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# Airflow Inclination Sensor Based on Temperature Field

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**Abstract.** It is the temperature field of the closed cavity that plays a decisive role in sensitive inclination. With numerical simulation of ANSYS, the temperature field was analyzed separately under the environmental temperature and heat source temperature unchanged. When the temperature difference between environment and heat source remains constant, the temperature gradient of flow field remains invariant. A circuit can be designed so that the temperature difference between the environment and the heat source does not change during the operation of the inclination sensor, and improving the stability of sensor performance further with the circuit.

## 1. Introduction

Convection is divided into forced convection and natural convection. Forced convection depends on the force of the wind or the external force of the pump to move the fluid. The flow of fluid in natural convection depends entirely on the action of mass force. Convective problems are usually due to natural convection caused by temperature or concentration gradients, which is generated by the mass force acting on a fluid with a density gradient. The net effect is that the floating force causes convection. In the most common case, natural convection is due to the density gradient formed by the temperature gradient, and the mass force generated by the gravitational field [1].

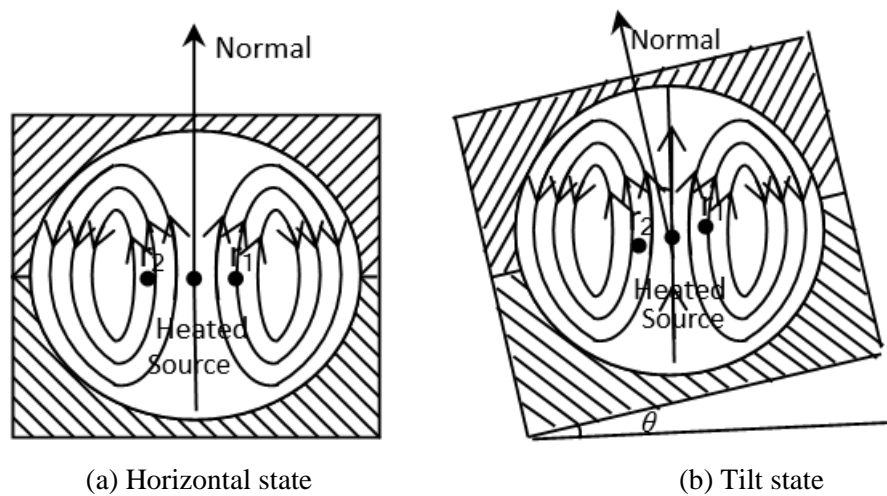
## 2. Natural convection in closed cavity

Airflow inclination sensor is made using the "pendulum" properties of natural convection gas in a closed cavity [2, 3]. Its basic structure is shown in Fig.1. It's a sealed chamber containing gas, there are two sensitive wires  $r_1$  and  $r_2$  symmetrically fixed in the cavity, the sealed chamber and two wires form its key sensitive structure. When the gas is heated by a heat source in a closed chamber, the unit gas in the closed cavity is not only affected by gravity and gas static pressure also affected by diffusion forces caused by density differences (temperature differences). The above combined forces are called levitation, ignoring the gas static pressure generated by the height difference of the cavity, there is

$$F = (\rho - \rho_{\text{ref}})g \quad (1)$$

Where  $\rho$  is the heated gas density which is the function of coordinate  $x$ ,  $y$ , and  $z$ ;  $\rho_{\text{ref}}$  is the unheated gas density;  $g$  is the acceleration of gravity.  $F$  is driving force of the natural convection of gas. After the gas is heated, gas density of this is decreased. The gas density is big in low place while is small in high place. According to the theory of diffusion, the gas moves towards the direction of low density. Due to driving of levitation force, main stream of the heated gas moves vertically, so natural convection is formed in closed cavity.



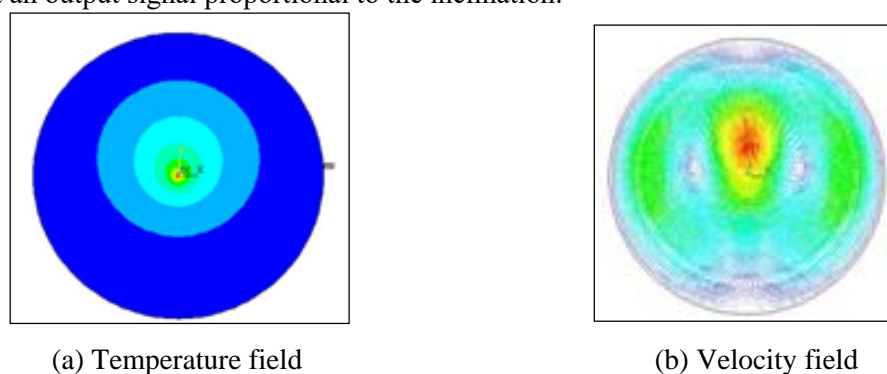


**Figure 1.** Schematic diagram of gas pendulum.

### 3. Flow field in closed cavity

Using ANSYS numerical simulation can calculate the flow field of closed cavity [4]. For steady state flow field is only a function of coordinates. Employing finite element method and ANSYS-FLOTTRAN CFD software, calculation of the distribution of the flow field caused by the heat source at the middle point of a two-dimensional closed cavity have been made through modeling, dividing grids, loading and solving, etc. The results are shown in Fig.2, in which heating temperature is 70°C and environment temperature is 20°C.

Sensitive wire is in different positions in the velocity field, the velocity of the fluid in the velocity field is different, flow drives vary heat to sensitive wire, and this leads to a change in the sensitive wire resistance. Meanwhile sensitive wire is in different positions in the temperature field, as different temperature, so does different resistance. It can be seen that the temperature field and velocity field in the closed cavity all affect the resistance of sensitive wire. It was explained in detail from the verification of theories and experiments in [5], the temperature field has a great influence on the resistance of sensitive wire. That is, the temperature field plays a decisive role in the sensitive inclination of the airflow tilt sensor. When the cavity is in a horizontal state, the two wires are at same temperature in the flow field. Therefore, the bridge composed of wires participation will be balanced, as shown in Fig.1 (a). When the closed cavity is tilted, natural convection gas is trying to stay in its original direction, the position of the two sensitive wires in the temperature field changes accordingly at different temperature points in the temperature field, wires resistance value changed, the balance of the bridge is broken, as shown in Fig.1(b). Thus, using the change of thermal sensitive wire relative to the position of the flow field, can get an output signal proportional to the inclination.



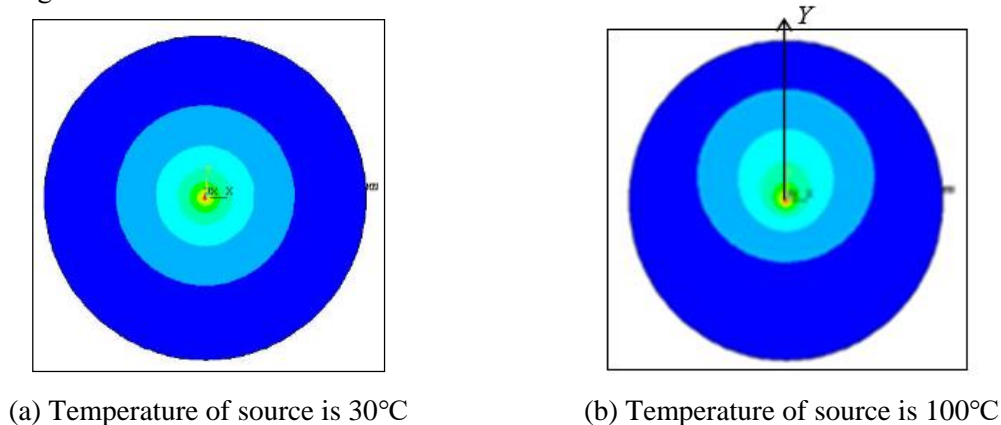
**Figure 2.** Flow field in closed cavity.

### 3.1. Temperature field in closed chamber

The temperature field is due to the difference between the heat source and the ambient temperature, so there's a temperature gradient in the chamber. Therefore, when the heat source or ambient temperature changes, it will cause changes in the temperature field.

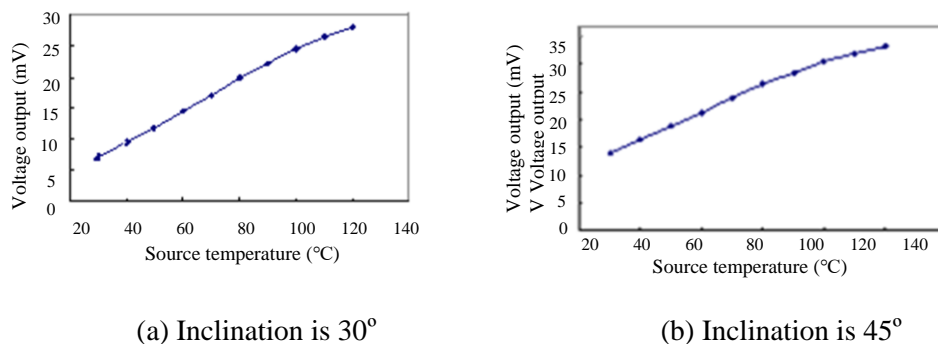
#### 3.1.1. The temperature of heat source changed and the environment temperature remained unchanged.

Keep the environment temperature at 20°C and change the heat source temperature, the temperature field cloud diagram of the same environment temperature can be obtained by numerical simulation, as shown in Fig.3.



**Figure 3.** Temperature field at environment temperature is 20°C.

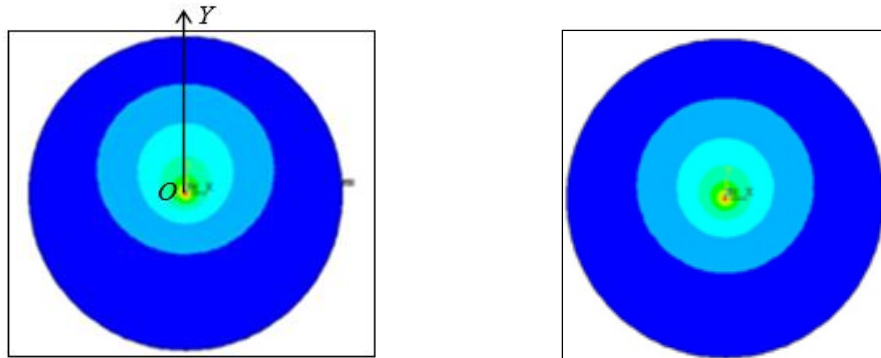
It can be seen from the Fig.3 (a), the circle formed by the temperature equivalent is basically concentric, indicating that the temperature radial gradient changes little. The center of the circle formed by the temperature equivalent line is gradually inclined upwards, indicating that the temperature radial gradient changes greatly from the Fig.3 (b). Therefore, under different heat source temperatures, the temperature distribution of the flow field in the closed cavity varies. The larger the temperature of the heat source, the greater the radial gradient of the temperature. That is, the greater the temperature difference between the heat source and the environment, the greater the temperature gradient. The relationship between the temperature of heat source and the voltage output of the bridge (condition on the same environment temperature) as shown in Fig.4. From the experimental results, it can be seen that when the temperature of the heat source changes, the output of the voltage changes for the same inclination, because variation of temperature field leads to measurement changes according to sensitive mechanism.



**Figure 4.** The relationship between the temperature of heat source and the voltage output.

3.1.2. The heat source temperature is constant and the environment temperature changes. Keep the heat source temperature constant at 100°C and change the ambient temperature, the temperature field

cloud diagram at the same heat source temperature can be obtained by numerical simulation, as shown in Fig.5.

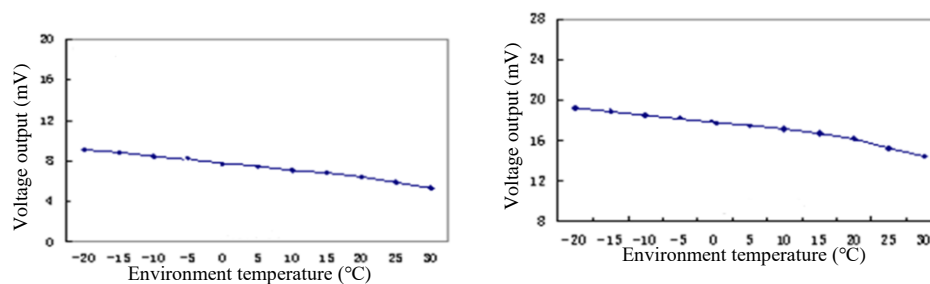


(a) Environment temperature is 20°C

(b) Environment temperature is 50°C

**Figure 5.** Temperature field at source temperature is 100°C.

From the simulation results, it can be seen that when the environment temperature is lower, the larger the temperature gradient of the formed flow field. When the environment temperature is higher, the flow gradient is smaller. That is, the greater the temperature difference between the heat source and the environment, the greater the temperature gradient, on the contrary, the smaller.



(a) Inclination is 30°

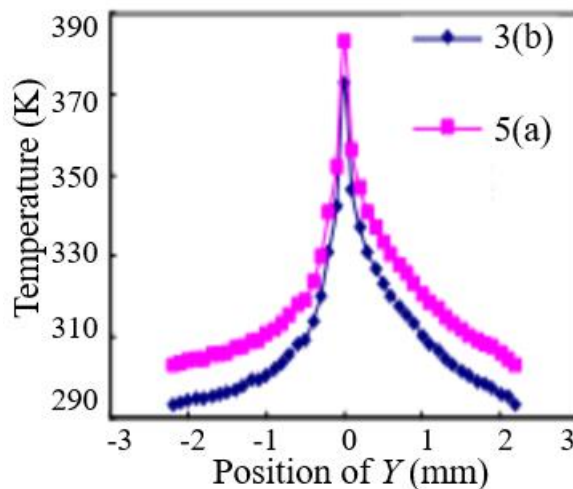
(b) Inclination is 45°

**Figure 6.** The relationship between the environment temperature and the voltage output.

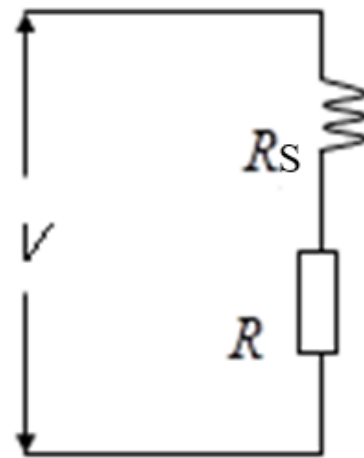
Relationship between the output voltage and environment temperature (condition on the same temperature) as shown in Fig. 6. It can be seen that when the ambient temperature changes, the voltage output of the sensor will change, that results in errors in the measurement of inclination.

*3.1.3. The difference between heat source and environment temperature remains unchanged.* From what discussed above, temperature gradients formed in closed chambers should be consistent on the condition of the temperature difference between heat source and environment remains unchanged. That means temperature gradients of Fig.3 (b) and Fig.5 (a) are same. The following methods can be used to make it more intuitive to show that the temperature gradients of the two graphs are the same.

Select the position of the upper point of the Y-axis as the horizontal coordinate in the two temperature cloud charts, the temperature of the corresponding point is a vertical coordinate, the relation curve is obtained. The temperature gradient of the two temperature fields is basically the same as shown in Fig.7. Similar flow fields can be obtained keeping the difference between heat source temperature and ambient temperature constantly.



**Figure 7.** Comparison of two temperature gradients.



**Figure 8.** Designed compensable circuit.

### 3.2. Application of temperature field.

Characteristics of changes in temperature field: the environment temperature is constant and the heat source temperature rises, the gradient of temperature field changes and the voltage output characteristic changes. The heat source temperature is constant and the environment temperature rises, the gradient of temperature field changes and the voltage output characteristic changes also. But when the temperature difference between the heat source and the ambient temperature remains constant, the gradient of the temperature field remains unchanged. The voltage output lies on the temperature difference between two sensitive wires, the output performance will not change. To maintain the stability of the output performance of the sensor, the gradient of the temperature field must be maintained unchanged. Compensable circuit can be designed, as shown in Fig.8.  $R_S$  is resistor of heat source.  $R$  is composed of ordinary resistors and thermistors.  $R_S$  and  $R$  is in series. Maintain temperature difference between heat source and environment temperature constantly by the circuit, which can improve the stability of the sensor. After adding the compensation circuit, the voltage output drift has been reduced at least 70%. For specific discussion can be seen in [6]. The output performance of the sensor can be greatly improved by using the characteristics of the temperature field.

## 4. Conclusion

The temperature field in different heat source temperature and the temperature field in different environment are discussed separately based on sensitive mechanism. Conclusion as follow: As heat source temperature changes, the temperature field of the closed cavity is changed; As environment temperature changes, the temperature field of the closed cavity is changed; The temperature difference between the ambient temperature and the heat source temperature is invariant, the temperature gradient of the closed cavity is unchanged; According to the characteristics of the temperature field, a compensation circuit can be designed to improve the performance of the sensor.

## Acknowledgments

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## References

- [1] Zhan, H.R, Foundation of Engineering Heat Transfer, China Petrochemical Press, Beijing, 2014.
- [2] Zhang. F.X, Pendulum characteristics of gas in hermetic chamber. Chinese Journal of Electronics, vol.27 (11), 1999, pp.141-142.
- [3] Zhang. F.X, Pendulum characteristics of natural convection and its application in sensor. Chinese

- Engineering Science, vol.4 (8), 2002, pp.50-53.
- [4] Li, L.M, ANSYS Finite Element Analysis practicality Course of Study, Tsinghua University Press, Beijing, 2005.
  - [5] Zheng, Y.H, Peng, S.L, Analysis of Stream Field of Gas Pendulum Tilt Sensor, Microelectronic Technology 2007, 7/8 242-244.
  - [6] Zheng, Y.H, Peng, S.L, Designs for Temperature Circuit Based on Fluid Similarity, Piezoelectrics&Acoustooptics, vol, 32 (2), 2010, pp. 223-225.