AIR SPEED SENSOR FOR MEASURING NATURAL CONVECTION IN DRYERS AND STOREHOUSES

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Abstract: The development of the quality control and the energy conservation needs more and more sophisticated methods in the post-harvest technologies i.e. the drying and the storage. To develop advanced methods detailed measurements are necessary to be carried out on the state of the product and the surrounding air. In this paper the development of a low range air speed sensor for this purpose is presented. During the work the commercially available sensors were analysed, from where the necessity of the development of a new sensor is shown. The analysed measuring approaches are presented with the advantages and disadvantages of the applied thermal principle. Modelling was elaborated for the sizing of the sensor and for simulation of the operation of the sensor under different conditions. As a prototype of the sensor was developed. Some control measurements are presented, as well. *Copyright © 2005 IFAC*

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1. INTRODUCTION

Concerning the post-harvest processes beside the energy going impacts the quality issues remain the most determining factor.

For most of the agricultural products the quality control means post-harvest treatments (cleaning, drying, conservation) and proper storage. The air ventilation for a part of these techniques (drying, storage) is essential. In some cases artificial ventilation is used for the higher airflow, but for some cases the natural ventilation is enough to provide enough fresh air. Such kind of conditions is occurring for example during solar drying or for long time storing of given products. But to achieve the proper natural airflow pattern, the measurement of the flow is very important. The accurate measurement of a low range (0,01 – 0,2 m/s) air speed is not a simple task, but there are a few solutions for it. In the next chapter the used methods and equipment will be considered, but as it will be shown, all of the commercially available equipment has some disadvantages for the desired conditions.

This is the background why the Department of Physics and Process Control, Szent István University Gödöllö, Hungary and the Department of Post-harvest Technology, Institute of Agricultural Engineering Bornim (ATB), Potsdam, Germany has started a common research on developing a low range (natural convection) air speed sensor.

The aim is to develop a sensor, which can be load to a pile of the agricultural products together with the product. The commercially available low range sensors are not fit to this need because of the mechanical impact during the load. Another important aspect if the sensor can be used with a normal data logging system (which does not need a special individual meter), what is not general for the law range sensors. This reason is important if we want to use bigger number of sensors for measuring the air flow distribution inside a pile.

2. SENSOR SURVEY

The different air flow meters can be categorized from different aspects, now it is done on the basement of the physical principle they use. The measurements generally mean energy transformation from one form of energy to another one. In case of flow measurement it means, that we convert the kinetic energy of the flowing medium to another kind of energy.

Categorization and short analysis of the used flow meters are as follows (Benedict, 1984; Upp and LaNasa, 2002):

- *Mechanical meters*

  Rotational anemometer, turbine
  Elbow (centrifugal) meter
  Coriolis meter

The mechanical meters can not fulfill the requirements of the aim, as generally they are not sensitive enough (the mechanical movements and friction needs more energy than the energy of the air in the low range), so this category was considered later on.

- *Meters based on the Bernoulli law*: (Sensors rely on the pressure drop or head occurring as a fluid flows by a resistance)

    Orifice meter
    Flow nozzle
    Venturi tube
    Pitot tube

This kind of meters give an important class of the velocity measurements, but considering the low air density and low air speed, the pressure difference is too small to detect accurately.

- *Magnetic meters*

  A nice principle, but the magnetic properties of the air are not good for it.

- *Meters based on acoustical or optical waves*

    Ultrasonic meters
    Time-of-travel meters
    Laser Doppler anemometer

These type of meters measure very precisely, but they can not be used to measure inside the pile. However during the calibration of the developed sensor, a laser Doppler anemometer is planned to use.

- *Meters based on thermal effects*

    Hot wire anemometer

The hot wire anemometer working well for low range air speed measurement, but it has a special measuring head, what is very sensitive for the mechanical impacts, so it can not be loaded to a pile. Another disadvantage is that the sensor can not be connected directly to a data logging system, it needs a special meter.

3. THE SELECTED MEASURING PRINCIPLE

As there was no ideal sensor for the purpose, the development of a new sensor was decided, with the principle (we call it thermal principle) as follows:

There is a heating element with a power of few watts in the air and a temperature sensor (e.g. a PT100 temperature dependent resistance) is fixed around it. With now flow through the system the sensor gets some heat from the heat source what can be measured by measuring the temperature of the sensor. But if there is airflow from the direction of the heating element, then the absorbed heat and the temperature of the sensor will be changed. This idea proper for measuring only one direction component of the air flow, but building a symmetrical setup with two PT100 sensor it can measure the all the flow direction in one dimension. The setup of the sensor for one dimension can be seen in Fig. 1.
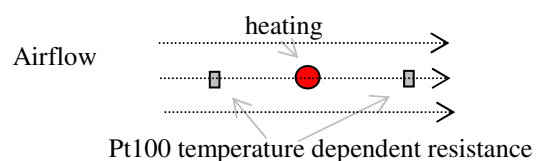

Fig. 1. Schematic figure of the developed sensor

4. MODELLING

After the defining of the proposed setup a modeling was started to simulate the behavior of the sensor, and to determine some basic quantities. The simulation was done with the ANSYS software, which has a special unit for dealing with fluid dynamics. This Computational Fluid Dynamics (CFD) package can handle laminar and turbulent flow, compressible mediums with heat transfer, and

can be used for steady state and transient models as well (ANSYS CFD Flotran, 1994).

First the model of a wind channel was set up with a steady state 2 dimensional model. In the model a constant (time independent, but changeable) inlet air speed was used on the left side of the channel, the boundary conditions on the side of the channel were to set to zero air velocity for each coordinate, and the pressure at the right side of the channel was set to equal to the surrounding pressure (ANSYS Operation Guide, 1996). The flow pattern in case of 0.1 m/s inlet airspeed for this model can be seen in Fig. 2.

NODAL SOLUTION
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VSUM
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SMX =.127206

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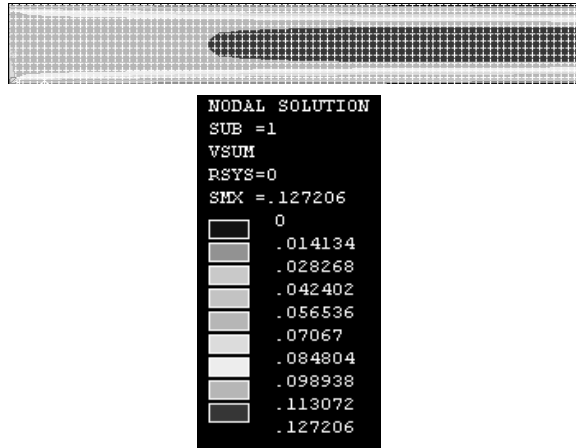
Fig. 2. The flow pattern in the wind channel model
(values in m/s)

This model was developed by installing a heating element in the middle of the wind channel. For this model the temperature field of a 0,1 m/s inlet velocity air is graphed in Fig. 3.
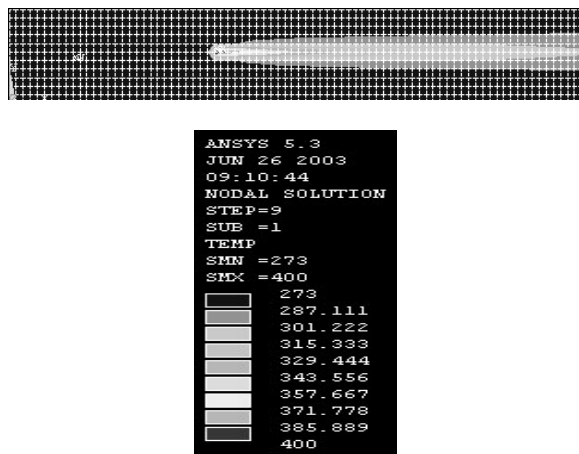

ANSYS 5.3
JUN 26 2003
09:10:44
NODAL SOLUTION
STEP=9
SUB =1
TEMP
SMN =273
SMX =400

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        287.111
        301.222
        315.333
        329.444
        343.556
        357.667
        371.778
        385.889
        400
```

Fig. 3. Temperature filed of the wind channel with
heating element (values in K).

For lower air speeds the effect of the buoyancy is stronger, as it is graphed as a result of the model with 0.01 m/s inlet air speed in Fig. 4.


```
        273
        287.111
        301.222
        315.333
        329.444
        343.556
        357.667
        371.778
        385.889
        400
```
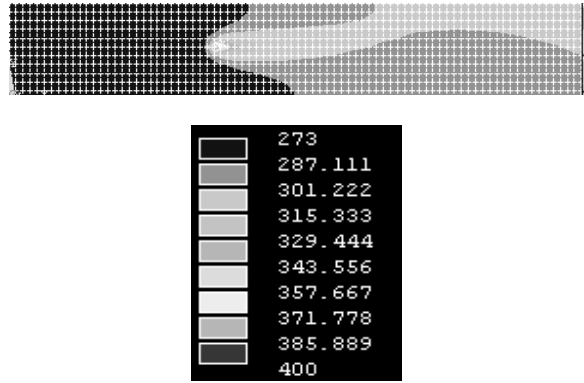
Fig. 4. Temperature field of the model wind channel
for low speed (0,01 m/s) inlet air (values in K)

As the principle of the developed sensor is based on the changing of the temperature in the middle of the wind channel, a special graph for that is shown in Fig. 5. The figure shows that the principle was considered can work, as installing two Pt100 sensors for the two sides of the heating element, represented by the peak in the temperature distribution graph, there are different air temperatures (273 K and 300K in our case) which cause so big difference in the resistance that it can be measured accurately.
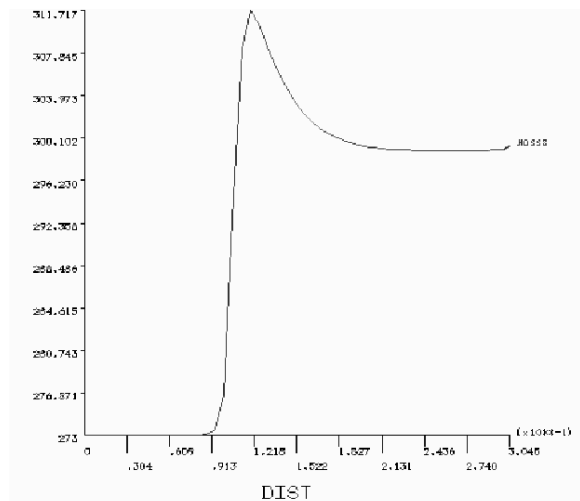

Fig. 5. Temperature changing along the axis of the
wind channel

5. PROTOTYPE SENSOR AND CALIBRATION

Parallel with the modeling construction of a prototype of the proposed sensor was started. The prototype consists of a maximum 10W/12V heating element and two Pt100 temperature sensors symmetrically to the heating. The picture of the prototype can be seen in Fig. 6.
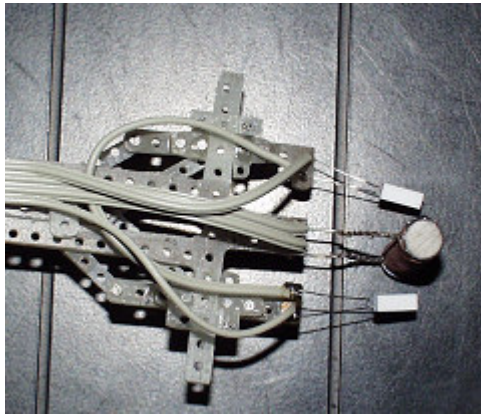
Fig. 6. The prototype of the developed sensor

As this prototype is planned to test the principle under different circumstances, the distance of the sensors from the heating can be changed by a mechanical equipment, where the common distance can be regulated by a screw.

The sensor prototype was tested in a wind channel. The sensitivity of the sensor was measured by measuring the time constant of the Pt100 resistance in resting air. (In flowing air the time constant should be smaller).

From the results 31 s time constant was considered for the used Pt100 resistance in resting air environment as can be seen in Fig. 7. This means a relatively slow sensor, but it is enough for the proposed aim, as fast changes are not usual in the storehouses and dryers.
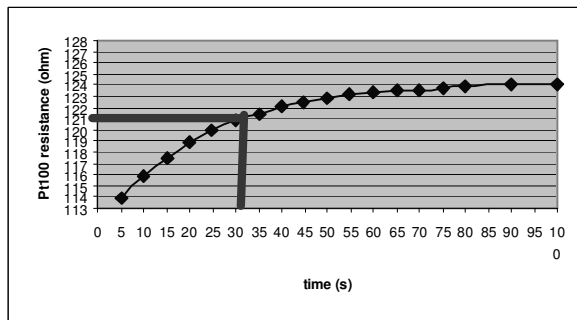
Fig. 7. Determination of time constant for Pt100 sensors in air

The symmetrically installed Pt100 sensors were connected to a Wheatstone bridge to convert the resistance sign to voltage, and to make the device direction dependent. The scheme of the connection is shown in Fig. 8.
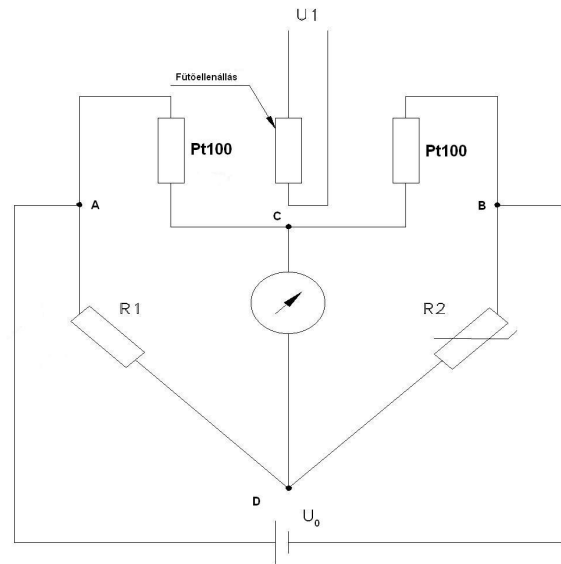

Fig. 8. The Wheatstone bridge connection of the sensor

With the Wheatstone bridge the sensor was tested in wind channel. The first results are graphed in Fig. 9. In the figure the output voltage of the Wheatstone bridge is graphed against the air velocity in the middle of the channel (where the sensor was fixed) with different Pt100-heater distances.
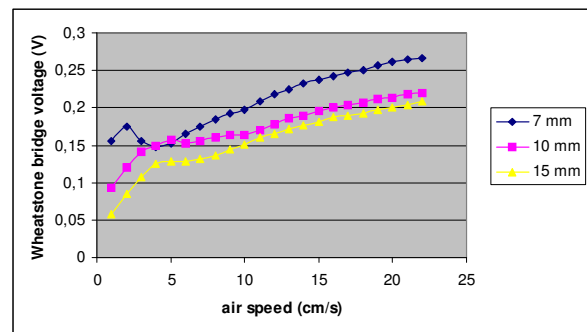

Fig. 9. Calibration results for the prototype with different Pt100-heater distances

The calibration of the sensor was performed in the Department of Post-harvest Technology, Institute of Agricultural Engineering Bornim (ATB), Potsdam, Germany, where a sophisticated wind channel is available.

6. TWO DIMENSIONL SENSOR DESIGN

As the prototype of the one dimensional sensor was developed and measured, as a continuation of the work, development of a two dimensional sensor was initiated. As because the air flow in the vertical direction is much more complicated as in the other two directions, first a horizontal two dimensional model was developed.

For the measurement of this temperature distribution, a two dimensional (horizontal planar) measuring equipment was developed and constructed. During the measurements the parameters of the heat flow generated by the heating element was examined with a planar grid constructed from Pt100 thermo sensors. The platinum thermometers were situated in the grid-points of a 1 cm division set for which the resistances of the Pt100 sensors, such as the temperature distribution,were measured in case of different airflow velocities. In the middle of the Pt100 grid-points a heating elements was operated, whose superficial temperature was measured by an infrared sensor.

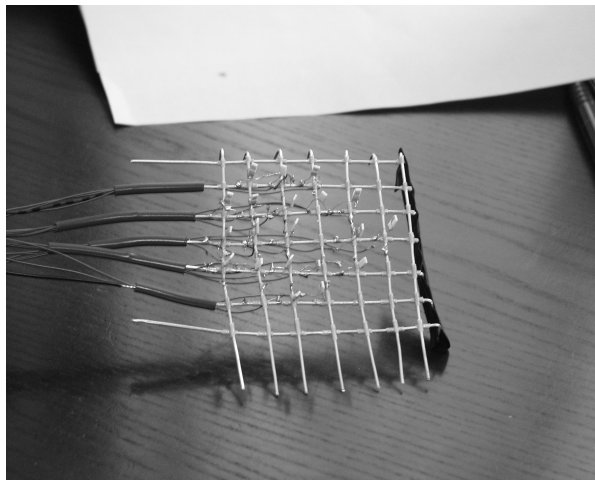The picture of the planar grid arrangements developed for measuring purposes can be seen in Fig. 10.

Fig. 10. The developed planar grid with Pt100 sensors

From the measured data the temperature distribution can be get along the grid. The temperature distribution depends on the heat convection from the heating element to the measured points. The distribution can be get from the measured resistance data, but it can be read from the thermo-camera photos, as well.

From the camera photos a bit harder to get beck exact measurement data as the results are coded in colours. This method is very useful for visualizing the result, but much harder to get back exact numbers for the modelling. Because of this reason the modelling was based in the Pt100 resistance data.

In spite of its un-exactness the camera photos were used for demonstrating the working principle of the sensor. In the following a photo set (Fig. 11a-d) will be presented, from which the changing of the temperature distribution around the heating element can be seen as the air speed was changed.

These kinds of thermo photo sets were taken not only as a function of air speed, but as a function of different heating power as well. The photo set of temperature pattern shown in Fig. 10a-d were taken with the power of 10 W.

From the photos it can be seen, that with the growing air speed the temperature values are going down (the cooling effect of the airflow) and that the temperature distribution is changing.
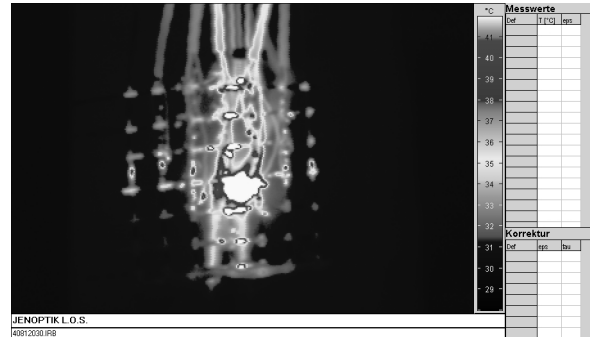

Fig. 11a Temperature patter at airspeed of 0,1 m/s
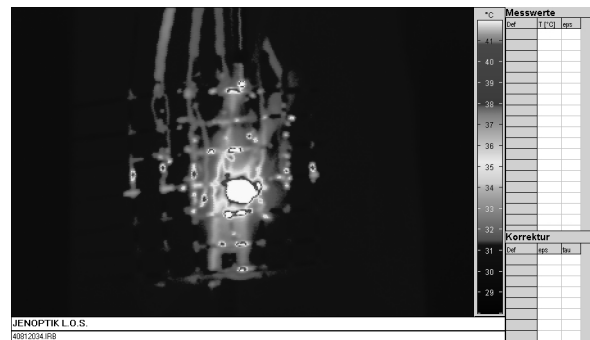

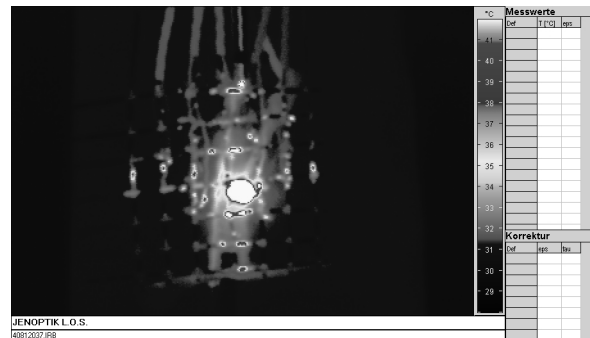Fig. 11b Temperature patter at airspeed of 0,3 m/s

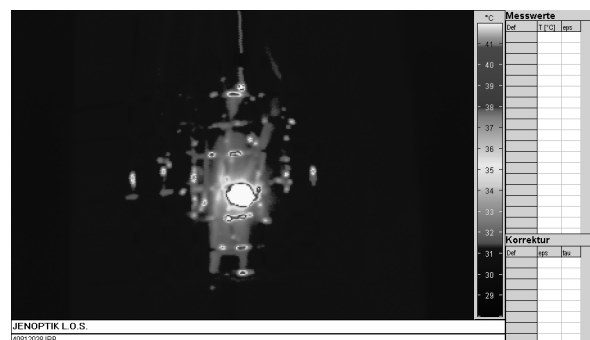Fig. 11c Temperature patter at airspeed of 0,5 m/s

Fig. 11d Temperature patter at airspeed of 0,8 m/s

7. CONCLUSIONS

- The natural ventilation range air speed measurement is not solved inside a pile of agricultural product, what was the initiation to develop a new sensor.

- After analyzing the used method the thermal principle was chosen, where the airflow has effect on the convective heat transfer from a heating element to the Pt100 resistance.

- The modeling of the process was carried out by the CFD unit of ANSYS software.

- A prototype of the sensor was built, and for experimental purposes a wind channel was set-up.

- For the two dimensional modeling a planar grid was developed, where Pt100 thermo sensors were used to measure the temperature distribution in special grid points.

- The results of the measurements and the modeling are further comparison.

ACKNOWLEDGEMENTS

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