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Temperature influence on capacitive sensor structures

INTRODUCTION

The non-contacting working principle of capacitive sensors is applicable for detection of dielectric and metallic targets in harsh industrial environments. Their advantages are the low power consumption, simple geometry and simple construction. The capacitance characteristic is insensitive to colour and surface of targets independent of visibility, but is influenced of various other factors like contamination, deposits, humidity, dirt and also changes of temperature over a wide range. For example its use should be stable independent of geographical area, season or any climate changes. Typical applications is the object detection in harsh industrial environments with capacitive changes better than $\Delta C = 10 \, \mu F$, especially with flexible dielectric layers. Two proximity characteristics with switching threshold are shown in Fig. 1. The influence of temperature dependent impedance changes makes detection difficult on different temperatures, so its compensation is one of the central requirement for accurate and reliable capacitive sensors.

Fig. 1. Typical proximity characteristic with temperature dependency.

To eliminate the temperature dependency it is possible to use temperature independent materials with low and stable permittivity between electrodes. Many capacitive sensors (i.e. proximity sensors) will manufactured of dielectric materials like thermoplastics, polyamide and polymers. These materials are applicable, because of their chemical and thermal resistance but especially of the low permittivity. Several studies show, that their permittivity is beside frequency dependence also depend to temperature ( [2], [5]). In addition to this, the thermal expansion causes electrode- and material displacements and consequently mutual capacitance changes. Concerning of simultaneous changes it is difficult to separate these effects. Thus the sensor cannot differentiate between target proximity or other environmental effects, so that a accurate detection is
not possible in a wide temperature range. The combination of using low permittivity materials and a suitable
compensation principle can minimize or even eliminate the problems of temperature drift.
Our aim is to develop a high sensitive and flexible geometric sensor system including operation check and
autocalibration, which is insensible to temperature changes in a range $T = -30^\circ\text{C}-220^\circ\text{C}$.

**Sensing Structure**

The analog measuring principle shown in Fig. 2 is based on the patented three electrode system [3],
which does not operate with an oscillation principle, but rather with an additional drive electrode which
is suitable for field formation [1]. A similar capacitive reflector principle is used by Vranish [4] for robot
collision-avoidance. So the three-electrode principle is able to detect objects at distances up to some deci-
metres, further it is simple to change electrode adjustments and scale the geometry of the sensor structure
with simple circuitry adaptation. The system has good electromagnetic compatibility (EMC) and intrinsic
burst-stability, because of using a trapezoid excitation signal $V_a$ with fundamental frequency at $f_0 = 20kHz$.
The output signal $V_m$ is primarily influenced of the capacitances $C_{me}, C_{mo}$ and $C_{am}$

$$U_m = \frac{C_{me} + C_{mo}}{C_{me} + C_{mo} + C_{am}} \cdot U_a\, .$$

Hardly important is $C_{ae}$, which is only a capacitive load for the generator. Serious temperature influence
have the capacitances $C_{me}$ and $C_{am}$ which are due to dielectric layers between electrodes. The intrinsic mea-
suring capacity $C_{me}$ should be low, to get a high sensibility as a result of a large influence of $C_{mo}$. This can
be achieved with a large drive electrode, which brings a shield effect to mass. The second important capa-
city $C_{am}$ can be minimized with a relative large distance between drive electrode and measuring electrode.
However, all dielectical materials should have low and stable permittivity over temperature.

Fig. 2. Capacitive three-electrode sensor principle and equivalent circuit [5].

**Experimental Configuration**

For analysis of temperature influence, a simple sensor structure in Fig. 3 with Teflon layers between
measuring- and drive electrode is modelled and measured in a complete electrical shielded climate chamber.
The temperature characteristic shows a continuous decreasing output signal $V_m$. Numerical field computations are based on a finite-element package MAXWELL and show similar tendencies by changing permittivity over the range $\varepsilon_r = 2.0 - 2.8$. Static measurements [5, p.37] could verify these values for relative permittivity with $\varepsilon_r = 2.175$ at $T = 20^\circ C$ and $\varepsilon_r = 2.791$ at $T = 88^\circ C$. Numerical computations are showing only tendencial conclusions, because it is difficult to make well-defined temperature to permittivity correlations of the dielectric materials. The reasons are basically incomplete manufacturer informations about permittivity characteristics over a wide temperature range.

![Diagram of proposed prototype sensor structure](image)

**Fig. 3.** Proposed prototype sensor structure [5].

![Graph of temperature characteristics](image)

**Fig. 4.** Temperature characteristics of a proposed prototype sensor.

**EXPERIMENTAL RESULTS**

To reduce or eliminate the decreasing temperature characteristic, the differential sensor structure with additional reference element only influenced by temperature changes, is used. This prototype with sandwich structure is measured for temperatures from $T = 20^\circ C$ up to $T = 90^\circ C$. For reduction of the thermal
expansion effect, the structure is fixed in a screw clamp. Fig. 4 shows the measured outputs (normalised to $T = 40^\circ C$) of measuring- and reference electrode and its differential signal $V_d$.

The differences of measuring- and reference graph are not practicable for object-detection with analog bridge compensation. But both have same tendencies and give base for optimisation of our differential structure. With a redesigned planar structure including epoxy resin isolator (FR4) (Fig. 5(a)) and a digital calibrating and measuring controller algorithm we developed a compensation function over a range $T = -40^\circ C-100^\circ C$

$$U_{ref}^*(T) = \frac{U_{ref}(T) - U_{ref}(T_0)}{X} + U_{ref}(T_0).$$

Equation (2) corrects the reference signal around the working temperature $T_0$ with a geometric dependent scale factor $X$. So the measurement signal and corrected reference signal should have identical temperature characteristics which are the requirements for temperature independent sensor behavior. Our sensor shows similar characteristics in Fig. 5(b) with a deviation about 1.0%. The difference voltage is calculated with the equation $\Delta V(T) = V_m - V_{ref}^*(T)$ and gives the information about the target distance.

![Differential structure.](image)

Fig. 5. Differential structure and temperature characteristics.

For correction of temperature characteristic the reference electrode must be independent on target distance. Numerical field computations are showing a stable output signal over target distance down to 30mm. At lower distances the reference output rises up to a maximum, which is 0.8% higher than its basis signal. Experimental results are showing different output levels. The simulated signal differences of measuring electrode are about $-2.5\%$ and about $6.5\%$ of reference electrode. Perhaps our equivalent circuit is not complete yet or the evaluated permittivity of isolator is different to reality. Except for the output level differences the qualitative outputs behavior are similar. Due to the geometrical position of the reference electrode, the reference output signal is almost independent on target distance with deviation under $1\%_0$ (Fig. 6).

**CONCLUSION**

A temperature-compensated, fixed capacitive proximity sensor with a measuring- and reference electrode is designed, developed and tested. The system operates with a differential principle [3], which does work with an additional drive electrode for field formation and high sensitivity. The reference output is used to
compensate temperature drifts of the measurement output signal, which is realised with a correction function. For object detection the outputs must have identical tendency characteristics. To adjust the tendency of reference output and the geometrical position and size of the reference sensor. So it is possible to detect objects accurate to distances of any decimetres over a range about $T = -40^\circ C - 100^\circ C$. Current results are a good base for developing further applicable structures with temperature stability in a range $T = -40^\circ C - 180^\circ C$.

References


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