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LOSS COMPENSATED AND OF HIGH ACCURACY THERMAL CONTROL

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Abstract. *Study of a thermal control, which is applied in obtaining high accuracy and short and long term stability response, are presented. Automatic dynamic electrical compensation is achieved by a feedback electronic circuitr and low thermal inertia thermal and compensating sensors. The sensor element is also employed as an actuator (heat generator) and the compensating sensor is also a reference sensor (resistance of manganine wire). The transducer (that is sensor and heater) is manufactured directly in the circuit board surface utilizing the circuit board plotter LPKF Protomat® C60. This manufacturing give us a high dimensional accuracy of the sensor/actuator (with minimum thickness of the track in 100 μm). Equations governing instrument response are derived and analyzed. After several experiments, the models are confronted with the experimental results. The obtained results with the first prototype confirm the validity of the proposed idea which should yielded a very accurate instrument with a self calibrating feature.*

Temperature control, Loss Compensated, Self-calibrated, High Accuracy

1. Introduction

The temperature control of high accuracy cavity is applied in special electronic circuits (high gain oscillators), according to Freking (1978), in an ambient for nanotechnology, (Merkle, 1997) and in interferometry applied in nanotechnology. Temperature is typically one of the biggest sources of instability in quartz oscillators that act in long periods..

A high accuracy wall or cavity would have applications in special references sources for high accuracy thermopar and temperature calibrators. An isothermal high accuracy wall would have great application in experimental studies of surface temperature measurements. These studies are performed through numeric methods (Heneck and Sparrow, 1970 and Souza and Zaparoli, 2000). For high accuracy, the model hardly corresponds to real experiment, due to parameters from the thermal properties, resistance of contact and geometry.

Several numeric studies of cavity rectangular with different aspect reasons were accomplished (Ganzarolli and Milanez, 1995, Pallarès et al, 1996). An experimental and numeric study of the cavity control was made by Paz (2002).

Modern crystal ovens often consist of the block or plate of high thermal material conductivity (known as the oven mass) to which the crystal is mounted. The oven mass is generally heated by one or two transistors, Karlquist et al, 1997.

This work presents a new technique of ambient temperature control, different from the ones that use semiconductors. This technique is based on a isothermal wall built a thermo-electric resistance sensor that works both as a sensor and as a heat generator element to leave, according to patent request of Belo et all, 2004. Um electronic circuit of feedback compares the sensor resistance with a resistance of reference of high accuracy, heating up or cooling the sensor in a way to maintain its value equal to the reference resistance, maintaining this way, the temperature equal to the desired value. The initial results here presented, based on Silva, 2002 seem to confirm the validity of the proposal, in that a high thermal earnings is had (reason among variation of the extern temperature and variation of the temperature in the controlled ambient).

2. THE CONTROL SYSTEM DESCRIPTION AND MODEL

A simplified diagram of the system is shown in fig. (1). The resistor Rx is the temperature sensor (with positive temperature in the coefficient of electric resistance and heath generator. The resistance Rx belongs to a Wheatstone bridge, with reference resistance Rr (which doesn't change with the temperature) in the same branch of the bridge, and determines the value of the sensor temperature .The resistances R2 and R3 of the other branch of the bridge are precision resistances, with the equal coefficients of electric resistances with temperature R2 and R3 can take much higher values than the ones of the other branch to reduce the power waste of the system. The amplifier A is a differential amplifier of high gain. The Vs and U12 values are the output and input of the amplifier. U1 and U2 are the electric tensions in the middle of the branches.

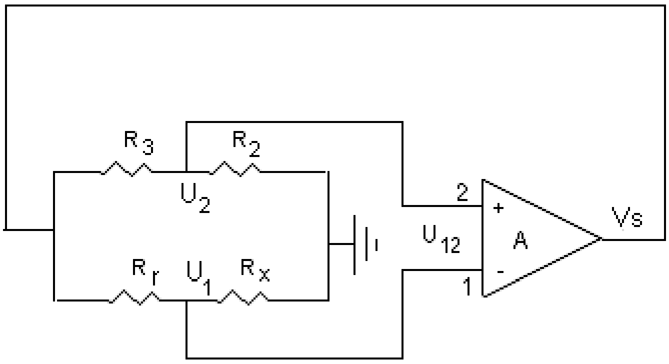

Figure 1. Electronic circuit of the system.

In operation, when the temperature that is external to the sensor decreases, the resistance Rx is reduced and consequently the U1 tension. A reduction in U1 does a increase in the U12 tension. The U12 increase does an increase on Vs output electric tension of the amplifier. This tension increasing will add more current through Rx, causing heating for joule effect and a temperature rise. Analogously, when the temperature that is external to the sensor rises, the resistance Rx increases and consequently the U1 tension .The increase in U1 does a decrease in the U12 tension. The decrease of U12 does a decrease in the Vs output electric tension of the amplifier. This tension decrease will add less current through Rx, causing a decrease in the temperature.

If the amplifier gain is very large and R2 = R3, the temperature of the sensor and generator will be equal to the reference temperature.

2.1. DESCRIPTION OF USED TRANSDUTOR

The heat sensor-generator consists of a thin copper film in the shape of a serpentine, built of the own printed circuit plate, fig. (2).

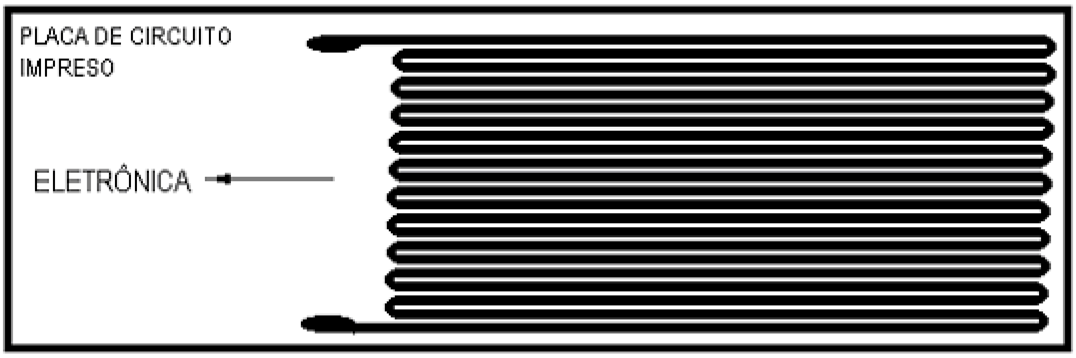

Figure 2. Pictorial representation of the sensor-generator along with the film tracks.

Considering a linear relationship between the temperature Tx and the resistance Rx of the sensor at reference temperature T_0, we obtain that:

$$R_x = R_0(1+\alpha(T_x - T_0)\qquad (1)$$

where R0 is resistance in the reference temperature T0(°C), α is the resistance coefficient with temperature (°C / Ω) and Tx(°C) is the average temperature of the copper film on the plate.

The average temperature of the copper film (Tx) is considered constant. The copper film will heat by Joule effect when the electric current flows through the resistance. Due to the small thickness of the copper film, its thermal capacity is considered low compared to those of the fluid (air) above and of the glass fiber below. Furthermore, since the electronic circuit answer is faster than the thermal system one, the temperature of the sensor - generator will remain equal to the reference temperature, independently of the thermal load, in other words, auto-compensating (repetitive). Considering that the resistivity and the coefficient with the temperature of the reference resistor don't change with the time, and it corresponds to a well determined temperature, a self-calibrated system (exact) would be obtained.

2.2. THE EQUATIONS OF THE SYSTEM

The thermodynamic balance of the system is based on the equilibrium between the heat produced by Joule effect through the sensor -generated and the heat supplied or absorbed by the thermal mass above and below it. According to section II.1, the equation of the electronic circuit will determine the temperature of the sensor-generator. In equation (2) we have the model of the answer of the amplifier used, without considering the intrinsic noise, according to

$$V_s = V_0 + AU_{12} \tag{2}$$

where V0 is the thermal drift of the amplifier and A the amplifier gain.

The amplifier differential input is given by:

$$U_{12} = \left(\frac{R_2}{R_2 + R_3} - \frac{R_x}{R_x + R_r} \right) V_s \tag{3}$$

Developing (2) and (3) we will have (4) and (5)

$$\left(\frac{R_2}{R_2 + R_3} - \frac{R_x}{R_x + R_r} \right) = \frac{1}{A} - \frac{V_0}{V_S} \bullet \frac{1}{A} \tag{4}$$

$$\left(\frac{R_2}{R_2 + R_3} - \frac{R_x}{R_x + R_r} \right) = \frac{\overline{V_0}}{V_S} \bullet \frac{1}{A} \tag{5}$$

where $\overline{V_S}$ is the output drift variation with the amplifier temperature. From (4) or (5) we will have the value of Rx.

3. MATERIALS, METHODS AND EXPERIMENTAL RESULTS

The fig. (3) shows in an enlarged way the film printed in the circuit plate and its geometry, elaborated through LPKF proto mat C60 LPKF (CAD/CAN Tool). In figure 3(a) a view of two segments of the parallel trails from above. The sensor-generator has trail width of 100μm. In figure 2(b), there’s a transversal cut, with the film of the copper height of 310μm.

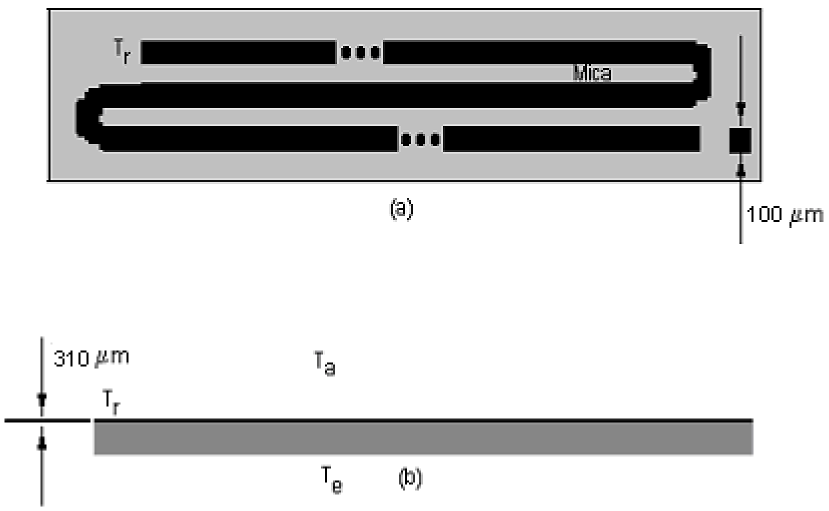

Figure 3.Details of the plate, with (a) enlarged view, (b) cut of the plate (b).

The printed circuit plate that contain the sensor (120mm of length and 120mm of width) was set up on a block of expanded polystyrene, EPS, with 120 mm of length, 120 mm of width and 30 millimeters of height. The dimensions of the sensor in the plate are: 10 cm of length and 10 cm of width. See figure (4 a). The figure (4b) shows a wood frame and screws for fixation, and also to minimize the transference of heat in the horizontal direction. This way, the heat flow will be practically in the direction of the glass fiber of the printed circuit plate.

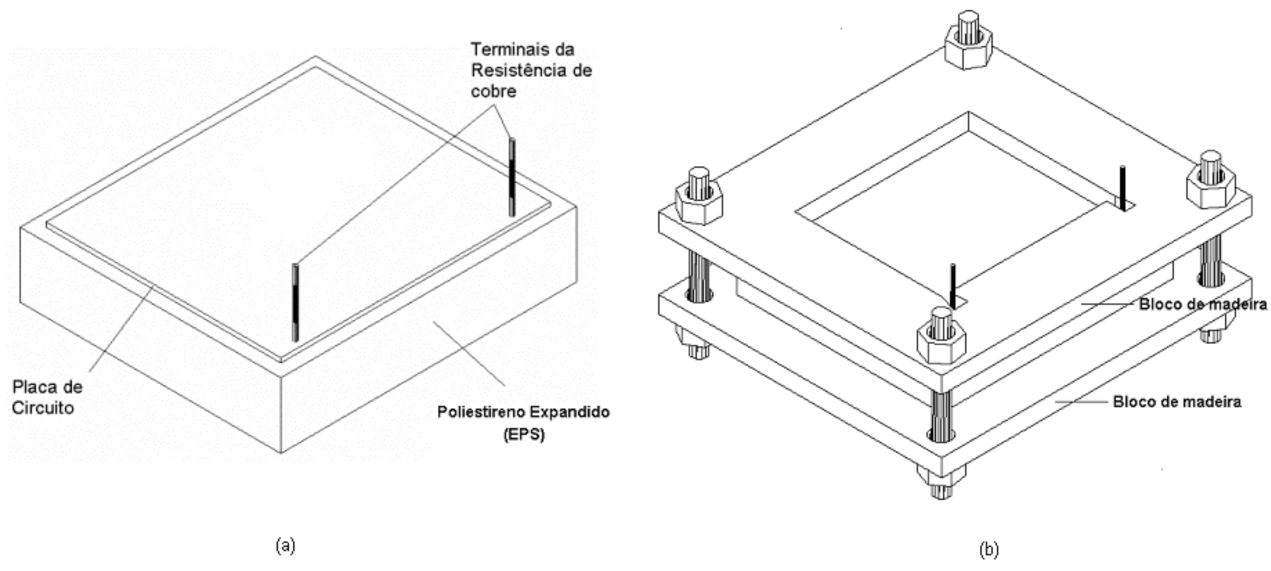

Figure 4. The sensor-generator set up

The curve of variation of the resistance with respect to temperature was obtained from the temperature of the sensor-generator, through the measurement of resistance of four wires (multimeter HP 3460 A) and a glass thermometer of 0,1 °C. To avoid convection on the plate, it was placed in a calibration ambient with height such that the Rayleigh number was smaller than 1708, according to Bejam, 1996. The regression curve of 20 dates is given by (6).

$$R_x = R_{copper} = 0{,}0946505 \bullet T + 26{,}1585 \qquad (6)$$

Where Rx =Rcopper is the resistance of the cooper, T is the ambient temperature, the correlation coefficient is 0,9988 , and the mean square deviation is 8,5x10e-6.

For the resistances of references it was set up two resistances of manganine wire. The manganine resistances had the values of 30,60 Ω and 31,73 Ω which, respectively, corresponds to the reference temperatures of 49,93 °C and 58,86 °C.

The figure 5 shows the electronic circuit used. A source of negative tension substituted the ground in one of the ends of the bridge, which allowed a range of operation suitable to the circuit without altering its operation principle. The gain of the direct network was nearly of 100.

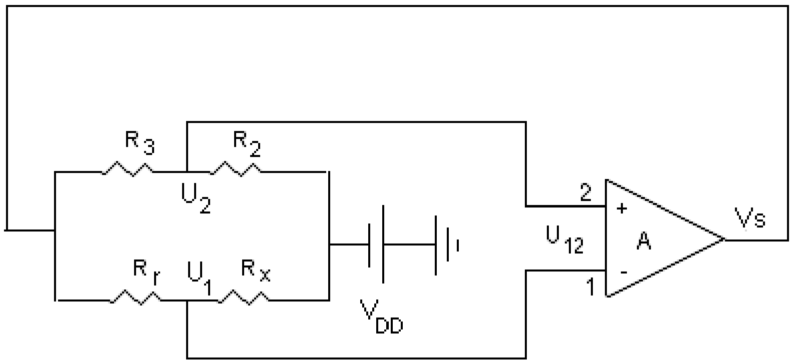

Figure 5. Electronic circuit used in the system control.

The measurements were done using a multimeter (HP 3460A) at three electric tensions along the following branch of the bridge: in the amplifier output Vs, in the connection point between the manganine resistance and the copper resistance, and in the negative constant tension Vdd with approximately 12 V.

Several measurements were realized using resistors of references of 31,73 Ω and 30,6 Ω. The figure 6 shows the values of the calculated resistances. The variations of the data around the central value must have been due to the measurements done with multimeter, in three different instants of time, although close. We verified that the slightest thermal variations provoke alterations in the measured signs. Considering that the mean values of the measurements we would have a standard deviation of 0,000538249 in 30,60 Ω and 0,00030038 Ω in 31,73 Ω, corresponding to 0,003°C in both cases.

The average values were 30,34 Ω for the copper resistor when the manganine resistance was of 30,60 Ω and 31,36 for the copper resistor when the manganine resistance was of 31,73 Ω (uncertainties of 0,26 Ω and 0,37 Ω) respectively. Figure 7 shows the results of the tensions measurements in the central points of the bridge branches and an ideal curve calculated in agreement with the equation 5, disregarding the drift.

When using the circuit of figure 5, disregarding the drift, the new formulation for equation 5 due to negative feed of the bridge would be:

$$\left(\frac{R_2}{R_2+R_3}-\frac{R_x}{R_x+R_r}\right)=\left(\frac{V_S}{V_S-V_{DD}}\right)\frac{1}{A} \tag{7}$$

Using the data of the manganine resistance of 30,60 Ω we would have the mean value 30.34033 and standard deviation of 2.264982E-2 for an expected value of 30,36Ω. The uncertainty in resistance measurement becomes 0,02 corresponding to a 0,2 °C value. Using the data of the manganine resistance of 31,37 Ω we would have the medium value 31.36067 Ω and standard deviation of 1.692301E-2 Ω for an expected value of 31.36 Ω, with measurement uncertainty of 0,00 Ω corresponding to a value of 0,0 °C.

Measuring the manganine temperature with infrared thermometer it was obtained 60°C. Using the resistance coefficient with the temperature ± 0,00002 (Holman, 1984), there is a variation of uncertainty of the manganine resistance of 0,018 Ω, indicating the validity of the proposal .

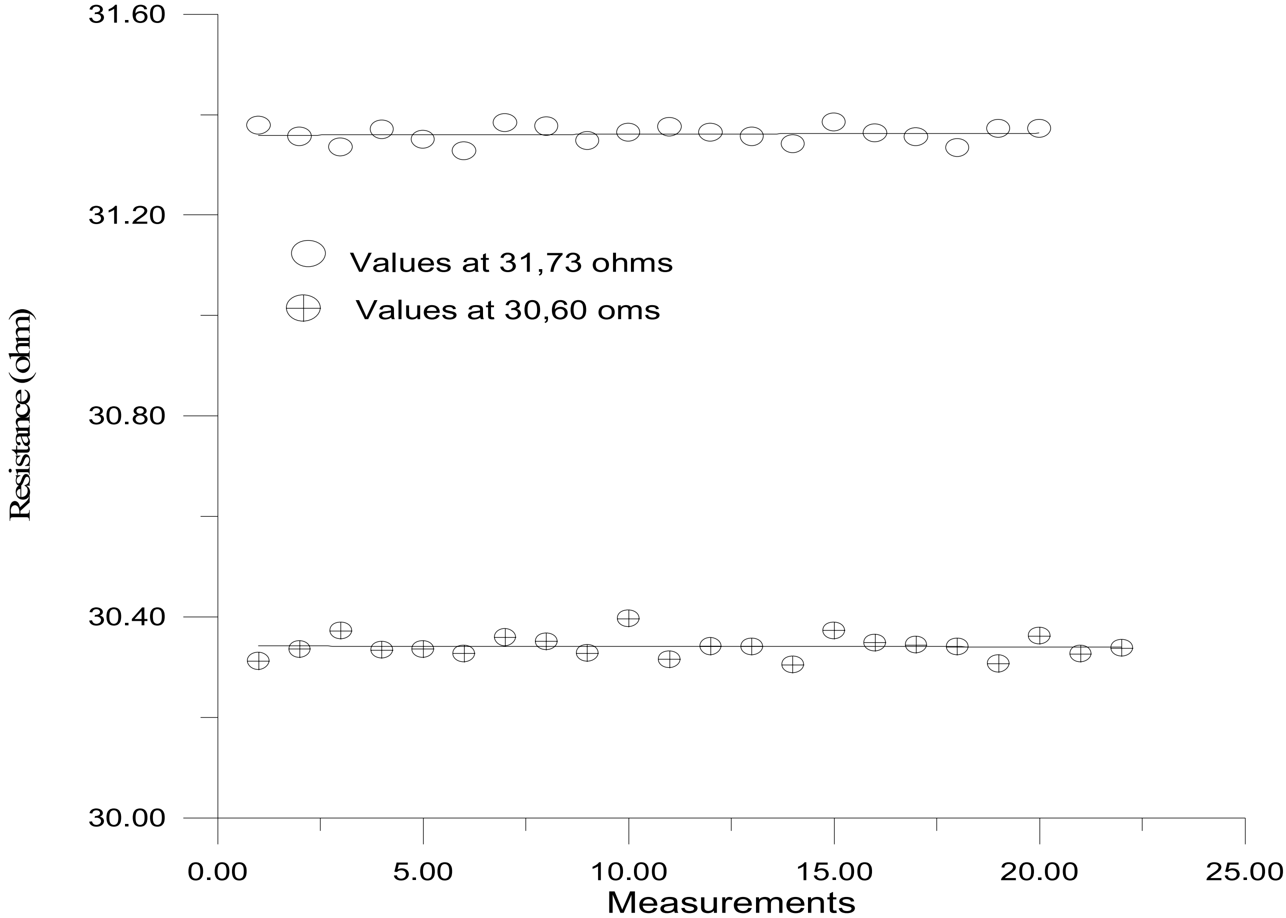

Figure 6. Values of the calculated resistances in several trials.

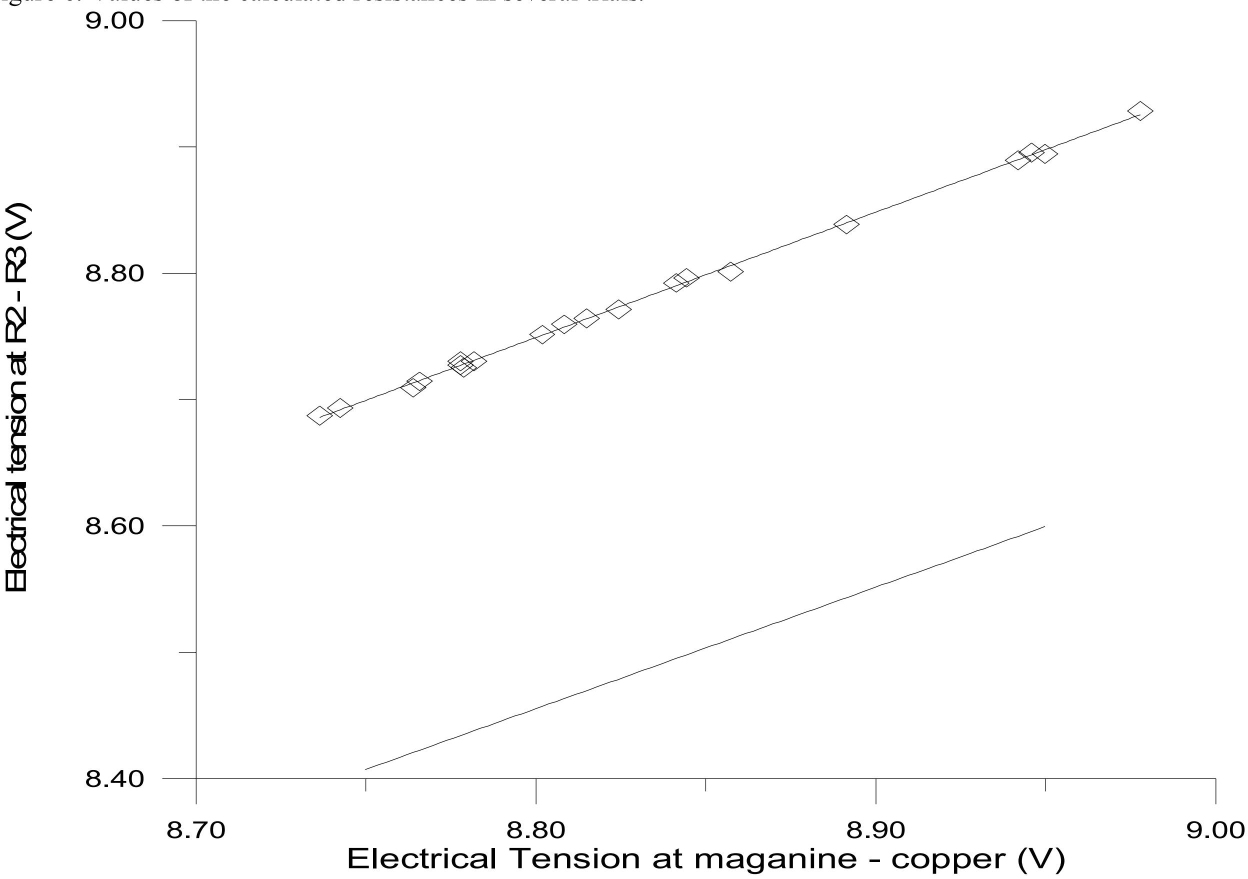

Figure 7.Values of the electric tension according to model in the section II.

The temperatures in several points of the sensor are not equal, mainly with the rectangular geometry. However the medium value must be. To outline this problem, a circular geometry and a mass of high thermal conductivity material, just as used by the controllers to semiconductor, according to Cutler, Karlquist et al, U.S. Patent. Improvement has also been made in the electronic circuit, the use of heat wastrel in the manganine resistor and the verification of the slightest variation of its value.

4. Conclusion

Preliminary theoretical and experimental foundation for loss compensated and high accuracy thermal control has been established. After the set ups, experimental results appear to confirm the validity of the concept (indicating a self-calibrated and high accuracy technical). The precision now is in the order of thousandth of degrees Celsius and the accuracy is larger than tenth of degrees Celsius. The error source was identified and techniques for reduction are being implemented.

5. References

Belo, F. A., Paz, M. M. A., Leite, A., P., L., Nascimento, L., N., 2004, "Loss Compensated and Self Calibrating Thermoresistive Temperature Control" Brasil, PI 0402948-7.

Bejan, A., 1996, Transferência de Calor. São Paulo: Edgard Blücher..

Cutler, L. S., Karlquist, R. K., Ingman, E. M., Johnson, J. L. , Parisek, T., "High Thermal Gain Oven with Reduced Probability of Temperature Gradient Formation for the Operation of a Thermally Stable Oscillator" , U. S. Patent 5, 729,181.

Frerking, M., E., 1978, "Cristal oscillator Design and Temperature Compensation" , Van Nostrand Reinold Company.

Ganzarolli, M. M.; Milanez, L. F., 1995, "Natural Convection in Rectangular Enclosures Heated from Below and Symmetrically Cooled from the Sides", Int. J. Heat Mass Transfer, Great Britian, Jun./Jul., v.38, n.6, p.1063-1073.

Holman, J. P., 1984, "Experimental Methods for Engineers", Fourth Edition, McGraw-Hill.

Hennecke, D., K., and Sparrow, E.M., 1970, "Local Heat Sink on a Convectively Cooled Surface, Application to Temperature Measurement Error", Int. J. Heat and Mass Trans., vol. 13, p.287.

Karlquist, R. K, , Cutler, L. S , Ingman, E. M., Johnson, J. L. , Parisek, T., 1997, "The Theory of Zero-Gradient Crystal Ovens", Proceedings of the 1997 IEEE Internation Frequency Control Symposium.

Merkle,R.,C., 1997. "A New Family of Six Degree Of Freedom Positional Devices, Nanotechonology, Vol. **8**, No. 2, pages 47-52.

Pallarès, J.; Cuesta, I.; Grau, F. X. e Giralt, F.,1996, "Natural Convection in Cubical Cavity Heated from Below at low Rayleigh Numbers", Int. J. Heat Mass Transfer, Vol.39, No. 15, pp. 3233-3247.

Paz, M., M., A., 2002, "Estudo Teórico e Experimental do Controle Térmico de uma Cavidade Retangular", CPGEM, João Pessoa, .Orientador: Francisco Antônio Belo, Dissertação (mestrado) – UFPB/CT

Silva, H. J. , 2002, "Estudo Teórico e Experimental do Controle Térmico Utilizando uma Nova Térmica: Aparede Termorresistiva", CPGEM, João Pessoa, Orientador: Francisco Antônio Belo, Dissertação (mestrado) – UFPB/CT

Souza, V. A., Zaparoli, E. L., 2000, "Analysis of Error in the Surface Temperature Measurement of Semi-Infinite Body", CONEM2000 - Congresso Nacional de Engenharia Mecânica,RN.