# Housing design for two-dimensional air flow sensors

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***Abstract*— Two-dimensional measurement of airflow requires the design of a special housing. Key issues were the distance between the sensor surface and protective cover, as well as the attachment of the cover. Even thin cover holding needles affect the air flow inside the gap. The newly designed anemometer with improved housing geometry can measure airflow in x- and y-direction down to 0.1 m/s.**

***Keywords—flow sensor; anemometer, sensor housing; airflow profiling***

## I. INTRODUCTION

If airflow is restricted to a tube, only one dimension of the flow vector has to be measured to monitor the flow conditions in general. However, in several technical applications this is not the case, e.g. the monitoring of air flow conditions in cold storage warehouses. There, the airflow is mostly restricted to gaps between boxes or pallets inside the warehouse, thus two components (x- and y-direction) of the flow vector have to be measured. Based on a better understanding of the airflow conditions, the speed of ventilation fans can be optimized and thus reduce energy consumption [1], [2]. Monitoring of airflow at surfaces is required in several other technical applications, e.g., optimization of hydrofoils.

One-dimensional thermal flow sensors are known since several years [3]. Our sensor is based on a heater surrounded by two thermopiles. The heater is excited by pulses [4]. The transport of warmed up air by the flow causes a temperature difference between the thermopiles.

Two-dimensional measurement can be achieved by combining two sensors. The sensors are mounted with 4 mm distance orthogonal to each other on a PCB. A single chip solution with 4 thermopiles surrounding a single heater is currently being developed.

The design of the housing turned out to be one of the key challenges in the development of a two-dimensional anemometer (2DA). The sensor has to be mechanically protected by a cover, mounted in some mm distance to the PCB with the sensors. Furthermore, the cover is necessary to avoid separation of the air flow from the PCB surface.

The housing has to be open on all sides and be rotation symmetric to achieve good sensitivity independent of the airflow angle α. In the ideal case, the magnitude of the external flow $v_0$ can be reconstructed by the measured difference of the thermopile pairs $\Delta_x$, $\Delta_y$ and two calibration factors $c_x$, $c_y$.

$$\Delta_x = c_x \cdot v_0 \cdot \sin(\alpha)$$
$$\Delta_y = c_y \cdot v_0 \cdot \cos(\alpha)$$

We started our tests with a narrow gap of height $d$=3 mm between PCB and cover, resulting in a good sensitivity of our sensor for an external velocity of $v_0$=1 m/s.

But more detailed measurements with the initial housing design revealed that a quasi linear relation between $v_0$ and sensor signals $\Delta_x$, $\Delta_y$ was only observed for $v_0$>0.3 m/s. The sensitivity of our 2DA was very poor for $v_0$<0.2 m/s (Fig. 1). Furthermore, we found that the pillars, which are necessary to hold the cover, severely affect the angle dependency of the sensor signal. Purpose of this study was to increase the sensitivity at low velocities and decrease the effect of the mounting posts by improved housing geometry.

## II. EXPERIMENTAL SETUP

To analyse these phenomena we started measurements and CFD (computational fluid dynamics) simulations for different gap heights.

### *A. Wind tunnel measurements*

The 2DA was tested in a wind tunnel with a cross section of 0.2 m by 0.2 m. The velocity in the tunnel $v_0$ was set to values between 0.1 m/s and 2 m/s. A servo motor for revolving the 2DA enabled fully automated measurements.

The main part of the housing had a height of 35 mm and a diameter of 65 mm (Fig. 2) to give space for sensor electronics, battery and a radio to enable wireless measurement in warehouses. The edges, adjacent to the gap below the cover, had an elliptic bending of 4 mm by 10 mm.

### *B. Air flow simulations*

The CFD simulations were carried out by the k-ε model for turbulent airflow using Comsol Multiphysics (Comsol Inc., USA, version 5.2). The parameters of the k-ε model were kept to the standard setup. The accuracy of the simulation largely depends on the meshing, i.e. the separation of the simulated volume into small cells. The maximum cell size inside the gap was manually reduced to force approximately 20 cells over its height, resulting in total 330 000 cells and a typical simulation time of 30 minutes on an i7 workstation.

## III. RESULTS

The CFD simulations and measurements in the wind tunnel both confirmed a high influence of the gap height on the sensor sensitivity at low velocities.

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### A. *CFD simulation*

Fig. 3 gives a plot of the velocity magnitude at a vertical cross section through the housing for $v_0$=0.3 m/s. The flow field hardly penetrates into the gap. The velocity at the centre of the gap $v_c$, close to the PCB surface, is reduced to 0.1 m/s. For a more detailed analysis, $v_c$ was plotted versus $v_0$ for different gap heights $d$ (Fig. 4).

The low sensitivity for d=3 mm was confirmed by the simulation. If $v_0$ is reduced by a factor of 3 to 0.1 m/s, $v_c$ drops by a factor of 20 to 0.005 m/s. for d=6 mm there is only a little ditch in the curve at $v_0$=0.05 m/s, whereas for d=10 mm the relation $v_c$ to $v_0$ is almost linear.

Tests with modifications of the elliptic bending and the thickness of the cover showed no significant changes compared to the influence of the gap height.

### B. *Experimental verification*

The signals of the thermopiles were recorded by a 16 bit ADC (Analog to Digital Converter). The average difference for the two thermopile pairs in x- and y-direction was calculated for each measurement over the length of the heater excitation. Due to space limitations only the $\Delta_y$ signal is plotted for α=0° in Fig. 1. The curves for different gap heights confirm the low sensitivity for narrow gaps. If $d$ is increased from 3 mm to 5 mm, the signal for $v_0$=0.1 m/s is more than doubled from 0.7 to 1.8 ADC units. For $d$=6 mm the curve is almost linear for $v_0$>0.1 m/s. For higher velocities, the sensitivity slightly decreased with increasing $d$.

### C. *Angular dependency*

Beside the gap height, the influence of the pillars on the measurements has to be considered. For our first series of 2DA, the cover was mounted by 4 screws with a 3 mm thick hull each. At velocities $v_0$>0.75 m/s the hulls created eddies with severely affected the measurement, if the air flow came directly from the direction of one of the hulls (Fig. 5). Afterwards the screws and hulls were replaced by 0.6 mm thick needles. An almost sinus-shaped response curve was achieved for this modification for a gap height of 3 mm for $v_0$≤1 m/s with only slight bending of the curves for higher velocities (Fig. 6). But after increasing the gap height to 6 mm to improve sensitivity at low velocities, the signal was distorted by the needles for $v_0$>1 m/s (Fig. 7).

## IV. DISCUSSION

The design of housing for a two-dimensional anemometer is not as trivial as it looks in the first place. As the 2DA is intended to cover a measurement range with relation of >20 between lowest and highest value, the Reynolds number varies by the same factor and causes substantial changes in the flow patterns. Air flow does not show a linear behaviour at low velocities as may be anticipated. Instead, the air takes rather a detour to avoid narrow gaps. The gap height had to be doubled to 6 mm to achieve a good sensitivity.

The mounting of the cover turned out to be the second critical design issue. The pillars have to be as thin as possible, although a certain thickness is required for mechanical stability. The thickness of the boundary layer with almost zero airflow has also to be considered because it limits the effect of further reduction of the pillar diameter.

A good result was achieved with needles of 0.6 mm diameter for a gap height of 3 mm. The Reynolds number increases with the gap height. Thus, the life-time of vortices, formed at the needles, also grows with the gap height until they reach to the sensor element in the centre and distort the measurement as for $d$=6mm.

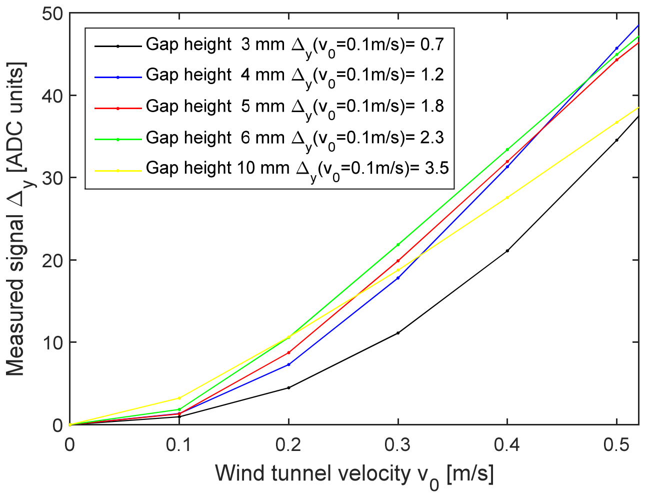

Fig. 1. Measured sensitivity of the thermopile pair in y-direction

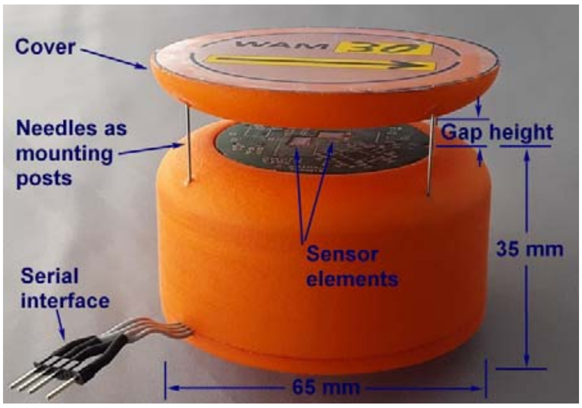

Fig. 2. Two-dimensional anemometer with 8 mm gap height

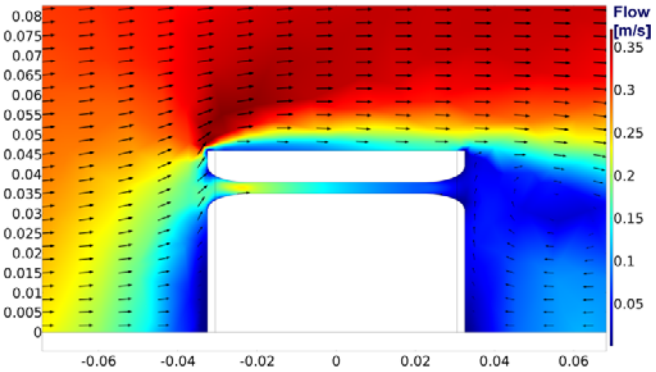

Fig. 3. Air flow magnitude for wind tunnel speed $v_0$=0.3 m/s and gap height $d$=3 mm. Dimensions in m, flow in m/s

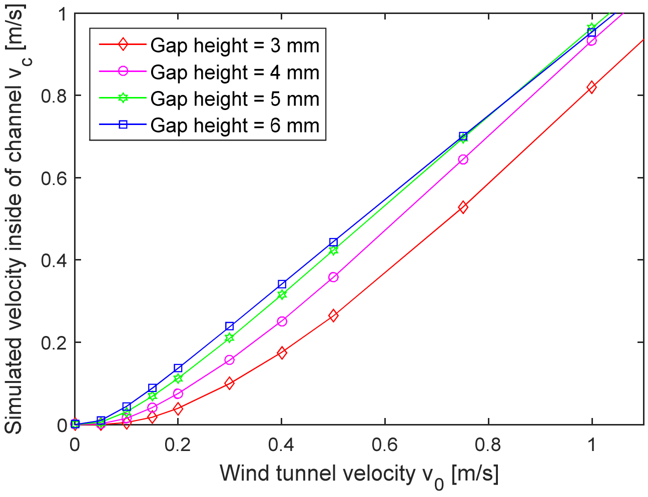

Fig. 4. Sensitivity of the thermopile pair in y-direction for different gap heights by simulation

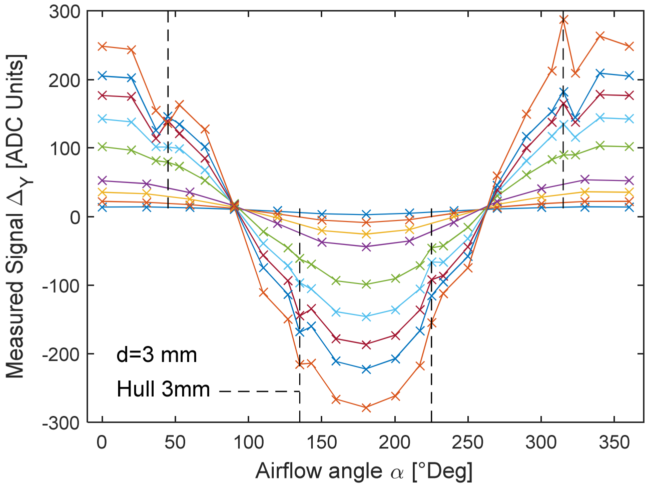

Fig. 5. Dependency of thermopile signal for different angles and velocities. Gap height d=3mm. Cover fixed with 4 hull of 3 mm diameter. For color legend see Fig. 6. Position of hulls marked by dotted line.

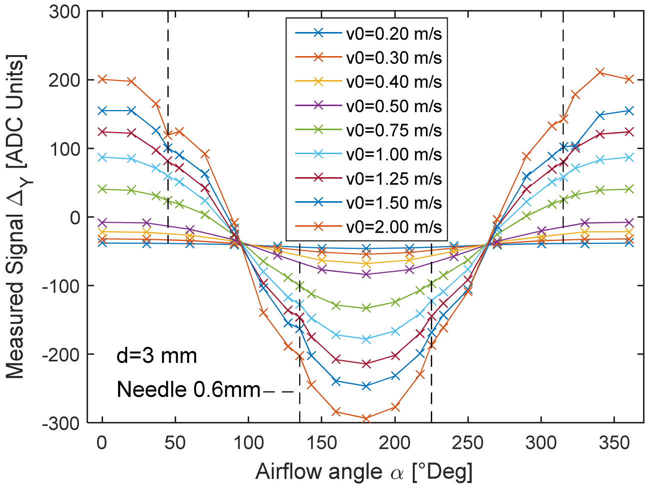

Fig. 6. Thermopile signal for d=3 mm and needles of 0.6 mm

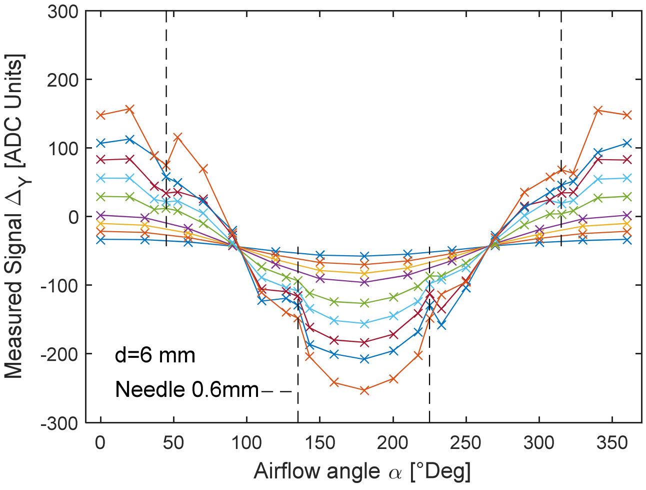

Fig. 7. Thermopile signal for d=6 mm and needles of 0.6 mm

## V. CONCLUSIONS

Our results show that it is necessary to find a trade-off for the gap height between sensitivity at low velocities and distortions at high velocities. Alternatively, the gap height could be optimized for the expected measurement range.

Furthermore, a truly linear or sinus-like response of the thermopiles to different angles and velocities cannot be expected. Residual deviations must be compensated by calibration and signal processing. By using more advanced signal processing, it may also become possible to reduce the effect of the needles, although further research is necessary.

With adequate housing, it is possible to achieve two-dimensional air velocity measurement for small flows of 0.1 m/s, which makes it possible to monitor the effects of reduced fan speed in cold storage warehouses. For accurate measurements at higher velocities > 1.5m/s, it is necessary to reduce the gap height.

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