DEVELOPMENT OF AN ANEMOMETER FOR MEASURING AIR FLOW VELOCITY IN AGRICULTURE

Ionuț Alexandru DUMBRAVĂ [1], Petru Marian CÂRLESCU [1], Ioan ȚENU [1]

e-mail: ionut.dumbrava@iuls.ro

Abstract

This paper presents the construction and calibration steps of a hot-wire airflow sensor (anemometer) using an incandescent filament as the sensor. Due to the properties of the filament, its high melting point and the materials from which it is made, the light bulb filament allows the filament to heat up when electric current is passed through it without the filament oxidising rapidly. The paper also describes the aerodynamic calibration of the filament sensor using a calibrated anemometer (testo 405i) as a reference point. The experimental results following the calibration process confirm that the electrical resistance of a conductor can be successfully used to measure airflow.

Key words: anemometer, hot wire, wind sensor, light bulb filament

Air flow velocity is an important parameter that needs to be regularly measured and monitored both in scientific research and in many fields of industry (Russo G. P., 2011). The problem with all anemometers is the certainty with which the measurement is performed (Lečić M. R., 2009).
A hot-wire anemometer is an instrument for measuring the air flow velocity with a sensor that is composed of a thin tungsten or platinum conductor of small dimensions, with a diameter of 5 µm and a length of a few millimeters. (Lundstr H., 2021). However, when an anemometer is used under conditions of high air flow velocity, due to high fragility, the sensor deteriorates (Korprasertsak N. *et al*, 2020).

There are several constructive types of hot-wire anemometers, Lia Z. et al. made a hot-wire anemometer using optical fiber. Experimental results showed that the measurement error is ±0.15 m/s in the range of 0 - 6 m/s. The hot-wire anemometer is widely used to measure air flow velocity. The working principle of the hot-wire anemometer is based on the convective heat transfer between the outdoor environment varying with the air flow velocity and the hot wire. (Khamshah N., 2011, Ardekani M.A., 2008).

Another principle of operation of hot wire anemometer is by keeping the sensor temperature constant. The electrical resistance of the sensor determines the value of the air flow velocity by means of an experimentally established relationship between the air flow velocity and the supply current. The disadvantage of such a constant-temperature hot-wire anemometer is that it can produce electromagnetic signals that influence the accuracy of measurements (Ligęza P., 2021).

The sensor of the anemometer is connected to a voltage source and is heated by the Joule effect. The sensor operates at constant temperature, so that the temperature of the sensor filament is maintained at a constant value regardless of the air flow velocity and the temperature of the outside environment. The electrical power supplied to the sensor to maintain its temperature can be correlated with the air flow velocity. This is accomplished by calibration to known air velocities. It has been shown that a 2.5 µm hot-wire sensor performs well in the velocity range 0.3 - 30 m/s and but at temperatures up to 30 ^{0}C (Lundström H., 2021). An anemometric sensor calibration method is based on moving the hot-wire sensor through air (Al-Garni A. M., 2007).

The measurement technique using the hot-wire anemometer is an indirect method to measure the air flow, on the output of the sensor is a voltage signal. Therefore, the calibration process is the most important step in the construction of an anemometer for efficient and accurate air flow velocity measurement (Özahi E. *et al*, 2022).

In this paper, the construction and steps of the calibration process of an anemometer sensor using a wind tunnel are presented. The experimental determinations of the air flow velocity being related to the results obtained with a hot-wire anemometer with calibration certificate. The measuring range of the anemometric sensor is 0 - 3 m/s.

MATERIAL AND METHOD

A Tungsten filament from a light bulb (HELLA R5W) with a supply voltage of 12V, power of 5W and a resistance of 2.4 Ω was used as an anemometric sensor (SA) for air flow velocity measurement. The filament length is

[1] “Ion Ionescu de la Brad” Iasi University of Life Sciences, Iasi, Romania

approximately 8 mm (figure 1a). Tungsten is used because it has a high melting point and withstands high temperatures when the bulb is in operation. The SA was connected in series with a power resistor (10 W) with a value of 30 Ω. The power of the resistor is an important parameter, as it must be large enough not to allow power loss through Joule effect and not to allow measurements to be influenced by heating the resistor. The powering of the SA and the power resistor was done using a 5V voltage stabilizer (LM7805).

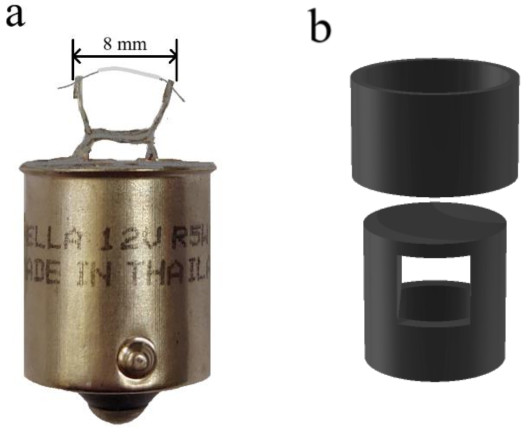


Figure 1 **Anemometric sensor**
a - bulb filament used as a sensor to determine the air flow velocity; b - body and protective cover

The airflow required for the calibration process was created by two fans with different constructive characteristics: a small V1 fan (Sunon EE92251B1) with dimensions of 92 x 92 x 25 mm and a blade diameter of 91.8 mm at a maximum flow rate of 87.5 m3/h; a large V2 fan (Sunon EEC0251) with dimensions of 120 x 120 x 25 mm, a blade diameter of 117 mm and a flow rate of 183.83 m3/h. Both fans have 12V supply voltage. Uniformization of the air flow created by the fan was achieved by a tunnel (PVC tube) with a diameter of 150 mm and a length of 1500 mm. The fans were mounted on the tunnel by means of two reducers at one end of the tunnel. The fans were powered with a ZHAXIN RXN-3050 adjustable voltage power supply unit, which allows the voltage supply to the fans to be varied.

The temperature measurement was realized with two sensors (NTC 100k), one is mounted next to the filament and measures the temperature of the airflow inside the tunnel and the other measures the ambient temperature.

To the acquisition board (Arduino Uno) are connected: two sensors for measuring temperature and SA on the analog ports, and the fan for measuring the speed is connected on one of the digital ports (figure 3).

Calibration of the anemometric SA sensor was done with the anemometer (testo 405i-calibrated) used as a reference. The measurement range of the air flow velocity is 0 - 30 m/s. In the range 0 - 2 m/s, the measurement accuracy is ± 0.1 m/s, and in the range 2 - 15 m/s the accuracy is ± 0.3 m/s according to the calibrated specifications. The testo 405i anemometer can be connected to a telephone via Bluetooth and thus acquires velocity and temperature data via the testo Smart application.

The Arduino IDE program was installed on the computer through which the data acquisition was performed during the calibration, where the program code for the microcontroller and the CoolTerm software for data acquisition was written. The CoolTerm program saves the recorded values in .txt format so that the data can be further processed, the file saving was done in .xls format. The connection between the Arduino Uno and the data acquisition computer was made via a USB 3.0 cable.

In order to protect the filament from the influence of air flows from the sides, the body and a protective cover were realized. The body is cylindrical in shape with a rectangular slit in its upper half (figure 1 b).

The tachometer (DT-2234C) was used to measure the fan speed.

Electrical resistivity underlies the principle of operation of the sensor. The scheme of operation comprises an SA connected in series with the power resistor fed to a voltage source. A voltmeter was connected in parallel with the filament to measure the voltage drop across the terminals of the SA (figure 2). When the SA is penetrated by electric current it heats up. When an air flow acts on it, its resistance changes and therefore, due to Ohm's law, the voltage also changes. The velocity of the air flow is determined on the basis of this change in voltage.

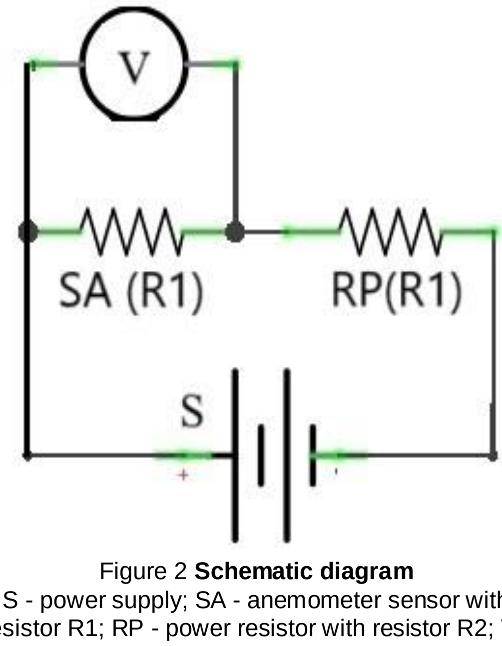


Figure 2 **Schematic diagram**
S - power supply; SA - anemometer sensor with resistor R1; RP - power resistor with resistor R2; V - voltmeter.

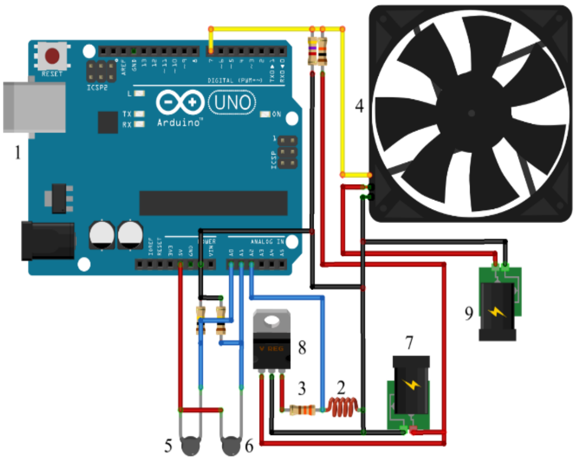


Figure 3 **Wiring diagram of the calibration stand**
1 - Arduino uno; 2 - filament (SA); 3 - resistor; 4 - fan; 5,6 - temperature sensor, 7 - 12v power supply; 8 - voltage stabilizer; 9 - adjustable voltage supply.

In order to calibrate the sensor, a stand (figure 4) consisting of a fan (4) fed from the adjustable source (5) was realized. Uniformization of the air flow created by the fan was achieved due to the length of the cylindrical tunnel (6).

The velocity profile obtained with the testo 405i anemometer (figure 5a) in the section of the air tunnel helped to position the sensor. The position of the SA (figure 5b) and the anemometer (testo 405i) at the exit of the tunnel is 2 cm vertically from the base of the tunnel.

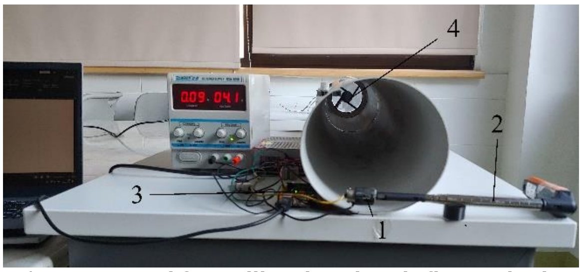
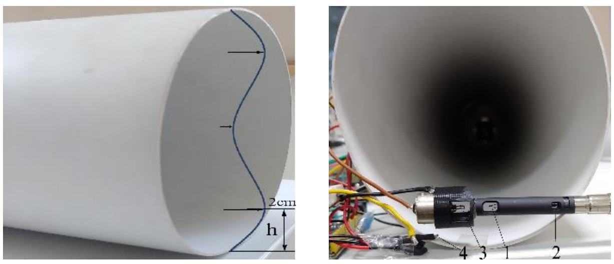


Figure 4 **Stand for calibrating the air flow velocity sensor**
1 - sensor; 2 - testo 405i anemometer; 3 - microcontroller; 4 - fan; 5 - adjustable power supply; 6 - wind tunnel.



a b

Figure 5 **Velocity profile and sensor positioning on the calibration tunnel**
1 - airflow velocity sensor (testo 405i), 2 - temperature sensor (testo 405i), 3 - SA sensor, 4 - temperature sensor; h - height; a - airflow velocity profile at the exit of the calibration wind tunnel; b - position of the sensors at the exit of the calibration wind tunnel.

The tachometer was used to measure the fan speed at different supply voltages and to compare the tachometer values with the values recorded by the microcontroller. The fan speed compensation was realized by introducing some coefficients in the relations of the programming code, thus the fan speed was accurately measured and the fan calibration was realized.

By changing the supply voltage of the fans with the adjustable voltage source, different fan speeds were obtained. The minimum speed of the fans is 900 RPM, in the case of fan V1 the maximum speed is 3300 RPM and for fan V2 the maximum speed is 3600 RPM. Fan V1 in the air tunnel produces an air flow velocity between 0 - 0,7 m/s and fan V2 in the air tunnel produces an air flow velocity between 0,7 - 3 m/s.

A microcontroller programming code was created and the following parameters are displayed in the CoolTerm program interface (figure 6): the voltage measured at the filament terminals, the fan rotation speed, the value of the temperature sensor subjected to the air flow created by the fan and the ambient temperature value.

Two temperature sensors were used in the calibration process, one encapsulated temperature sensor that was shielded from the air flow and the second one that was subjected to the air flow created by the fans. This made it possible to identify and determine the temperature difference between the environment and the temperature of the air flow created by the fans.

Calibration was performed at a temperature of 24 ^{0}C. The temperature difference between the sensor measuring the ambient temperature and the sensor measuring the air flow temperature was approximately ±0.5 ^{0}C.

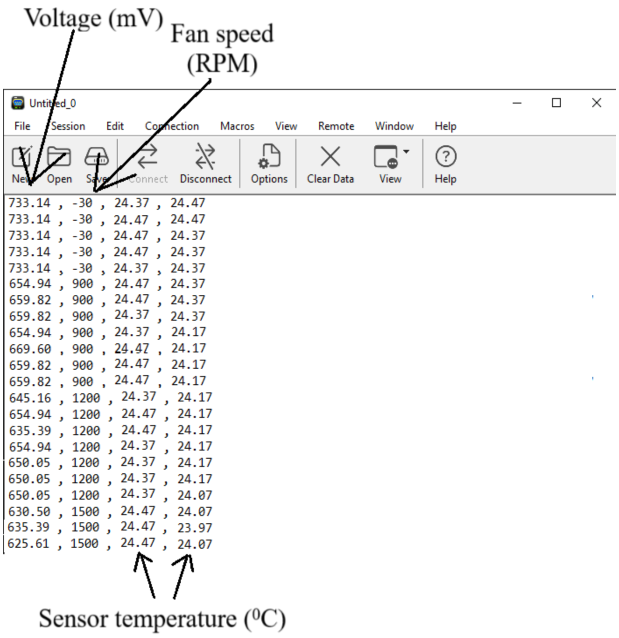


Figure 6 **Parameters displayed in the CoolTerm program interface**

Calibration started with connecting the Arduino Uno to the data acquisition computer via the CoolTerm program and the testo 405i anemometer via the testo Smart application. With the fan switched off, voltage and air flow velocity data was acquired from the testo 405i anemometer.

By changing the fan supply voltage using the adjustable source, the V1 fan speed reached 900 RPM. In parallel with the recording of the values by Arduino Uno, the air c flow velocity was measured with testo 405i anemometer. In order to increase the accuracy of the obtained values, five recordings of the same air flow with the testo 405i anemometer were made at one second intervals.

The V1 fan speed was increased by an interval of 300 RPM until the maximum speed of 3300 RPM was reached.

After performing this calibration, fan V1 was replaced with fan V2, following the calibration steps from fan V1.

Having the correlation between the electric current voltage and the air flow measured with the testo 405i anemometer, the calibration could be performed.

RESULTS AND DISCUSSIONS

After all the results were obtained, the 5 values of the air flow measured with the testo 405i anemometer were averaged with the average of the SA electric current voltages acquired by the Arduino for a given fan speed.

The plot in Figure 7 shows the results obtained after correlating the voltage with the air flow velocity.

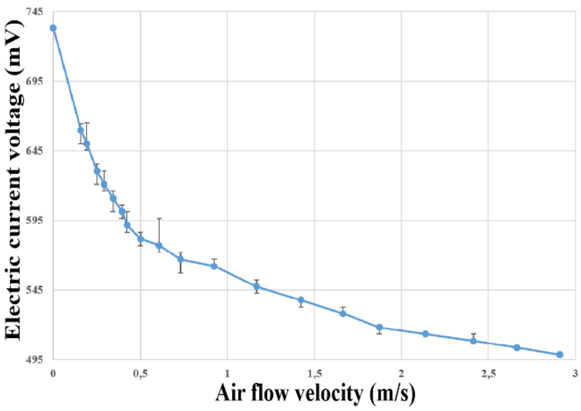


Figure 7 **Average air flow velocity - electric current voltage diagram**

The voltage values acquired by the Arduino from the SA in the range 0 - 3 m/s are about 200 mV with an accuracy of about 5 mV. In the range 0 - 1 m/s, the voltage measured by SA is about 150 mV, while in the range 1 - 3 m/s the voltage measured by SA is about 50 mV.

A polynomial relationship of order 3 between the air flow velocity measured with the testo 405i anemometer and the electric current voltage recorded by the SA was obtained by regression using the Minitab v21.4 program.

$v = - 0{,}0000005423 * (u^3) + 0{,}001082861 * (u^2) - 0{,}7215098744 * u + 160{,}6341269355$

where: v (m/s) - air flow velocity; u (mV) - electric current voltage measured at SA terminals

The diagrams in Figures 8 and 9 show the air flow velocity measured with the testo 405i anemometer and the air flow velocity at the SA obtained from the third order polynomial relationship at different fan speeds V1 and V2 respectively.

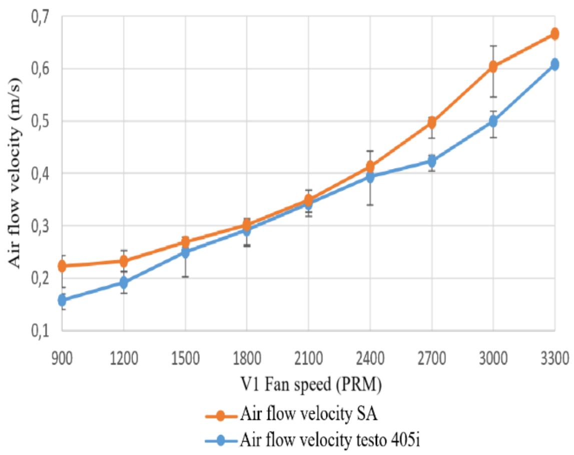


Figure 8 **Air flow velocity diagram determined by testo 405i anemometer and SA in the range 0.1 - 0.7 m/s**

The average difference between the air flow velocity measured with the testo 405i anemometer and the air flow velocity measured with the SA is

±0.04 m/s, and the largest difference in air flow velocity is about ±0.1 m/s (figure 8).

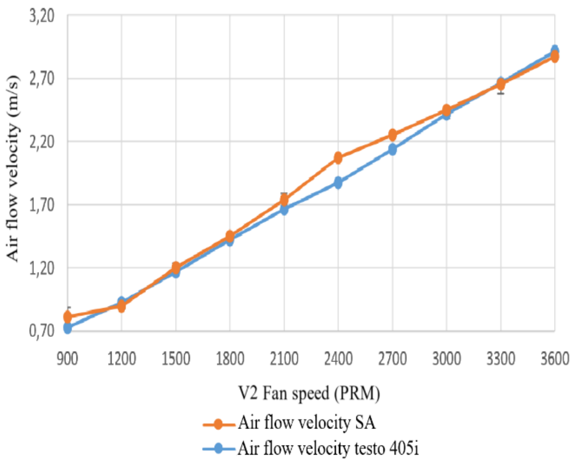


Figure 9 **Air flow velocity diagram determined by testo 405i anemometer and SA in the range 0.7 - 3 m/s**

The mean difference between the air flow velocity measured with the testo 405i anemometer and the air flow velocity measured with the SA is ±0.05 m/s, and the largest difference in air flow velocity is about ±0.2 m/s (figure 9).

The measurement sensitivity of the SA also depends on the reading accuracy of the microcontroller, and after entering the programming code, the accuracy is about 5 mV.

CONCLUSIONS

This sensor has a high sensitivity at low air stream velocities due to the size and characteristics of the filament. Therefore the SA accuracy is inversely proportional with increasing air flow velocity, so the accuracy is high at low air flow velocities and decreases with increasing air flow velocity.

The calibration process showed that the sensor is not very sensitive to temperature.

The accuracy of the sensor is related to the type and performance characteristics of the microcontroller, how it measures and reads the voltage.

REFERENCES

Al-Garni A. M., 2007 – *Low speed calibration of hot-wire anemometers.* Flow Measurement and Instrumentation, 18(2), 95–98.

Ardekani M. A., 2008 – *Hot-wire calibration using vortex shedding.* Measurement, 42(5), 722–729.

Khamshah N., Abdalla A. N., Koh S.P., Rashag H. F., 2011 – *Issues and temperature compensation techniques for hot wire thermal flow sensor.* International Journal of the Physical Sciences, 6(14), 3270 –3278

Korprasertsak N., Leephakpreeda T., 2020 – *Novel wind measurement via thermoelectric anemometer.* Measurement, 149, 107037. doi:10.1016/j.measurement.2019.107037.

Lečić M.R., 2009 – A new experimental approach to the calibration of hot-wire probes. Flow Measurement and Instrumentation, 20, 136-140, https://doi.org/10.1016/j.flowmeasinst.2009.04.00

Lia Z., Wang J., Zhong X., Liu T., Ning Y., Hou M., Zhao L., Dong G., Liu Y., Wang J., Sun T., Grattan K. T. V., 2020 – *Temperature-compensated fiber-optic gas flow speed sensor based on the 'Hot-wire' principle.* Optik, 241, 166118.

Ligęza P., Jamróz P., Ostrogórski P., 2021 – *Reduction of electromagnetic interferences in measurements of fast-changing air velocity fluctuations by means of hot-wire anemometer.* Flow Measurement and Instrumentation, 79, 101945.

Lundström H., 2021 – *Investigation of heat transfer from thin wires in air and a new method for temperature correction of hot-wire anemometers.* Experimental Thermal and Fluid Science, 128, 110403.

Özahi E., Çarpınlıoğlu M. O., Gündoğdu M.Y., 2022 – *Simple methods for low speed calibration of hot-wire anemometers.* Flow Measurement and Instrumentation, 21, 2, 166-170.

Russo G.P., 2011 – *Hot wire anemometer,* Aerodynamic Measurements, Woodhead Publishing.