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Calibration of Capacitive Hydrostatic Leveling Sensors

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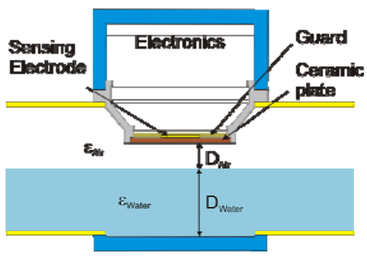
For the measurement of height differences Hydrostatic Leveling Sensors (HLS) have been investigated at SLAC. The Linac Coherent Light Source (LCLS) project demanded accuracies on the order of one micrometer. During the investigation of capacitive sensors and ultrasound sensors discrepancies between the two sensor types were discovered. The capacitive sensors had been calibrated to a metal plate assuming that the difference to water would not exceed the accuracy level demanded. For the determination of the different behavior between a water surface and a metal plate the actual parameters of different types of water had to be determined. By calculating a finite element (FE) model of the capacitive sensors with the actual parameters the difference to the metal plate could be determined. Finally a calibration routine to satisfy the required accuracy level was established.

The Principle of Capacitive Measurements



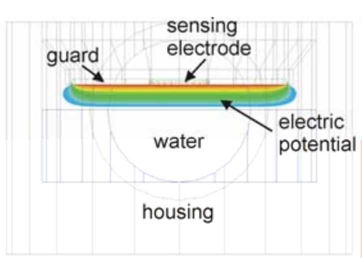
The capacitance measured at the sensing electrode can be calculated as a first approximation as follows:

$$\frac{1}{C} = \frac{1}{C_{Air}} + \frac{1}{C_{Water}}$$

Where the capacitance C can be calculated from the physical parameters of the dielectric.

$$C = \frac{A \cdot \varepsilon}{D} + \text{fringe capacitance}$$

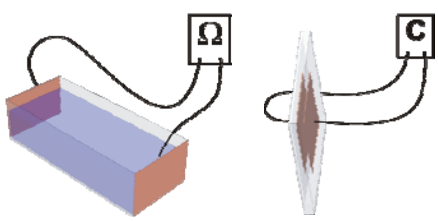
With the surface area A and the distance D. The fringe effects are caused by a finite surface of the electrode. A guard reduces this effect but can not completely eliminate it. The second deviation from the ideal is that the water is conductive. Therefore the distance D_{Air} can not be analytically derived from the capacitance measured. Alternatively a finite element (FE) model was developed.



Electrical Properties of Water Solutions

To establish an FE model we had to determine the actual parameters of the dielectric. For pure water at 25°C a dielectric constant of 78.2 is given in the literature (Baxter [1997]). This value changes with temperature by -0.4 per ºC. At frequencies higher than 10 MHz the dielectric constant is also frequency dependent. For our case the measuring frequency is about 80 kHz and the frequency dependence can be neglected.

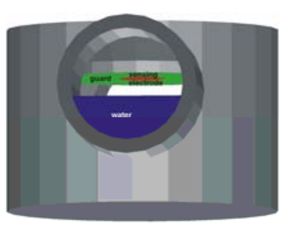
Experimental determination of Capacitance and Conductivity (results are only guiding values)



Fluid	Dielectric constant	Conductivity [Ω m]
Distilled water (Safeway Inc.)	48	6507
De-ionized water	48	439
De-ionized water with chloride	150	52
Drinking water (Alhambra® Drinking Water)	143	230
Drinking water with chloride	148	63

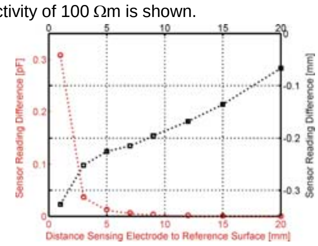
FE Model

As stated above an analytical formula for the simulation of the sensors is difficult. For the simulation of different parameters, a finite element model of the sensor was created with Maxwell 3D (Ansoft).

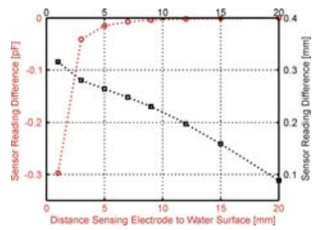


Simulation Results

One way of calibrating the sensors is to use a metal plate. For this to be correct the conductivity of water must be 0 Ωm, this is not the case as shown before. In the example below the difference between metal plate as reference and water with a dielectric constant of 90 and a conductivity of 100 Ωm is shown.



Different solutions of water have different electrical parameters, e. g. depending on the amount of chloride added. Presented below is the difference between de-ionized water (dielectric constant: 50; conductivity: 500 Ωm) and de-ionized water with chloride added (150 / 50 Ωm).



Calibration of the Sensors

If a metal plate is used to calibrate the sensors it is necessary to know the electrical parameters of the fluid to adjust for it. By adding an anti-algae treatment in the form of chloride we change the parameters. Another concern is that the parameters change over time, e. g. de-ionized water does not stay de-ionized in metal pipes. Our proposal is therefore to calibrate the sensors in situ using an alternative method to determine the water level. With the installation of ultrasound sensors we provide this option for the LCLS project at SLAC. We will use remotely activated pumps to change the water level. By monitoring the changes with ultrasound sensors we can calibrate the capacitive sensors in relation to them.

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