Development of X-Wire Probe for Hot Wire Anemometry

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Abstract:- *This paper is about the development of a bi-directional hot wire probe of the "X-wire" type that will be used in future atmospheric studies. In the methodology, the main points to be observed to reach the complete probe are the sensitivity of the filament used in its construction, and the voltage signal generated by the filament when exposed to various atmospheric conditions (atmospheric pressure, temperature and air moisture. After the analysis of these results, it is noticed that it is sufficient to monitor simultaneously only the air temperature, since it is the external variable that has greater correlation with the wire voltage. Also, considering the exposure of the probe to the weather, and consequently the completely random factors, a protection structure was also developed in order to minimize damage to the filament. At the end of development, a hot wire probe was obtained with cold resistance of 3(bottom) and 3.5(higher) ohm, and hot resistance 5.5(bottom) and 6.5(higher) ohm.*

Key Words: hot wire anemometer, flow measurements, atmospheric measurements, wind speed, turbulent flows, arduino.

1. INTRODUCTION

The development of the hot wire anemometry technique began with the studies of L. V. King in the year 1914, when his work that defines how to obtain the forced convection constants was developed [1]. In essence, the technique consists of exposing a very thin conductor that is heated up by an electric current, to a fluid. The resistance of the conductor varies directly as a function of a temperature coefficient, that is, the more heat dissipated by the conductor, the greater is the electrical resistance of the conductor. In contrast, when the thin conductor is cooled, his resistance decreases. This variation of resistance due to heat exchange is related to the changing in velocity of the moving fluid which is responsible for the cooling of the conductor. [2].

The applications of the hot wire anemometry technique can range from measurements in a simple wind tunnel as performed in [3], to more complex analyses and more elaborate experiments such as the study of supersonic velocities in [4]. Within the anemometry application set, the focus of this research is to develop a X-Wire type (two-filament hot wire sensor) that will be used to carry out atmospheric studies because of its high sensitivity and high frequency response characteristics , this type of sensor can be used to study the turbulent flux under the atmospheric boundary layer.

1.1 Initial steps

An important preliminary step in the development process is the choice of the filament to be used in the sensor, for this research was used tungsten with characteristics of 20 µm in diameter and 5% gold coating layer. After defining the filament, sensitivity tests are performed in order to determine the intensity of the electric current to be applied, and consequently, the operating temperature of the filament. The effects of external variables on the behavior of the electrical voltage signal obtained in the filament must also be measured. In this research, the atmospheric pressure at the altitude at which the sensor will be used, temperature, and air humidity around the filament are considered. This measurement allows the correcting of final sensor's response, so that the magnitude in evidence to be studied, which is the wind speed, is correctly quantified.

2. RESEARCH METHODOLOGY

2.1 Wire Sensitivity Study

For assembly the probe, a PLA (Polylactic Acid) filament was 3D printed as shown in Fig. 1. This piece is intended to support two pairs of stainless steel needles, and according to the spacing between the needles (which is equivalent to length of the tungsten filament), the sensitivity of the sensor will be directly impacted. Based on this, it should be determined which length (d) is more convenient to use, and the tests were applied for d equals to 5mm and 10mm for each spacing.

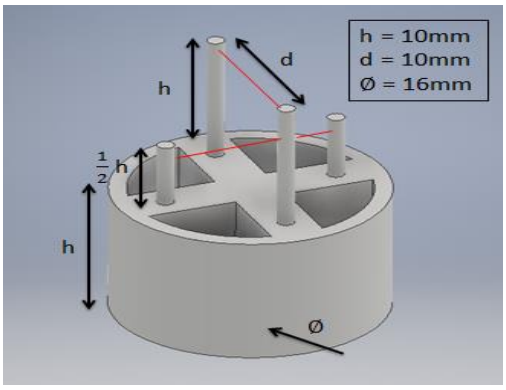

Fig -1: Conceptual Probe Image.

Fig. -2: Each length - 10mm probe (left) and 5mm probe (right).

During the tests procedure, different electric current intensities were applied in the filament ranging from 50 to 160 mA in increments of 5 mA. Different sensitivities can be observed by setting up a series connection with a fixed value resistor (according to Fig 3), characterizing a voltage divider; from this connection it is possible to simultaneously monitor the current values and maximum voltage variation in the filament when exposed to a reference air flow changing. For each electric current intensity, two voltage measurements were made, at first in the condition without air flow (the probe was covered by a plastic cup) and the second with maximum air flow; from these measurements it is possible to plot a graph of the maximum voltage variation as a function of the current in the filament, as shown in figure 1.

Fig -3: Current and Voltage measurements.

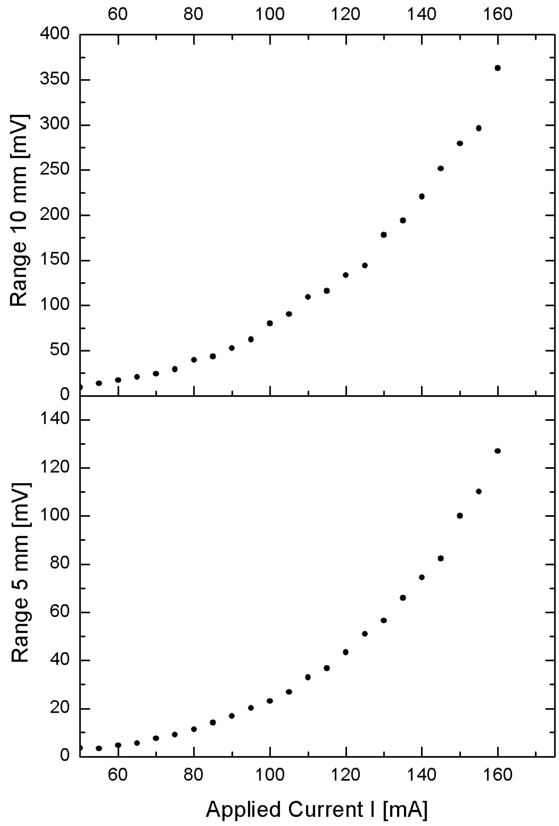

Chart -1: 5 and 10mm tests.

From these measurements, it can be seen that the 10 mm filament has a higher voltage variation relation due to a lower excitation current in relation to the 5 mm filament, so this length was selected to develop the hot wire probe. Once the length to be used was selected, the test was repeated in increments of 1 mA in order to achieve a chart of the electrical resistance variation of both probe filaments as a function of the applied electric current (Chart 2), because these data will be used as basis parameters for designing the probe electronic circuit that will be addressed in a future study.

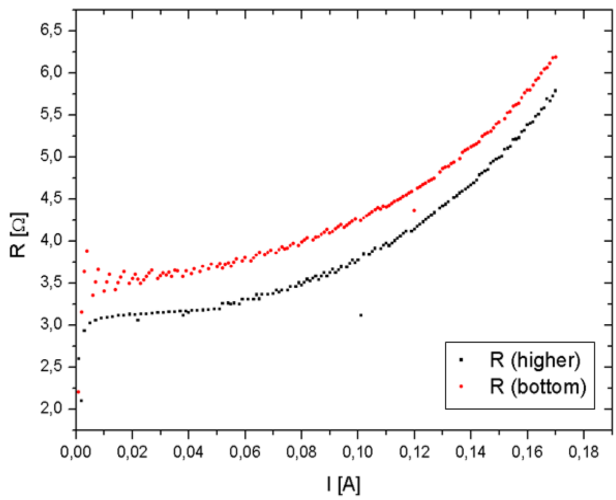

Chart -2: Higher and Bottom resistance values.

2.2 Study of external variables effects

At this stage of the work, it is considered that the probe to be developed has as its purpose, applications in atmospheric studies. Therefore, during its use, it will be exposed to the time and so, it is necessary a previous study of how the filament behaves for different conditions of atmospheric pressure, temperature and air moisture. For this study, a glass container was used with an acrylic plate to serve as controlled environment (Fig. 4); where it is possible to force a changing of each variable to be analyzed.

Two sensors (Fig. 5) were coupled to the probe, one to measure atmospheric pressure (BMP 180, Bosch Sensortec) and another to measure air temperature and moisture (DHT-22, Aosong Electronics Co.). Both sensors and the probe were connected to a data acquisition system based on an Arduino Nano card, SD card recorder, and analog-to-digital converter (Fig. 6), where values were recorded each second. The purpose of these measurements was to verify the correlation of each variable with the voltage signal of the probe in an isolated way of the air flow.

Fig -4: Glass and acrylic controlled environment.

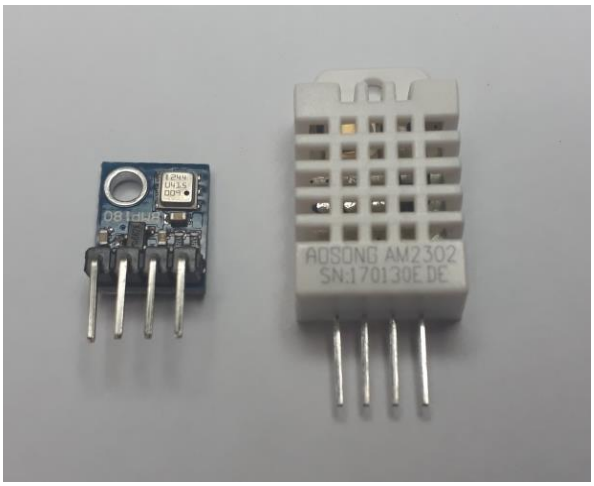

Fig -5: BMP-180 to left, DHT-22 to right.

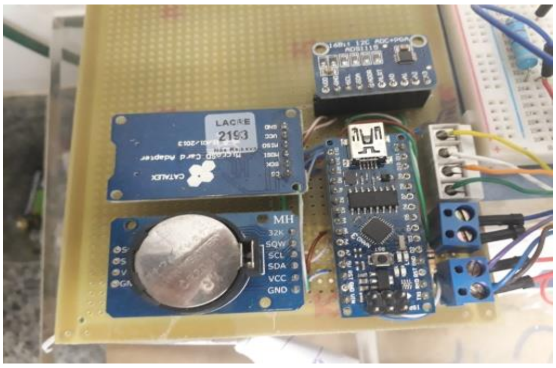

Fig -6: Data acquisition system

2.2.1 Natural changing of external variables

The first data recording was made from the whole system in natural condition, without forcing any of the external variables, only the probe and the data acquisition system were connected as shown in Fig. 7. For this condition, the data obtained were plotted in synchrony in Chart 3.

Fig -7: Natural condition of external variables.

2.2.2 Forced changing of internal pressure

The second data recording was taken from the changing of glass internal pressure. This test (Fig. 8) had the goal in simulating different values of atmospheric pressure which may also represent possible different altitudes where the probe can be used. The effect of the pressure changing was simulated using a 1.8 CFM dual stage vacuum pump; as a result we have the chart 4.

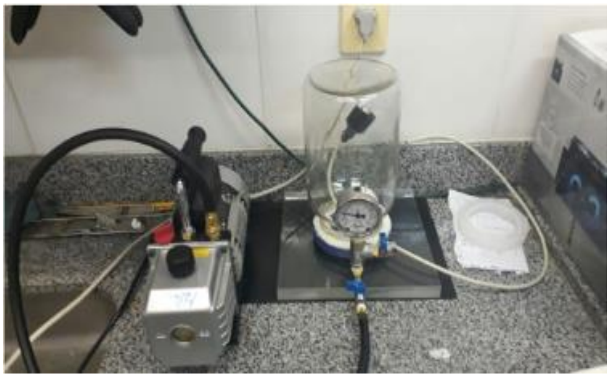

Fig -8: Forced pressure simulation.

2.2.3 Forced changing of internal temperature

The third data recording was taken from the changing of glass internal temperature. This test (Fig 9) had the goal in simulating different values of air temperature around the probe. The effect of the temperature change was simulated using a 2 kW thermal blower, specifically, it should be noted that an air leak must be left on the glass to avoid an increase in internal pressure due to an increase in temperature; as a result we have chart 5.

Fig -9: Forced temperature simulation.

2.2.4 Forced changing of internal moisture

The fourth data recording was taken from the humidity changing inside the glass container. This test (Fig 10) had goal in simulating different humidity values around the probe. The effect of the moisture changing was simulated by placing a wet flannel inside the container; as a result we have the chart 6.

Fig -10: Forced Humidity simulation.

2.2.5 Design of probe protection structure

Considering that after installed, the hot wire probe will be exposed directly to weather changing and eventually unpredictable factors such as birds that may try to land on it, then a protective structure must be developed to allow the wind passing and minimize the probabilities of breaking the filament. The structure developed has as reference an ultrasonic anemometer "Gill WindSonic", and was also printed on a piece of PLA, according to figures 11 and 12.

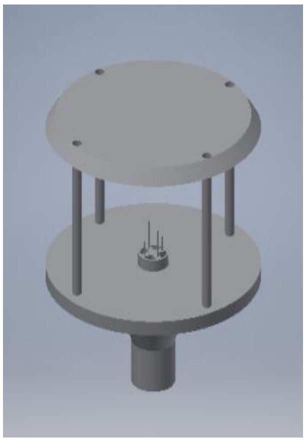

Fig -11 Conceptual Structure **Fig -12**: Printed Structure

3. RESULTS

3.1 Data obtained from natural changing

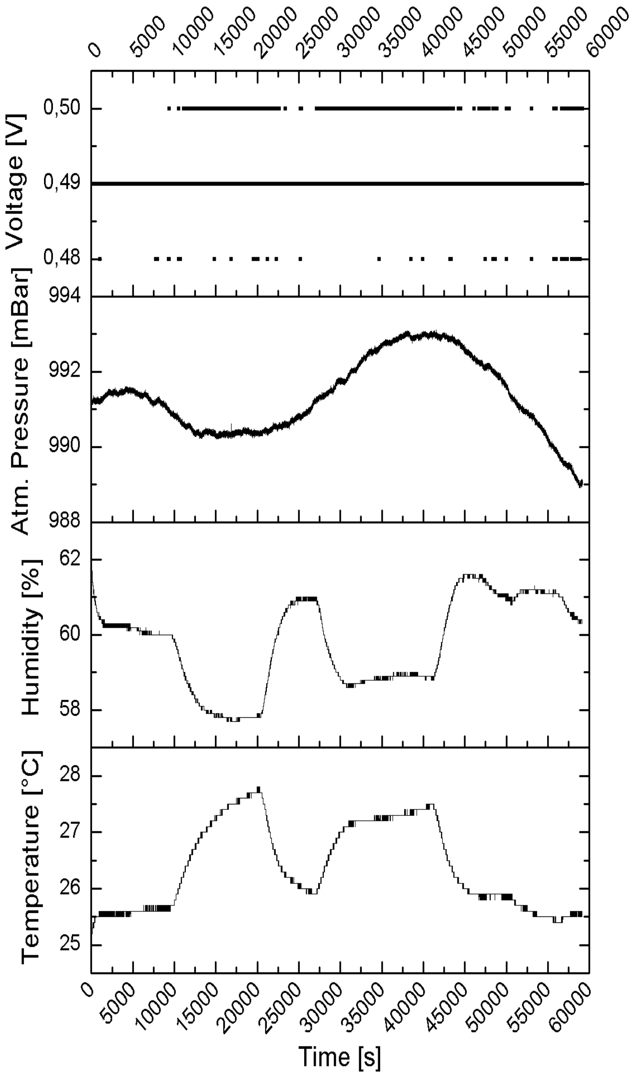

Chart -3: Natural floating of external variables.

Table -1: Data obtained from natural condition.

Descriptive Statistics					
	N	Mean	SD	Min	Max
[V]	59173	0,49089	0,00292	0,48	0,51
[mBar]	59173	991,34419	1,00255	988,91	993,12
[%]	59173	59,79371	1,19094	57,7	62
[°C]	59173	26,39669	0,76044	25,2	27,8
Pearson Correlations					
	[mBar]	[%]	[°C]		
[V]	-0,02956	-0,14835	0,15192		

Table -2: Data obtained from forced pressure.

Descriptive Statistics					
	N	Mean	SD	Min	Max
[V]	2630	0,62099	0,01105	0,6	0,69
[mBar]	2630	654,95556	305,62828	19,59	990,31
[%]	2630	45,75593	14,79261	9,6	60,6
[°C]	2630	31,3157	0,43375	30,1	31,8
Pearson Correlations					
	[mBar]	[%]	[°C]		
[V]	-0,51692	-0,50354	-0,54851		

3.2 Data obtained from forced pressure

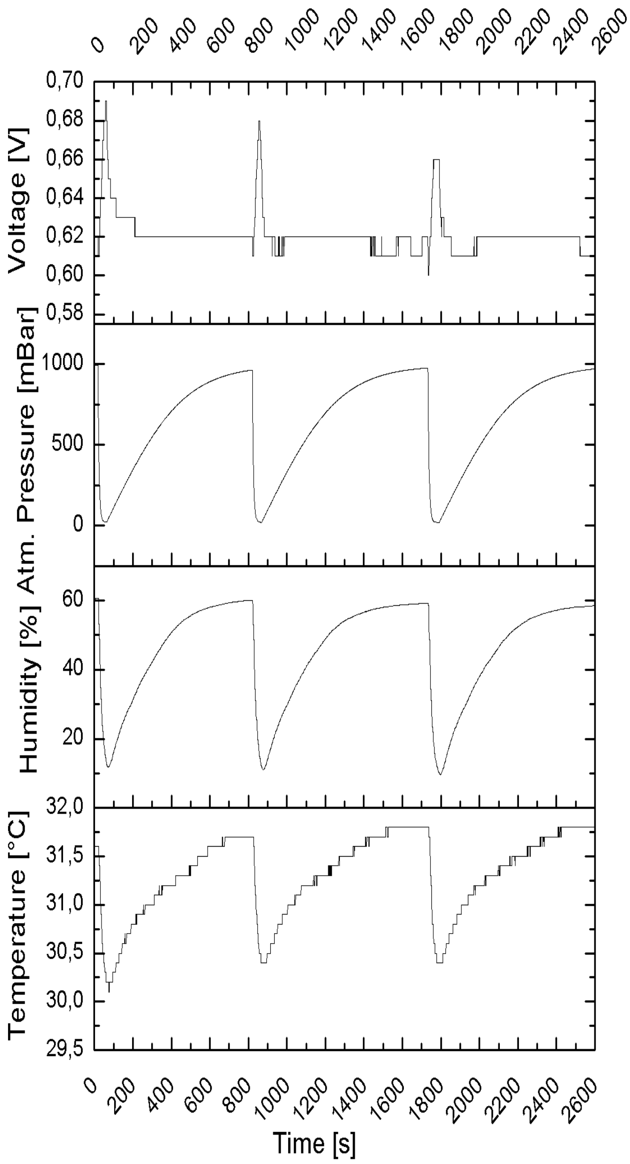

Chart -4: Floating of forced pressure.

3.3 Data obtained from forced temperature

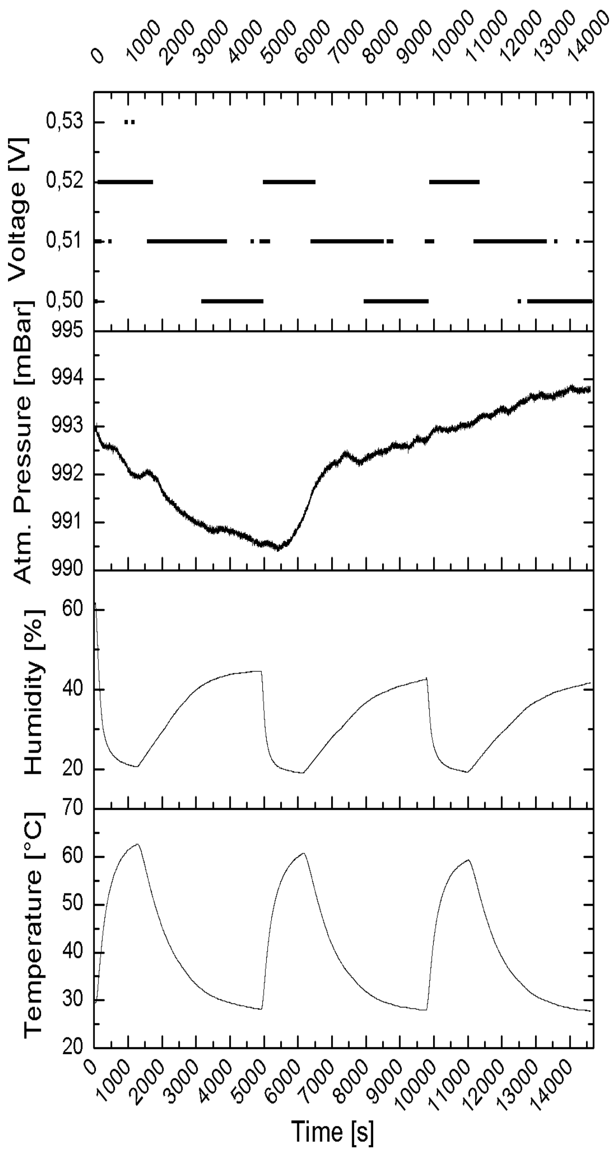

Chart -5: Floating of forced temperature.

Table -3: Data obtained from forced temperature.

Descriptive Statistics					
	N	Mean	SD	Min	Max
[V]	14609	0,5097	0,00771	0,5	0,53
[mBar]	14609	992,23763	1,03145	990,39	993,89
[%]	14609	32,37801	8,82121	19	61,7
[°C]	14609	40,34714	11,62892	27,7	62,7
Pearson Correlations					
	[mBar]	[%]	[°C]		
[V]	-0,14897	-0,86117	0,88168		

Table -4: Data obtained from forced humidity.

Descriptive Statistics					
	N	Mean	SD	Min	Max
[V]	5546	0,49983	0,00402	0,48	0,69
[mBar]	5546	989,76424	0,08106	989,58	990,22
[%]	5546	83,23736	9,4756	57,7	93,5
[°C]	5546	25,56246	0,16893	25,2	25,8
Pearson Correlations					
	[mBar]	[%]	[°C]		
[V]	0,02604	-0,08503	-0,14821		

3.4 Data obtained from forced humidity

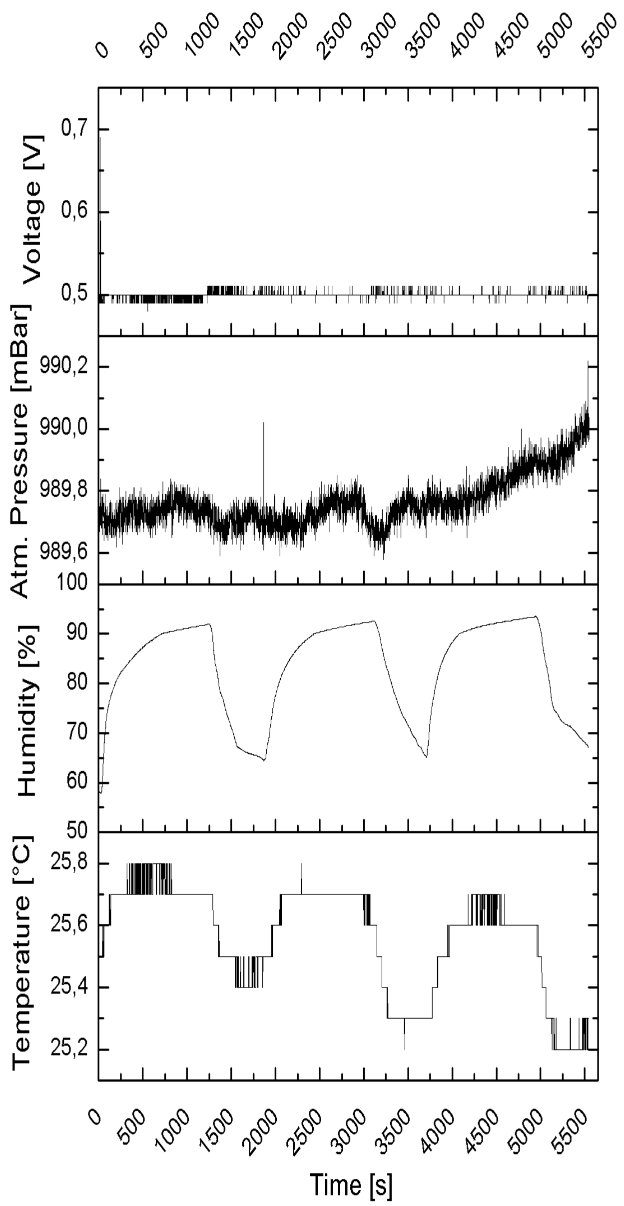

Chart -6: Floating of forced humidity.

3.4 Considerations over results

Based on results of graphs and tables for each condition tested, it is logical to observe that we can discard the effects of voltage variation on the filament due to atmospheric pressure and air humidity for punctual measurements. This observation is justified by the Pearson coefficients; for the case of forced temperature simulation, the coefficient found is 0.88168, which is the highest among the tests performed. In the pressure simulation, the coefficient found is - 0.51692, but the effects are disregarded because the pressure variation required to cause the standard deviation found in the test is practically impossible to achieve even in extreme atmospheric conditions. In the simulation of relative air humidity, the coefficient found is -0.08503 being the lowest of all cases; although the humidity had a correlation of -0.86117 in the temperature variation test, it is still not considered, since this behavior is due to the fact that it varies inversely proportional; and it is also observed that even during the forced variation of humidity, it is the temperature that presents the highest correlation with the voltage signal.

4. CONCLUSIONS

From the results presented, it can be considered only the need of one temperature sensor installed near the needles to monitor the signal. Based on this, the LM35 [Texas] temperature sensor was chosen because it has small dimensions and accuracy consistent with the measurements that will be performed by the probe.

After determination of the voltage correction's constant as a function of temperature, the probe is ready to be used together with an electronic circuit that can operate to ensure a constant temperature or current in the tungsten filaments.

At the end of development, a hot wire probe is obtained with 3 and 3.5 ohm cold resistance filaments (higher and bottom respectively); 5.5 and 6.5 ohm hot resistance (higher and bottom respectively).

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