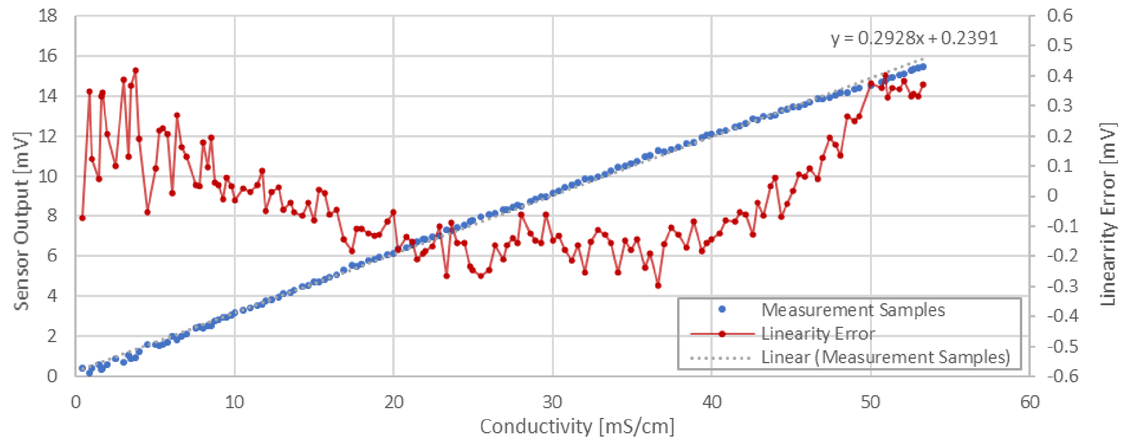


Figure 4: Cost-effective TICS output amplitude vs. solution conductivity. Linear equation of the trend line is shown on the plot. Linearity error defined as the difference from linear trend line in mV.

Stability of developed TICS may be disturbed by the surrounding electromagnetic noises and permeability influences. Repeatability experiement was conducted to assess the reliability of the TICS measurements. Continuous short- and long-term samples were taken from constant state solution, then measurement uncertainty was approximated.

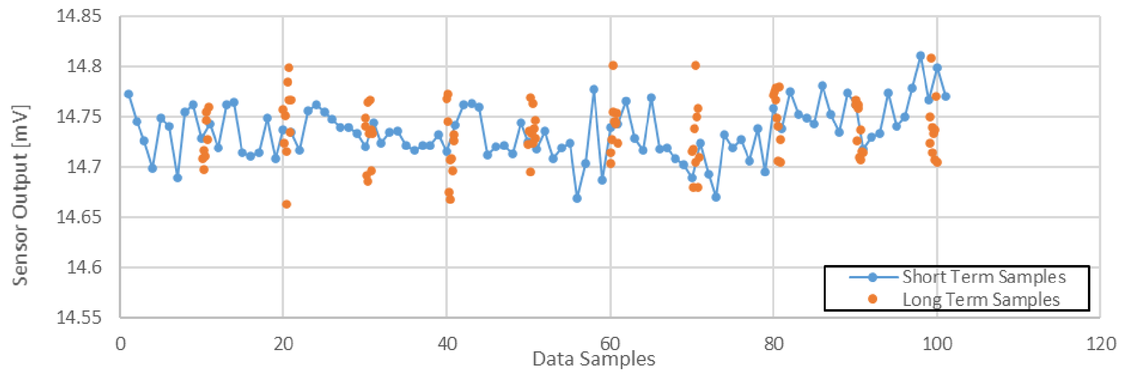


Figure 5: Uncertainty of sensor measurement is determined by the repeatability experiment.

4. Discussion & Conclusion

Experiment results show that developed low-cost TICS is able to provide sufficient linear behaviour in conductivity measurement compared to high precision inductive sensor. It is seen that temperature has critical impact on the permeability. While developed TICS has lower cost than existing alternatives, it displays similar uncertainties.

Presented study gives a better understanding on the low-cost TICS production process, performance and uncertainty characteristics. Further improvements can be done on the manufacturing methods and material selection, which may enhance the sensor gain, while providing better noise shielding.