Influence of Heat-source Temperature on Convection-based Tilt Sensor Output

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Abstract—**According to the sensitive mechanism of convection-based tilt sensor, temperature field plays a key role in the sensing tilt. The tilt sensor output has one to one correspondence with the temperature field, which is variety with heat-source temperature. Using ANSYS, temperature flow fields are simulated by variety heat-source temperatures in a two dimension hermetic chamber, the differences of temperature between hotwires are obtained, the outputs based on these are calculated, also compared with measured values. From the results the output relation with the heat-source temperature is given qualitatively1.【医】 figurate; qualltative, through this relation the output of sensor can be improved, meanwhile output drifted with heat-source temperature can be decreased by provided circuit.**

Keywords- heat-source; convection-based; difference of temperature; tilt

I. INTRODUCTION

In 1990's, convection-based tilt sensor had been found broad application as in [1-4]. Because the mass of gas is small and there is no proof mass, the tilt sensor has its characteristics of resisting oscillation and shock. At present, convection-based tilt sensor can be seen in many fields like military, spaceflight, aviation, civil and so on.

Convection-based tilt sensor is made according to pendulum characteristics of the natural convection of gas. Sensitive mechanism of gas convection-based tilt sensor is shown in Figure. 1. A heat-source and two hotwires are placed in a hermetic chamber; a wire like heat-source is placed along axis of the chamber, hotwires are placed symmetrically and compose the arms of bridge circuit. Yet temperature distribution induced by the heat source plays a key role in the sensing tilt as in [5]. When the sensor is in horizontal state two hotwires sense the same temperature of fluid flow, their resistances are equal. The difference of temperature between hotwires is zero. The output of bridge circuit is zero. When sensor is in tilt state two hotwires sense the different temperature of the flow, the corresponding resistances are not equal to each other. The difference of temperature between hotwires is variety with the tilt. The bridge outputs a voltage signal corresponding to the angle.
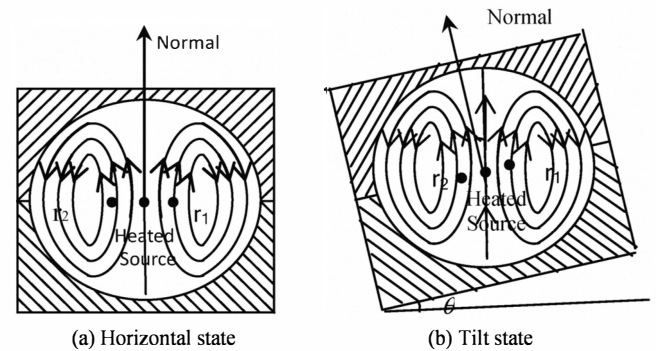

(a) Horizontal state   (b) Tilt state

Figure 1. Schematic diagram of gas pendulum

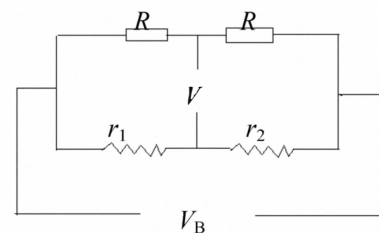## II. THE DETECTING CIRCUIT

Figure 2. Bridge circuit

Bridge circuit is showed in Fig.2. The output of bridge circuit is given as in Zheng, Y.H. [6].

$$V = V_B \frac{r_1 - r_2}{2(r_1 + r_2)} \tag{1}$$

where r_1 and r_2 are the resistance of hotwires, R is accurate resistance, V_B is power supply volt of bridge, V is output of bridge. As sensor is in tilt state, the resistance of one hotwire increases, the other must decrease, and increased value is approximate to decreased value, $r_1 - r_2$ is constant basically. Let $r = r_1 - r_2$, then the bridge output is written by

$$V = V_B \frac{r_1 - r_2}{2r} \tag{2}$$

Variety of resistance with temperature is

$$r(T) = r_0[1 - a_1(T - T_0)] \qquad (3)$$

where $a_1 = 3.90802 \times 10^{-3} \, {}^0C^{-1}$, r_0 is resistance of reference temperature T_0, referenced to Sheng, S.Z., Xu, Y.T. and Yuan, H.J. [7].

By the expression of (3), r_1 and r_2 are written as

$$r_1(T) = r_{10}[1 + a_1(T - T_1)] \qquad (4)$$

$$r_2(T) = r_{20}[1 + a_1(T - T_2)] \qquad (5)$$

where T_1 and T_2 are the temperature of r_1 and r_2. Hotwires are same long, therefore $r_{10} = r_{20}$. Let $r_0 = r_{10} = r_{20}$, a relation can be gotten

$$\Delta r = r_2 - r_1 = r_0 \alpha_1 (T_2 - T_1) \approx r_0[4 \times 10^{-3}(T_2 - T_1)] \qquad (6)$$

By (1) and (6), another relation can be gotten again

$$V = \frac{V_B}{2r} \alpha_1 r_0 (T_1 - T_2) \qquad (7)$$

The difference of temperature between hotwires determines bridge output due to the expression of (7). If heat-source temperature changes, difference of temperature between hotwires will change too. The test of tilt is altered under the variety heat-source temperature. The property of convection-based tilt sensors is changed, that is sensitivity drifted with temperature.

III. NUMERICAL SIMULATION OF FLOW IN THE HERMETIC CHAMBER

It is convenient to use software for analysis in details; the software of ANSYS is used to get numerical solutions as in [8].

A. Modeling

1) Establish a Title and Preferences
Choose FLOTRAN CFD analysis.

2) Define Element Types
Choose 2D FLUID141.

3) Create Areas
Choose round represents hermetic chamber.

4) Define Lines, Mesh, and Plot Elements
Set the number of element division to 625.

B. Loading

1) Apply Velocity Boundary Conditions
Set velocity of nodes on outside edge are zero along x and y direction.

2) Apply Thermal Boundary Conditions
Set temperature of nodes on outside edge are 293K, temperature of heat source is 303K, 323K, 343K, 373K.

3) Set C Solution Options and Execution Controls
Set the field to thermal, EXEC to 200, RFL File Overwrite Freq field to 50.

Set the Output summary frequency field to 50.

4) Set Fluid Properties
Set the Density, Viscosity, Conductivity and Specific heat fields to AIR-SI. Allow density variations.

5) Set FLOTRAN Environment Parameters
Set the Acceleration in y direction field to 9.8.

C. Solve the Problem

Choose TDMA. Make sure that the value of the No. of TDMA sweeps for pressure field is 100.

Now keeping environment temperature is 20℃, heat-source temperature (HT) is changed. In Figure.3 is the temperature distribution with different heat-source temperature as tilt of sensor is 20. From Fig3, it is very clear that these four temperature fields are different. The isometric lines of temperature forming circles are concentric shown in Fig.3 (a), which indicates the gradient of temperature field is little. The isometric lines of temperature forming circles move above gradually shown in Fig.3 (d), which indicates the gradient of temperature field is large. There are dissimilar temperature distributions at different heat-source temperature, while the temperature is high, and the gradient of temperature along radial direction is apparently large. Using the same way temperature fields are simulated at different sensor tilt.

(a) HT is 30℃   (b) HT is 50℃

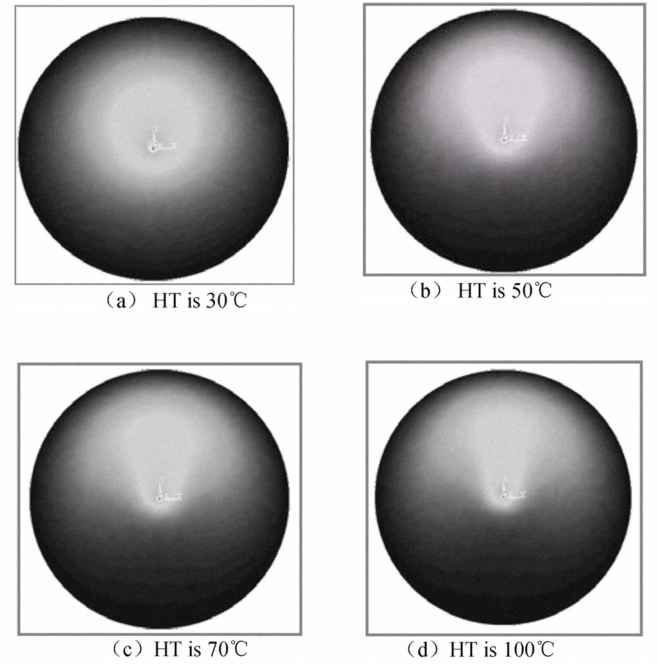(c) HT is 70℃   (d) HT is 100℃

Figure 3.   Temperature field diagram

From simulated temperature fields, the differences of two hotwires can be calculated at the variety temperatures of heat-source. The table 1 gave separately the differences of two hotwires as sensor tilt is 20°, 30° and 45°.

TABLE I.   THE RELATIONSHIP BETWEEN HEAT-SOURCE AND THE DIFFERENCE OF HOTWIRES

Heat-source temperature (℃)	The difference of hotwires (℃)		
	Sensor tilt 20°	Sensor tilt 30°	Sensor tilt 45°
30	0.47	1.84	3.49
40	1.23	2.47	4.12
50	1.96	3.01	4.78
60	2.61	3.67	5.33
70	3.21	4.26	5.91
80	3.82	4.87	6.40
90	4.40	5.62	7.02
100	4.85	6.14	7.43
110	5.37	6.63	8.03
120	5.79	7.11	8.31

It is obvious that the more heat-source temperature is raised the more difference of hotwires is gotten. In accordance with the difference of hotwires and the expression of (7), the outputs of sensor are calculated with variety temperatures of heat-source when tilts are 20°、30° and 45°. Furthermore the above results are compared with the values of experiment. Figue.4 shows the final results.
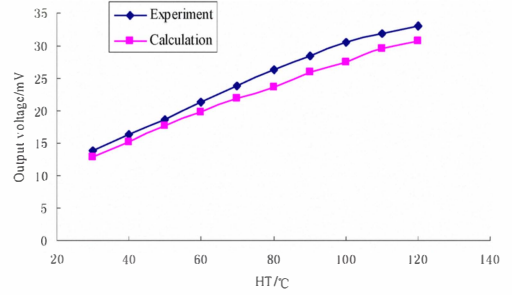
The output of sensor changed with the heat-source temperature even at the same tilt, which means the sensitivity of sensor drifted with heat-source temperature. When heat-source temperature is low, the output voltage is large; when environment temperature is high, the output voltage is small. The output voltage is proportion to the heat-source temperature. For improving the sensitivity of sensor, the heat-source temperature is raised as far as possible.
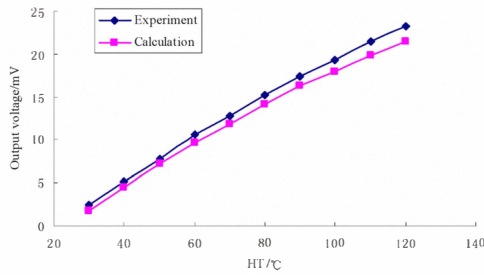
(a) Inclination angle is 20°
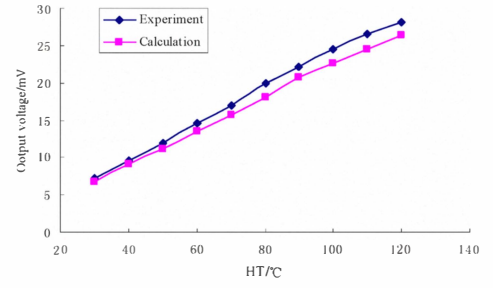
(b) Inclination angle is 30°

(c) Inclination angle is 45°

Figure 4.   Outputs with different HT

On the other hand if temperature field would be kept invariant, output of sensor is not changed because of the heat-source temperature unchanged, as in [9]. Circuit can be designed for keeping the heat-source temperature invariant. The circuit is drawn in Figure.5. R is a resistance of bridge, R_b is adjustable resistance of the same bridge.
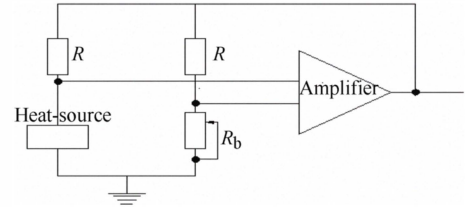
Figure 5.   Feedback circuit of heat-source

IV.   CONCLUSIONS

According to the numerical simulation and the experiment, the output voltage of sensor is proportion to the heat-source temperature. The more the temperature is raised, the more the output is gotten. So the sensitivity of sensor is high.

Through raising the heat-source temperature, the sensitivity of sensor is improved. Not only is the temperature restricted by the power of electrical source, but also approximation of boundary conditions of flow in hermetic chamber is not always right as in [10], and these confined the increase of the temperature.

Using the results above, circuit can be designed for keeping the heat-source temperature invariant. The output voltage of bridge is unchanged, so the sensitivity of sensor is unchanged.

REFERENCES

[1] Zhang Fu-xue. Gas Pendulum Acceleration Sensor[J]. Chinese Journal of Electronics, 2000, 9(1): 14-16.

[2] DAUDERSTADT U A, SARRO P M,FRENCH P J. Temperature Dependence And Drift of a Thermal Accelerometer[J], Sens,Actuators, 1998, A66:244-249.

[3] DAO R, MORGAN D E, KRIES H H, et al. Convective Accelerometer And Inclinometer:US,5581034[P].1996.

[4] Zhang Fu-xue, Chen Zhan-xian, Luo Yu-hua. Gas Pendulum Tilt Sensor. China CN1064351[P].1992.

[5] Zheng, Y.H., " Analysis of stream field of Gas Pendulum Tilt Sensor" [J]. Micronanoelectronic Technology2007, 7/8 242-244.

[6] Zheng, Y.H., Peng, S.L. "A Method of Eliminating Influence of Environmental Temperature on Tilt Sensor Property" Piezoelectrics&Acoustooptics, vol, 30（1）, 2008, pp. 33-35.

[7] Sheng,S.Z.,Xu,Y.T.,and Yuan,H.J., Hot Wire Anemometry, China Science Technology Press ,Beijing, 2003.

[8] Li, L.M., ANSYS Finite Element Analysis practicality Course of Study, Tsinghua University Press, Beijing, 2002.

[9] Zheng, Y.H., Peng, S.L. "Application of Flow Similarity to Convection-based Tilt Sensor," Journal of University of Electironic Science and Technology of China. 2007,36（5）:931-934.

[10] Zheng, Y.H., Peng, S.L. "The Dependence of Sensor Property on Flow in Hermetic Chamber of the Gas Pendulum Tilt Sensor", CMCE. 2010.84-87.