PROTOTYPE OF CALIBRATION FOR HOT WIRE ANEMOMETERS UNDER LOW SPEEDS

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Abstract.
Hot wire anemometers are devices to measure the fluids speed through thermal sensors of temperature, when they are heated by an appropriate electronic circuit until a value of temperature, which is higher than the temperature of the fluid in circulation. The thermal imbalance caused by the heat transfer from the heat sensor to the fluid indicates indirectly the value of the punctual speed. Such devices are so used in applications that require low response time, as in detection of turbulence, due to the high sensitivity and very high response rate, which are presented by the transducers, however these devices require a reliable calibration system with low uncertainty of measurement in order to compare the true value of speed and the value of the voltage signal that is read by the data acquisition system of the hot wire anemometer, thus raising the calibration curve of the meter for the studied temperature. This requirement becomes even more complicated when the anemometers are operating in applications with wide range of temperature, requiring the lifting of the calibration curve for each value of corresponding temperature. With these assumptions, this present work describes the conception, assembly and tests of a prototype of calibration for hot wire anemometers under low speeds, which got two concentric climate chambers. A rotating arm that is located in this inner chamber, and is driven by a motor of variable speed, promotes the speed sensor rotation of the anemometer in an environment with stationary air, providing speed conditions until 1.0 m/s and variable temperature between 10.0 and 20.0 ºC, with a guarantee of thermal stability and minimization of convective chains of air in the interior of the prototype.

***Keywords**: Hot wire anemometer, thermal sensors, calibration.*

1. INTRODUCTION

Hot wire anemometers have been, during many years, used as research tools in fluid mechanics. These measurers are characterized by the effect of convection direct cooling in the surface of a warm thermal sensor by an electric current, as illustrated in fig. 1.

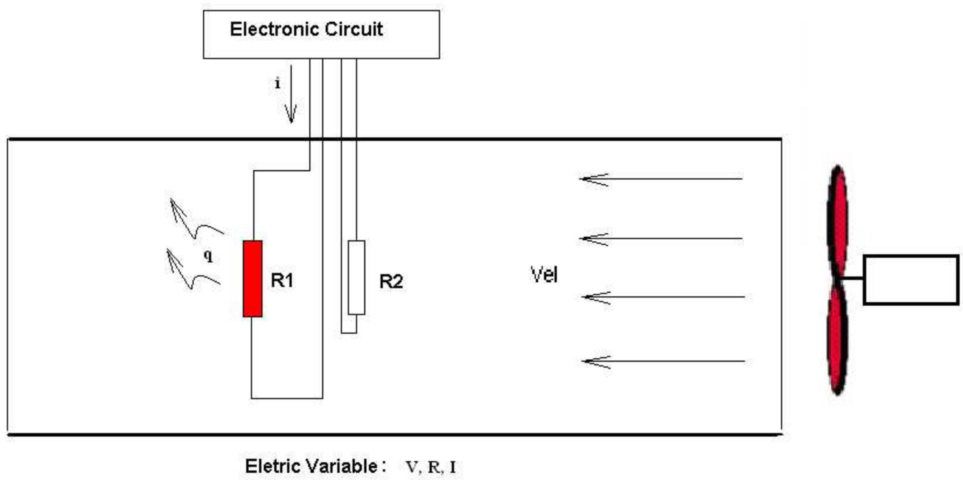

Figure1. Position of thermal sensors in hot wire anemometers.

Hot wire anemometers are characterized by using two sensors. The velocity sensor is warmed by Joule effect, with temperature between 10 and 100 ºC above the fluid temperature, while another one measures the temperature of the fluid (Webster, 1999).

The heat transferred of the sensor surface to the fluid is a function of the velocity, density, temperature of the fluid and of the temperature in the warm sensor (Stainback and Nagabushana, 1993).

Hot wire anemometers have high sensibility, wide frequency band with reasonable exactness (Webster, 1999).

There are some methods for signal conditioning, like constant voltage, constant resistance and constant current. Each one of the methods keeps one of the electric properties (resistance, current or voltage) constant and measures the variation of the remaining properties. The use of each method elapses of the application necessity, because each one presents different time constant, frequency band characteristic and sensibility.

2. HOT WIRE ANEMOMETERS

2.1 Constant Temperature Hot Wire Anemometers (CTA)

The constant temperature hot wire anemometer (CTA) is the most used method. They are called constant resistance anemometers, a time that the resistance is a function of the temperature in these transducers.

There are very circuits to construct a constant temperature hot wire anemometer. The conventional method keeps the constant temperature and, logically, the resistance through of a bridge of Wheatstone fed in its top by an operational amplifier in a configuration with feedback (fig. 2).

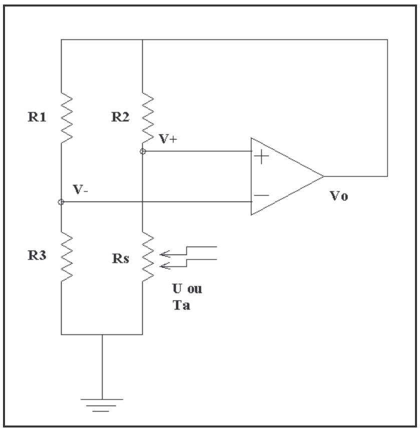

Figure 2. Circuit for CTA hot wire anemometer with NTC sensor.

The modeling of the constant temperature hot wire anemometers get from the Thermodynamics first law, as shown in Eq. (1) (Oliveira, 1997).

$$V_{Sensor}{}^{2} = R_s.h.S.\left(T_{sensor} - T_f\right) = R.h.\pi.d.l.(T_{Sensor} - T_f) \tag{1}$$

V_{Sensor} – Voltage across the sensor (V);
R_s- Sensor Resistance in Ω;
h – Convection coefficient in W/(m^2.K);
S – Lateral Section of Sensor in m^2;
d – Diameter of sensor in m;
l – Length of sensor in m;
T_{Sensor} – Surface temperature of sensor in K.
T_f - Fluid temperature in K.

The measurement of the fluid temperature, as in any type of conditioning of signal for wire anemometers/hot film is necessary for the correction of the out signal, as described by Ferreira et al (2001). An error between 1 and 2% for ºC can be introduced in the measurement of velocity due to variation of the fluid temperature.

2.2 Calibration Techniques For Hot Wire Anemometers

In the equation (1), the convection coefficient (h) relates with the Nusselt number (Nu) through Eq. (2).

$$Nu = \frac{h.d}{K} \tag{2}$$

K – Thermal conductivity of fluid (W.m^{-1}.K^{-1}) in the surface temperature.

The convection coefficient (h) depends on the adimensional parameter (Nusselt number), as described by King's Law in Eq. (3) (King, 1975).

$$Nu = a + b.\mathrm{Re}^n \tag{3}$$

a and b – Constants determined by the calibration process.

It's possible to combine the equations 1, 2 and 3 in case of conventional constant temperature anemometer and to get a simplified expression of the variation of the voltage in the top of Wheatstone bridge and the velocity as described in Eq. (4).

$$V_{out}{}^2 = A + B.v^n \tag{4}$$

V_{out} – Voltage in the top of Wheatstone bridge in V;
A e B – New constants of calibration;
v – Velocity of fluid in m/s;
n – Constant of calibration between 0.4 and 1.3 (Al-Garni, 2001).

The relation between the out voltage, that feeds the top of Wheatstone bridge, and the velocity of the fluid, presents the form illustrated in fig. 3 (Webster, 1999).

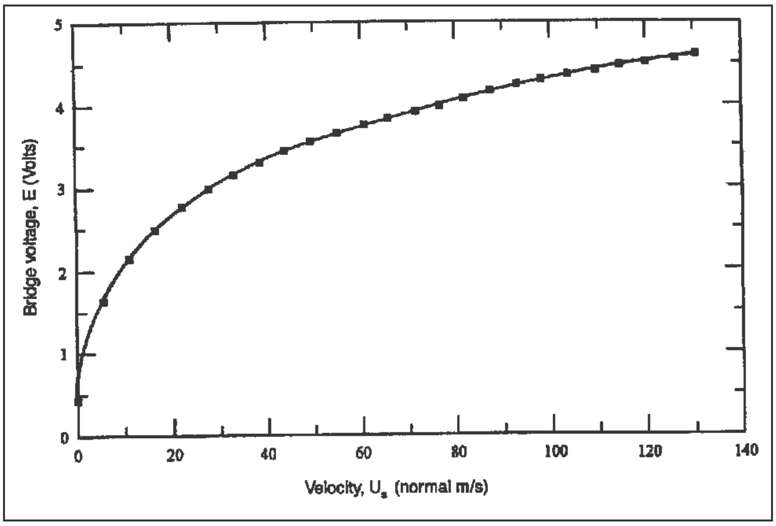

Figure 3 - Graphic of bridge Voltage x Velocity for constant temperature anemometers.

The curve in fig. 3 is based in isothermal flow. Thus, it must be made a calibration curve for each fluid temperature, in applications that demand greater exactness.

Many times, a precision Pitot tube have been used as standard measurement systems, however as the pressure drop varies as squared of the velocity, this system is not efficient for hot wire anemometers calibration in very low speeds.

Al-Garni (2001) demonstrated a device that creates a speed primary standard. It has a rotating arm moved by a DC changeable speed motor. This device generates a linear speed in an environment with steady temperature, as shown in fig. 4.

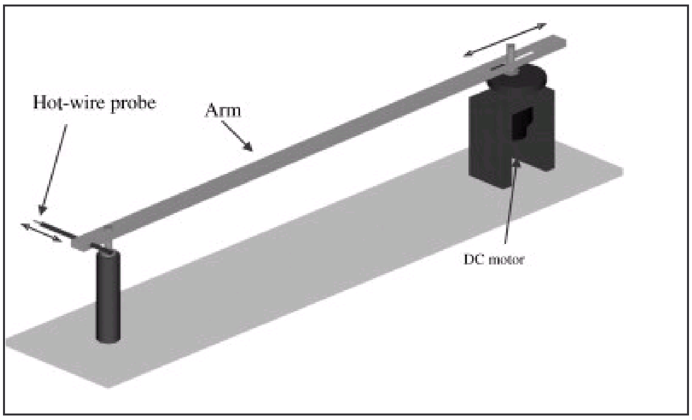

Figure 4- Hot wire anemometers calibration device in very low speeds.

Al-Garni (2001) had demonstrated that, for the speed range of 3.0 until 15.0 cm/s, exists a linear relation approximately between the square of the out Wheatstone bridge voltage and the velocity. This relation is established by the King´s law, being to the value found for this equal constant the 0.998 (Al-Garni, 2001).

3. THE PROTOTYPE DEVELOPMENT

Following the established one for Al-Garni (2001), was constructed a device that could serve as primary standard of speed. It has a rotating arm (ray equal to 180mm) moved by DC changeable speed motor. The linear velocity will be gotten through the product of the angular speed with the ray, as shown in fig. 5.

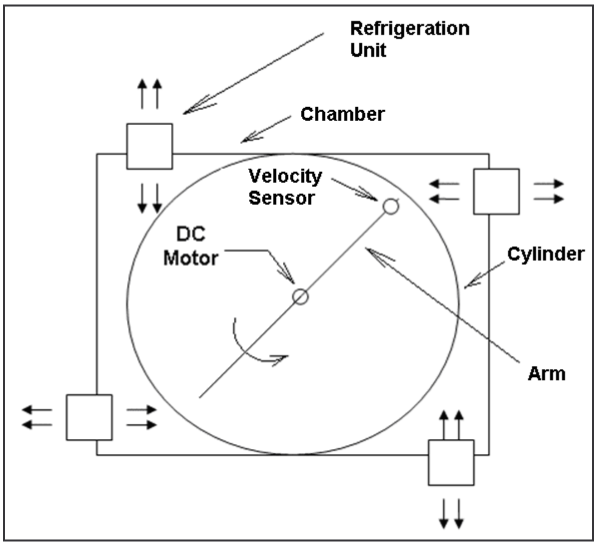

Figure 5 – Hot wire anemometers calibration prototype draw

The temperature can to vary into the calibration prototype between 10.0 and 20.0 ºC. A box (400 x 400 x 300 mm) was mounted as described in fig. 6.

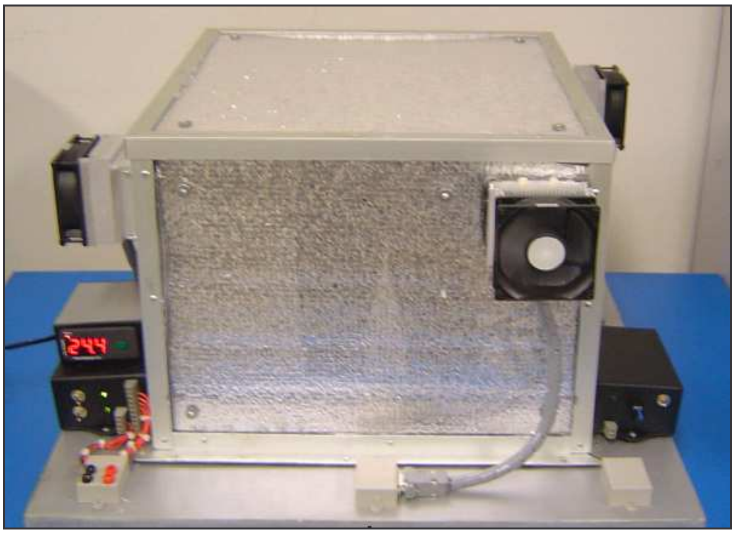

Figure 6 - Hot wire anemometers calibration device picture

The variation of the temperature into the calibration prototype is made by four refrigeration units with Peltier cells. The thermal load estimate is 100 W, thus four units DV 40-06 model (Danvic, 2008) had been chosen, with nominal capacity of 25 W, 3,6A.

Each refrigeration unit is composed of the two heat exchangers and two fans for the cold junction and the hot junction, as it suggests the manufacturer. The schematical assembly appears in fig. 7.

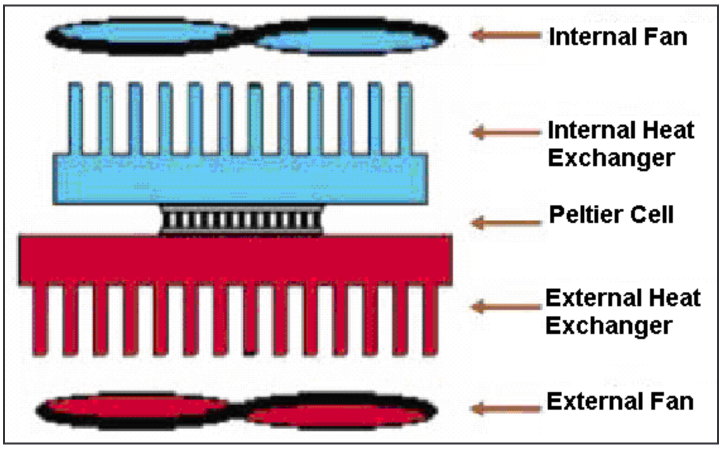

Figure 7 – Detail of heat exchangers and fans.

The prototype walls were thermally isolated with polyethylene foam to guarantee stability of the temperature during the data acquisition. For reduction of internal gradients of temperature micron-fans had been used (forced convection). The internal fans (fig. 8) are turned off at the calibration moment.

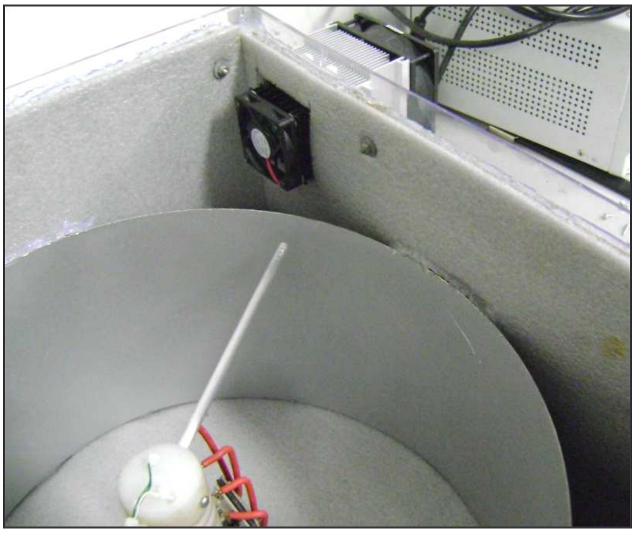

Figure 8 – Internal detail of calibration prototype.

A digital on-off type controller manufactured by Full Gauge was used to control the cells, model TIC 17Ri, with resolution of 0,1 ºC, as shown in fig. 6. The internal temperature can be adjustable between 10.0 and 20.0 ºC and, thus, it's possible to describe the calibration curves for the anemometer, one for each value of temperature.

The variation of speed is made by a pulse width modulation generator (PWM). In this case, the variation of rotation of the arm (180 mm) is obtained by the alteration of the active cycle (+VDC) of the motor. The width of this modulation can be commanded by the potentiometer.

The angular frequency, or the motor rotation, can be determined by the counting the electric pulses of an incremental encoder established in the interruption of a luminous beam. The encoder has four orifices in 90º. The frequency is calculated by total counted pulses at sixty seconds. The optical encoder detail is illustrated in fig. 9.

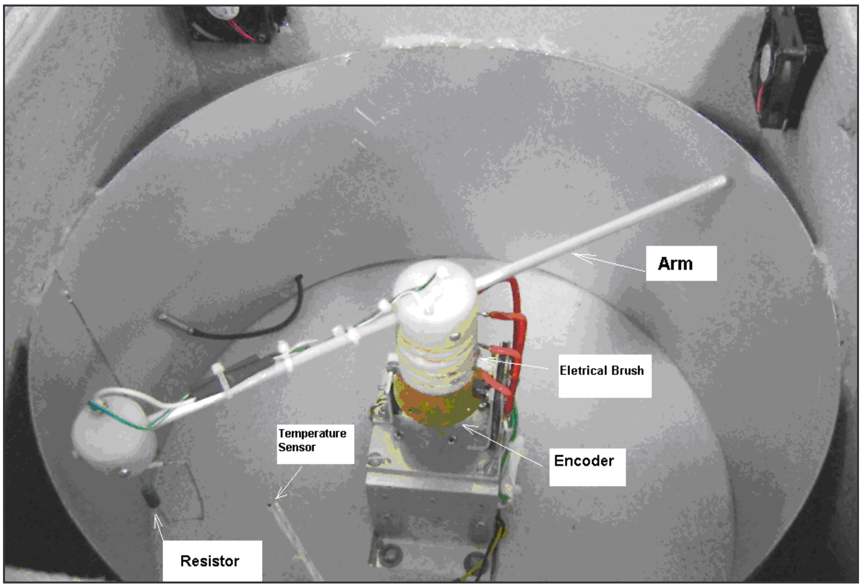

Figure 9 – Detail of optical encoder and the rotating arm.

The first problem founded in the prototype was to prevent the twist of the sensor cables in the extremity of the rotating arm. An "electric brush" was created to prevent this problem and to collect the signal of voltage of the thermal sensor during its characterization. It is composed for metallic tracks and flexible cables, both in copper. The "electric brush" is shown in fig. 10.

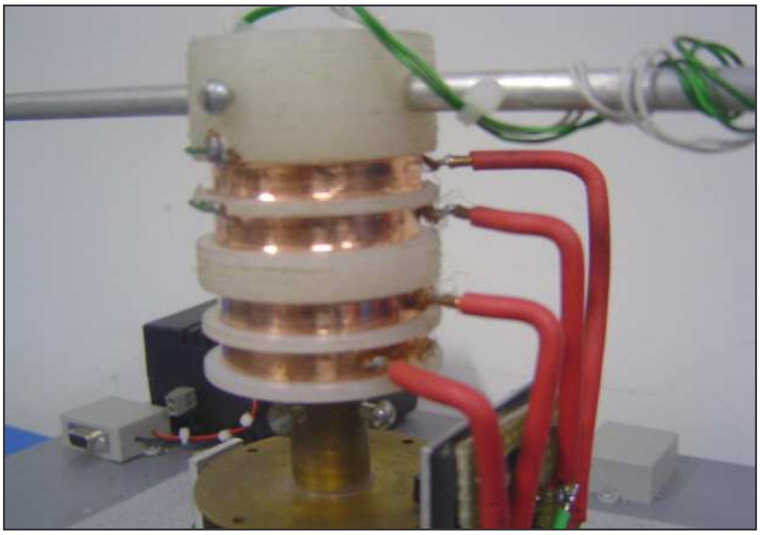

Figure 10 – Detail of electrical brush.

Two metallic tracks for each terminal of feeding of the sensor had been used with redundancy intentions, in order to prevent discontinuities in the feeding of the sensor, in way to guarantee adequate electric contact (fig. 10).

The electric noise of contact produced for the brush was evaluated for five different values for the angular speed. A direct current of 500mA was generated across the fixed test resistor 2,7Ω. The relative variation of the continuous tension was 2.4%. A small eccentricity in the collector of the brush confectioned in nylon caused this.

The prototype development founded another problem with the internal temperature stability, a time that the internal fans need to be turned off during the calibration phase, in order to minimize chains of convection in the interior of the equipment.

The increasing internal temperature rate into the device was minimized when it was placed in an acclimatized chamber. The chamber is encapsulated in acrylic and cooled by a forced convection evaporator. This evaporator and the condensing unit were controlled by a Full Gauge model MT-512 on-off type controller. The assembly with the calibration device into the acclimatized chamber is illustrated in fig. 11.

The test of internal homogeneity in the prototype was evaluated in six points when the calibration prototype is inside of the acclimatized chamber and the temperatures (chamber and calibration device) were adjusted for 10.0 ºC. The maximum error was 0.3ºC. With this assembly configuration, the increasing internal temperature rate in the prototype was 0.002 K/s.

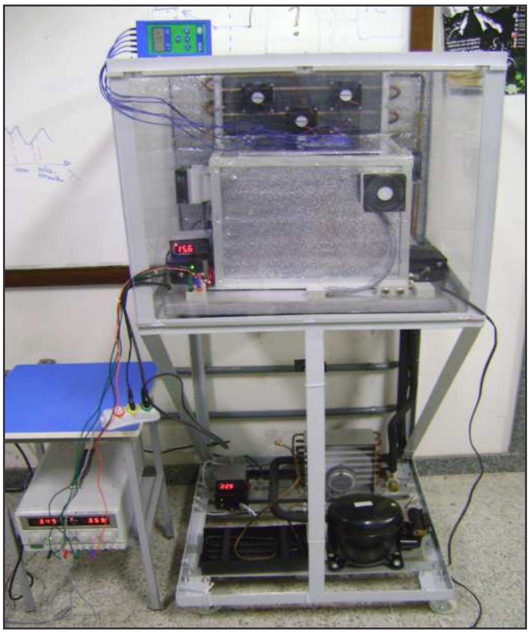

Figure 11 – The calibration prototype into the acclimatized chamber.

4. RESULTS

A conventional hot wire anemometer (CTA) was calibrated using the prototype described in item 3 for velocity from 0.0 until 0.94 m/s, in a temperature range between 10.0 and 20.0 ºC. The velocity points were 0.00 m/s; 0.15 m/s; 0.31 m/s; 0.48 m/s; 0.64 m/s; 0.76 m/s and 0.94 m/s. These values had been tested in five different temperatures: 10.0 ºC; 12.5 ºC; 15.0 ºC; 17.5 ºC and 20.0 ºC.

The calibration procedure was:

The arm speed is initially adjusted, using for in such a way the PWM generator described in chapter 3 (fig. 6). The velocity value is determined by the counting of the pulses of the incremental encoder (fig. 6). The linear velocity value is calculated by the acquisition data program. The velocity evaluated uncertainty was 0.02 m/s.

When the internal temperature is near to the desired value, the internal fans are turned off and the out voltage of the NTCs (temperature and velocity) are acquired by the PC parallel port, with an interval of 0.01 s. Obviously, a minimum time of fifty seconds must be waited to minimize the uncertainties originated of the convection chains in the internal device.

This procedure was used for others temperature values in the prototype and others velocity values of the rotating arm.

The square values of the anemometer out signal converted by the ADC, for the diverse velocities and investigated temperatures are presented in table 01.

Table 1 –Calibration data (Vout^2 x Vel x T) for velocity until 1.0 m/s.

Vel (m/s)	T=10.0 ºC	T=12.5 ºC	T=15.0 ºC	T=17.5 ºC	T=20.0 ºC
0.00	154661	84559	65726	13158	946
0.15	424713	334778	256026	173048	99042
0.31	675914	540666	404700	298466	196116
0.48	859088	719426	546919	403390	264381
0.64	978042	788366	630118	471323	331603
0.76	1053497	876770	698294	545663	384226
0.94	1201874	976085	805488	599804	480249

The relations between square voltage and the velocity can be founded by eq. 4 for each temperature.

For T=20.0 ºC:
$$[V_{out}(ADC)]^2 = 945.56 + 494.5.10^3.Vel^{0.847}$$

For T=17.5 ºC:
$$[V_{out}(ADC)]^2 = 13158.38 + 637.10^3.Vel^{0.653}$$

For T=15.0 ºC:
$$[V_{out}(ADC)]^2 = 65726.58 + 775.1.10^3.Vel^{0.706}$$

For T=12.5 ºC:
$$[V_{out}(ADC)]^2 = 84558.82 + 942.10^3.Vel^{0.631}$$

For T=10.0 ºC:

$$[V_{out}(ADC)]^2 = 154661.29 + 1099.10^3.Vel^{0.667}$$

The results (points) and the adjusted curves for the square voltage and the velocity are presents in the fig. 12.

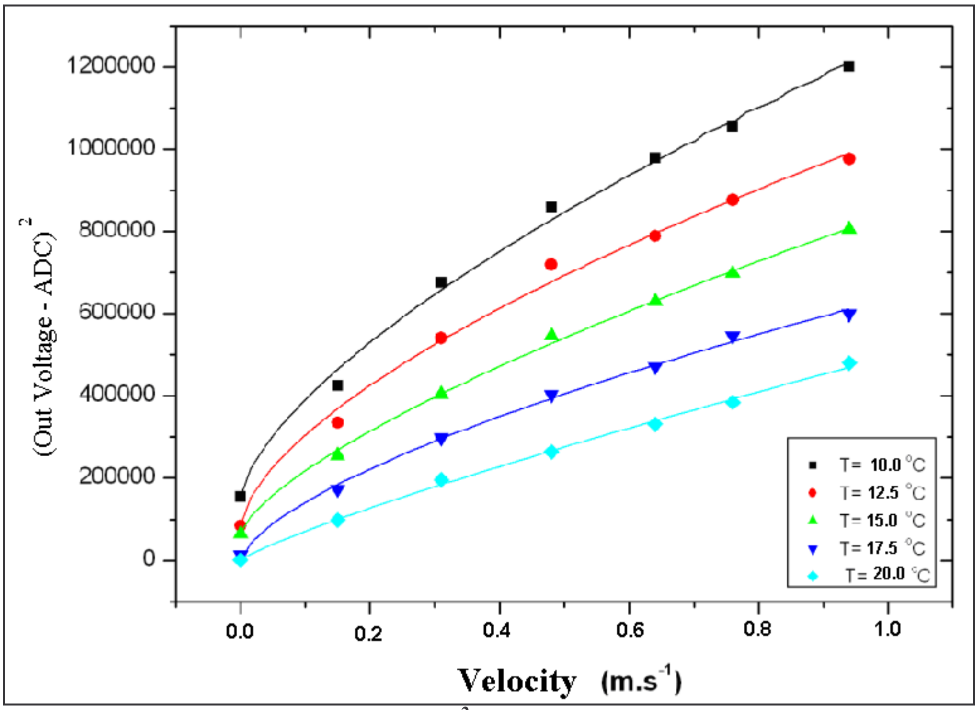

Figure 12 – Adjusted curves for Vout^2 (anemometer) x Velocity x Temperature.

5. CONCLUSIONS

There is great difficult to calibrate hot wire anemometers in low speeds mainly. Thus, in this work a calibration prototype for hot wire anemometer was presented. The high sensitivity, variability of the temperature, thermal stability, low noise level, small necessary time for the calibration had demonstrated the good effectiveness of the prototype.

The average value to the n coefficient was 0.7, coinciding with the interval cited by bibliographical references.

The good results suggest the adaptation of the prototype for velocity range until 2.0m/s.

6. ACKNOWLEDGEMENTS

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