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# Influence of heat source location on the performance of air-flow inclination sensor

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# Influence of heat source location on the performance of air-flow inclination sensor

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**Abstract.** According to sensitive mechanism of air-flow inclination sensor, discussing the influence of heat source location on zero output, sensitivity, resolution and response time of the sensor. If the heat source deviates from the centre in horizontal direction, zero output is not zero. If the heat source deviates from the centre in vertical direction, sensitivity and resolution are decreased, while response time is increased. For resolving these problem a solution is proposed finally. Results show this method may reduce the influence of heat source location on the performance of air-flow inclination sensor.

## 1. Introduction

Inclination sensor used in attitude measurement of carrier is a very important kind of sensor.For air-flow inclination sensor its mass is small, and the inertia force produced by the large impact or high overload is small, so it has strong anti-vibration or impact ability. Now it has been widely used in missile, ship, tank fire control system, robot attitude control system and so on [1,2].

Sensitive mechanism of air-flow inclination sensor is shown in Figure 1. A heat source and two hot wires are placed in a hermetic chamber. A heat source is placed along axis of the chamber, hot wires are placed symmetrically and compose the arms of bridge circuit. When the sensor is in horizontal state two hot wires sense the same temperature of fluid flow, their resistances are equal. The output of bridge circuit is zero. When sensor is in tilt state two hot wires sense the different temperature of the flow, the corresponding resistances are not equal to each other. The bridge outputs a voltage signal corresponding to the angle.


(a) Horizontal state (b) Tilt state

**Figure 1.** Schematic diagram of air-flow inclination sensor

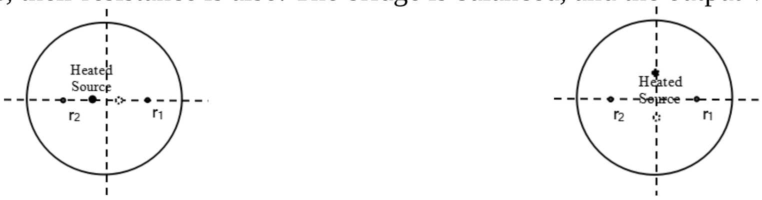
Adopting finite element method [3], the distribution of the flow field caused by the heat source at the middle point of a two-dimensional closed cavity is calculated, by modelling, dividing grids, loading and solving, etc. Under the different environmental temperature, because of the change of flow fields, performance of inclination sensor is changed. About the influence of environmental temperature on performance of inclination sensor is also discussed in [4]. Meantime the influence of heat source temperature on the performance of air-flow sensors has been discussed in [5].

## 2. Influence of heat source location on the performance of sensor

The position of heat source is also very important, which is often neglected. In many cases, there is no discussion. In the light of the sensitive mechanism of air-flow inclination sensor, it can be seen that the natural convection in the closed chamber is caused by the heat source. Therefore, the natural convection in the closed chamber is different because of the different location of the heat source, which will affect the performance of inclination sensor.

### *2.1. The effect on the zero position output of sensor*

Zero position output is the voltage output of the bridge when the inclination is zero. The heat source is located in the centre of the sealed chamber, and the two hot wires are symmetrically placed on both sides of the heat source. As the inclination of the sensor equals zero, the temperature of the two hot wires is the same, their resistance is also. The bridge is balanced, and the output voltage is zero.




(a) Horizontal deviation (b) Vertical deviation

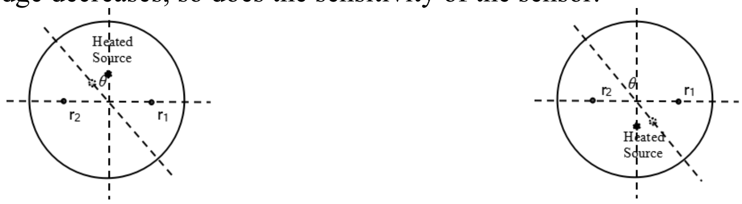
**Figure 2.** Diagram of heat source deviation from centre

When the position of heat source in the enclosed cavity deviates from the centre to the left (solid black spot) or to the right (hollow point), as shown in Figure 2(a), because of the deviation of the heat source from the centre horizontal direction, the position of the two hot wires relative to the heat source has changed, so the position of the two hot wires in the flow field is not symmetrical, there is a temperature difference between the two hot wires. Obviously at zero position, the bridge has a voltage output. The experiment result shows the relative centre of the heat source deviates to the left and the distance between the two hot wires and the heat source is 0.5mm and 1mm respectively, the temperature difference between the two hot wires is about 5.4℃ and the zero output of the bridge is 7.2mV. The position of heat source has an effect on the zero output of the sensor visibly. The bigger the deviation, the bigger the temperature difference. However, when the heat source deviates from the centre in the vertical direction, as shown in Figure 2(b), it can be seen that the two hot wires are still symmetrical relative to the heat source. Consequently, the temperature of the two hot wires is the same, so the resistance is. The bridge is balanced, and the voltage output is zero. Apparently, the heat source deviates from the vertical direction, does not affected the zero output of the bridge.

### *2.2. The effect on the sensitivity of sensor*

Sensitivity of the sensor is defined as $\mathrm{d}V/\mathrm{d}\theta$, $\mathrm{d}V$ is the output voltage of the bridge when the inclination of the sensor changes $\mathrm{d}\theta$. According to the working principle of the inclination sensor, it depends on the temperature difference between the two hot wires in the temperature field before and after the angle changes. The deviation of the heat source in the vertical direction has no effect on the zero output, so what effect does it have on the sensitivity of the sensor?

Figure 3(a) is the installation diagram with the heat deviates upward from centre. It can be seen that as the cavity is inclined, the position of the vertical direction of the heat source also changes (hollow points in the figure), the flow field in the cavity also changes with the different inclination angle. Although the relative position between the two hot wires and the heat source remains unchanged, due to the change of the vertical distance between the heat source and the cavity, the flow field in the cavity is not symmetrical, the temperature of the two hot wires is different, and the bridge has voltage output. Similarly, the same is true when the position of the heat source in Figure 3(b) is vertical downward. Figure 4 shows the voltage output of the bridge as the heat source is above or below, and compare these with that when the heat source is at the centre. From the experimental results, it can be seen that when the position of heat source is up or down in the vertical direction, the output voltage of the bridge is smaller than that in the normal position of the centre, the slope of the curve becomes smaller after linear fitting, namely the sensitivity of the sensor becomes smaller. When the heat source is above or below, the temperature difference between the two hot wires decreases, and the output voltage of the bridge decreases, so does the sensitivity of the sensor.




(a) Above the centre (b) Below the centre

**Figure 3.** Diagram of vertical deviation centre of heat source

*2.3. The effect on the resolution and response time of sensor*

Resolution refers to the difference between the output voltage of the bridge before and after inclining the sensor to 0.01°. From the sensitivity measurement of the sensor in Figure 4, it can be seen that the resolution of the sensor is smaller than that of the central position of the heat source with the position of the heat source is above or below. The output voltage difference of airflow inclination sensor is not less than 0.5mV in practical application. Because of the heat source position deviates, the experimental measurement value is only about 0.15mV with the below position after signal amplification.

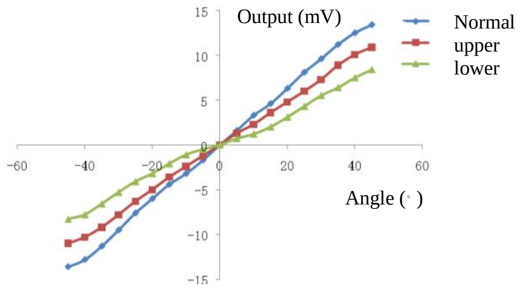



**Figure 4.** Relation of bridge voltage with angle in different heat source positions

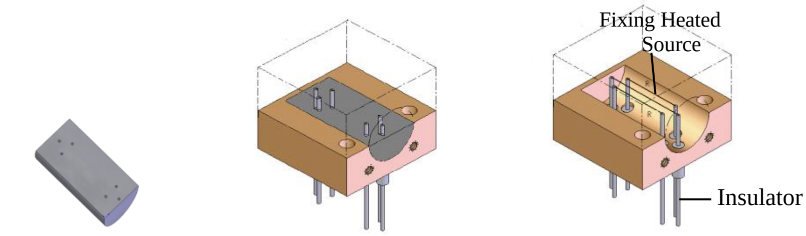
While the inclination of the sensor changes, the sensor can't respond to it immediately. Generally, there is a lag. The lag time is the response time. There are many factors affecting the response time of the sensor, such as the structure of the cavity, the material of the cavity, the conversion speed of the embedded system MCU and so on. For the inclination sensor, according to the characteristics of the air-flow, when the heat source is in the central position, the flow field of the closed chamber does not change with the change of the inclination angle. However, when the position of heat source is upper, the flow field formed in the enclosed chamber will change with the change of inclination angle. That is, as the inclination angle is different, new flow field will be regenerated. When the new flow field reaches stability, the temperature difference will be generated through the different positions of the two hot wires in the new flow field. Therefore, the response time of the sensor will be increased no matter the position of the heat source is above or blew.

Inclining the sensor through the ramp at a certain angle, then quickly twitch the slant to keep the sensor level, the required time is the response time of the inclination sensor when the signal output drops from 100 % to 36.8 %. The heat source is in the centre, the response time is less than 80ms. The heat source is up or down, however, the response time is greater than 200ms after many measurements. The greater the deviation, the longer the response time.

## 3. Resolving

From the above discussion, may see through that the location of the heat source is deviated, the performance of the sensor will be affected. Apparently the installation of heat source location is very important. This means that, the heat source and the two hot wires must be in the central horizontal plane and parallel to each other.

About the cavity structure of sensor that has been probed as in [6]. At the same ambient temperature and heat source temperature, the circular cavity is obviously easier to form natural convection and the flow rate is faster, the temperature gradient is also significantly better than the square cavity. In designing the cavity structure of the airflow inclination sensor, the circular cavity is obviously better than the square cavity.




(a) Flat, parallel calibration fixture (b)Assembly diagram (c)Sensitive cavity structure

**Figure 5.** Technological process of sensitive structure

In the sensitive structure of air-flow inclination sensor, in order to ensure that the heat source is parallel to the two heat sensitive wires on the central horizontal plane, a planar and parallel calibration fixture is designed as shown in Figure 5(a). The cavity is made of copper material and is conducive to conduction and heat dissipation with the outside world. Hot wire is made from platinum wire, the resistance of platinum wire has a good linear relationship with temperature and is resistant to high temperature. The insulator supporting the heat source and hot wire in the cavity is made of valve wire (iron, nickel and cobalt), which has good toughness. After locating and welding the insulators with the fixture of Figure 5(a), they should be placed in the tightening state for more than 10 hours as shown in Figure 5(b), so as to eliminate the stress generated during welding and ensure the parallelism between insulators. The height of insulator in the cavity is adjusted in the same plane as the calibration fixture. When welding heat sources and hot wires, attention should be paid to making them pass through the centre of insulator accurately to ensure the parallelism of heat sensitive wires, as shown in Figure 5(c). At the same time, due to the use of fixture, not only can reduce the influence of the deviation of heat source position on the performance of sensors, but also can ensure the consistency of products. It greatly reduces the debugging time of the product and improves the productivity of the product.

Comparison between without the mold and with the mold is shown in Table 1. The percentage of the decrease is represented by $P_d$, which results are calculated by (1) for zero output and respond time. *B* is measurement without applying the fixture, *A* is measurement after installing the fixture.

$$P_d = \frac{B - A}{B} \quad (1)$$

The percentage of the increase for resolution and sensitivity is represented by $P_i$, which results are calculated by (2). *B* is measurement without applying the fixture, *A* is measurement after installing the fixture by signal amplification.

$$P_i = \frac{A-B}{B} \tag{2}$$

Under the conditions of using the fixture, zero output is decreased 72%, and respond time is decreased 60%, while resolution the difference between the output voltage of the bridge before and after inclining the sensor to 0.01°is increased 200%, sensitivity is increased 125%. So the use of the mould is effective and necessary.

**Table 1.** Comparison of performance changes before and after using mould

| | Before | After | Percentage |
|---|---|---|---|
| Zero output | 7.2mV | 2mV | 72% |
| Respond time | 200ms | 80ms | 60% |
| Resolution | 0.2mV/0.01° | 0.6mV/0.01° | 200% |
| Sensitivity | 40mV/° | 90mV/° | 125% |

## 4. Conclusions

The influence of the position of the heat source on the zero position, sensitivity, and resolution and response time of the sensor is analyzed in detail. When the heat source shifts to the centre position horizontally, the zero output is affected. When the vertical position of heat source is upward or down from the centre position, the zero output is not affected, but the sensitivity, resolution and response time decrease. After designing the planar and parallel calibration fixture, the insulator can be positioned and welded with this fixture, ensure that the heat source and the two hot wires are in the same plane and parallel to each other, so as to reduce the influence of the heat source position on the performance of the sensor. It can also ensure product consistency and reduce the modulation time of the product, thus improving the efficiency of the product.

## 5. References

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