AN ELECTRICAL MODEL OF THE THERMAL INTERACTIONS IN AN INTEGRATED WIND SENSOR

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A not-central placement of a two-dimensional integral wind sensor in its packaging causes thermal unbalance in it. Such unbalance adds an offset to the sensor's output signal. The thermal distribution in the sensor can reduce the offset by small changes in the heating power. Adjustment of the heating power is realized on trial-and-error basis. We developed a method for fast calculation of the necessary change of the heating power.

1. INTRODUCTION

Thermal interactions between objects are described with complex mathematical expressions requiring a lot of computational time, especially when three-dimensional problems are concerned. In order to simplify the resolving of thermodynamical problems, the thermal interactions are described with different models. The models differ from simple analytical descriptions to complex numerical models. Computer programs as CoventorWare and ANSYS solve the three-dimensional problems giving detailed solutions for the different parameters of the thermal processes.

An integral wind sensor determines wind speed and direction by measuring thermal differences that are induced by the airflow [1]. Sensor's packaging influences the device work. An inaccurate placing of the device chip on its ceramic carrier causes thermal asymmetry, which in turn adds an offset to sensor's output signal. An adjustment of the thermal distribution in the sensor [2] compensates for the offset. This process is currently performed on trail-and-error basis.

We investigated the influence of the asymmetrical packaging of the sensor on its carrier using the means of CoventorWare. In order to easily find the compensating thermal distribution, was developed an electrical model of the sensor. The electrical model was investigated with MicroSim. On the basis of the obtained results an analytical expression was derived for the required correction. The expression can be applied on the uncompensated output data of the sensor and it gives the compensating heat distribution. This method of compensation was verified in a numerical model of the sensor.

2. THE INTEGRAL WIND SENSOR AND ITS NUMERICAL MODEL

The integral wind sensor consists of a measuring chip and its packaging. Four integrated heaters warm the sensor up to temperature 10°C above the ambient temperature. Four integrated thermopiles measure the flow induced temperature differences. The sensor's IC is developed in a standard bipolar process. The chip is 4x4 mm with thickness of 0.35mm. The thermopiles are of type p-diffused silicon/aluminum consisting of 22 thermocouples, with sensitivity of 13 mV/K per thermopile. Each thermopile is divided into two serially connected parts placed at the sides of the chip. The heaters are from p-diffused silicon and have resistance of 80 Ω. A centrally located diode measures the temperature on the chip.

The chip is glued on the backside of a thin ceramic carrier with diameter 22 mm, and thickness 0.25 mm. Both are placed in the middle of an aluminum pedestal in a way that the surface of the aluminum pedestal and the surface of the ceramic carrier form a flat plane. In figure 1 is shown a schematic view of the sensor.

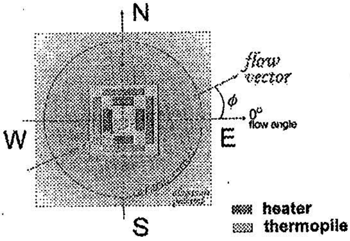

Figure 1. Integral wind sensor: a. Schematic view of the sensor, b. Schematic structure of the sensor, c. numerical model of the sensor.

A 3D-model of the sensor was built with CoventorWare (Figure 1) [3]. With its help the influence of a displacement of the chip on the ceramic carrier was investigated. The structure of the sensor was thermally isolated. The temperature of the air was defined to 300K and airflow speed was varied from 1 to 6 m/s.

The dependence of the temperature differences measured by the thermopiles on flow direction for different displacements is shown in figure 2, a constant wind speed of 6 m/s was used. The chip is displaced along the East-West axis only, in eastern direction. The temperature difference of the East-West thermopile is almost unaffected by the chip's displacement, whereas, North-South deviates from the centered case. It should be noted that due to its square geometry, even a centered sensor exhibits small amplitude and angle errors.

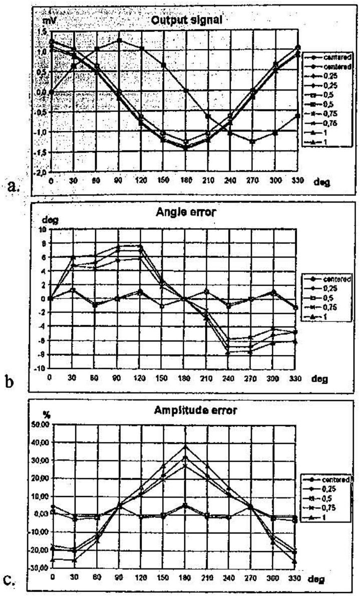

Figure 2. a. Dependence of the output signal of the thermopiles from the flow angle at 6 m/s for different displacements; b. Error between the obtained by simulation and the ideal flow angles; c. Error between the obtained by simulation flow speed and the 6 m/s

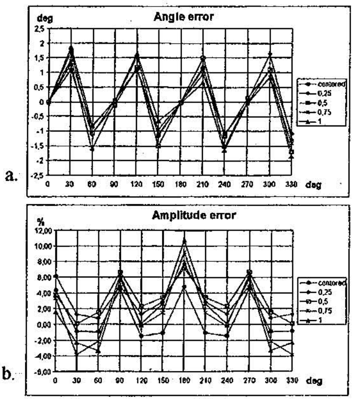

Figure 3. a. Error between the obtained by simulation and the ideal flow angles, at 6 m/s, when a thermal compensation is applied; b. Error between the obtained by simulation flow speed and the 6 m/s, when a thermal compensation is applied.

3. COMPENSATION OF THE THERMAL ASSYMETRY

In order to compensate for the displacement a procedure of adjusting the heating powers in each of the heaters could be performed. But, such process is cumbersome since detailed numerical simulations take a lot of resources and computational time even for a good processing engine. That is why we decided to simplify the process of investigation using a different method of modelling the thermal processes in the device. Namely, using an electro-thermal analogy. The electro-thermal analogy is based on the fact that when the thermal and electrical processes are described with similar equations, an analogy between the two processes could be drawn. In this manner stationary thermal process could be easily investigated with simulators like MicroSim, for example.

A simplified electrical model of the sensor was built and was used to explore the thermal distribution in the chip and the ceramic in absence of flow (Figure 4.).

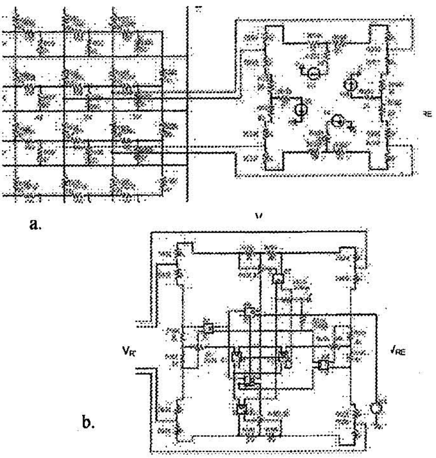

Figure 4. An electrical model of the integrated wind sensor.

Circuit for an automatic correction

In the electrical model the temperature differences that should be measured are measured as voltages between the terminals of the heaters (noted as V_{RE}, V_{RW}, V_{RN} and V_{RS}). The heaters are depicted as circuit of current sources and resistances.

The air on top of the sensor is considered as an element with a constant thermal resistance. Hence, the thermal transfer between the air and the sensor is only by thermal conduction. The ceramic was modeled as a matrix of thermal resistances, in order to model accurately the thermal conduction in it. A reconnection of the chip circuit between two neighbouring columns or rays of the ceramic resistance matrix represents a displacement of the chip on the ceramic surface.

The output voltage of a thermopile should be $V_{thp}=0$ when the chip is well centred on the ceramic and for absence of flow. Similarly, in the electrical model all voltage potentials at heaters' terminals are equal and $V_R=0$. If the chip is displaced then the potentials on the heaters' terminals differ. This means that sensor "measures" presence of airflow. In order to compensate for this effect we designed a circuit that performs the compensation automatically. The idea is to adjust the currents through the heaters in a way that the heaters terminals have equal potentials, i.e. $V_R=0$ although $V_{RE} \neq V_{RW} \neq V_{RN} \neq V_{RS}$. This circuit gave us also the possibility to investigate the relation between the current through the heaters and the offset airflow signal.

In the automatic calibration circuit four voltage-controlled voltage sources are used as comparators. The comparators work in pairs for each of the directions East-West or North-South. They compare the voltage potentials at the heaters' terminals. A pair of folders sums the output voltages of the comparators in the pairs and the total output voltage is then fed to the perpendicularly positioned heaters, in this manner the feedback is closed.

Consider $V_{REW} = V_{RE} + V_{RW}, V_{RNS} = V_{RN} + V_{RS}$, then

$$V_{bias} = \sqrt{V_{REW}^2 + V_{RNS}^2} \qquad [V] \qquad (1)$$

is the amplitude of the flow signal and

$$\phi_{bias} = \tan^{-1}\left(\frac{V_{RNS}}{V_{REW}}\right) \qquad [deg] \qquad (2)$$

is the calculated flow angle.

The relative error between the current supplied to a heater obtained after an automatic calibration and the current when the chip is in the center is

$$\delta(I_{ao}) = \frac{I_{Xao} - I_{ao0}}{I_{ao0}} \qquad (3)$$

A coefficient *C* is assumed.

$$C = \left|\frac{\delta(I_{ac})}{V_{bias}}\right|\left[\frac{1}{mV}\right] \qquad (4)$$

Simulations showed that this coefficient is relatively constant on the regarded range of displacements. Therefore, an average value was assigned. Since *C* represents the effect of displacement on the currents through the heaters, it can be used as a correction coefficient. Hence,

$$I_{predict} = I\left(1 - C.V_{bias}.\sin\left(\phi_{bias} + \phi_0\right)\right) \qquad (5)$$

where I is the current before a compensation, ϕ_0 could take the values 0°, 90°, 180°, 270° depending on the position of the heater on the chip, beginning from heater East counter-clockwise.

In order to verify the formula (5), the compensation currents calculated with it were substituted in the electrical model without automatic correction (Figure 4.a.).

4. VERIFICATION

In the numerical model

The expression (5) was firstly used to correct the displacement of the chip on the ceramic surface in the numerical model of the sensor. The result of this compensation when the flow speed is 6 m/s for the different displacements could be seen in figure 3.

In the different cases of displacement the coefficient *C* ranged from 0.18 to 0.22. The compensation lowered the angle error from 7 degree to 2 degree difference with the ideal angle, and restored as behaviour (predicted in [4]) the amplitude of the output signal.

5. CONCLUSIONS

In the investigated 2-D wind sensor a possible packaging asymmetry is one of the major causes of errors. In order to compensate for it, different techniques of modeling were used. With the help of a model based on the electro-thermal analogy an expression was derived. The expression was used to calculate the compensation heat powers. It was then used in a numerical model, which represents the displacement of the chip on the ceramic surface. After the compensation, the angle error was lowered to 2 degrees maximum difference from the ideal angle. The compensation also affects the amplitude of the signal in a way that it stays in the limits of the predicted behaviour.

6. REFERENCES

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