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MEASUREMENT OF TEMPERATURE USING RTD AND SOFTWARE SIGNAL CONDITIONING USING LABVIEW

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***Abstract*— This paper aims at measuring temperature using Resistance Temperature Detector (RTD) and its software Signal conditioning stages using LabVIEW. The objective of this paper includes (i) measurement of temperature using the RTD (ii) signal conditioning stages of voltage/current excitation, amplification, and linearization (iii) the analysis of static and dynamic resistance characteristics of RTD. The 4 wire RTD provides good interchangeable configuration and cancels out the lead resistance effectively compared to other RTD wire configuration. In the proposed technique, it is observed that the best suited way for static resistance temperature measurement of RTD is by using Rational Polynomial equation as it provides high linearity compared to other technique and the calibration curve exhibits good linearity between electrical resistance and temperature. In dynamic resistance temperature measurement, it yields high gain and increases the efficiency of the system. The data acquisition process is done by using NI 9219 module along with Hi-Speed USB Carrier NI USB-9162. The RTD (PT100), temperature sensor is used for temperature sensing and the software signal conditioning is done using the LABVIEW 2014 tool.**

***Index Terms*— Amplification, Calibration, Excitation, Linearization, Resistance Temperature Detector (RTD), Static and Dynamic Resistance.**

I. INTRODUCTION

Measurement of temperature plays a very important and pivotal part in the quality of end product in many process industries.Almost all chemical processes and reactions are temperature dependent. Several types of temperature sensors are available in the market with varied degrees of accuracy. RTD is one such sensor which finds a wide application in a process industry because of its very high coefficient of resistivity, good linearity along with a very stable operation over a considerable period of time.

Resistance Temperature Detectors (RTDs) operates on the principle of changes in the electrical resistance of pure metals and are characterized by a linear positive change in resistance with temperature. Edval J.P. Santos and Isabela B. Vasconcelospredict that these transducers display a high linearity and are observed to be better due to its noise immunity [3].They are among the most precise temperature sensors available with resolution and measurement uncertainties of ± 0.1°C [1].

The data acquisition system is used to gather signals from the measurement sources and LabVIEW is used to create the DAQ applications. It includes a set of VIs to configure, acquire data from, and send data to DAQ devices. Nasrin Afsarimanesh and Pathan Zaheer Ahmed proposed LabVIEW based characterization and optimization of thermal sensors for reliable high speed solution [5].Each DAQ device is designed for specific hardware, platforms and operating systems. The DAQ process is done by using NI 9219 module along with Hi-Speed USB Carrier NI USB-9162.

The optimization of the real-world signals is done by using the signal conditioning stages which varies widely in functionality depending on the sensor. For example, RTD produce very low-voltage signals, which requires voltage/current excitation, amplification and linearization.Santhosh.K.V, B.K.Royproposed a technique that makes the output independent of the physical properties of the RTD and avoids the requirement of repeated calibration every time the RTD is replaced [7]. It requires very low excitation current to prevent self-heating. The RTD (PT100), is used for temperature sensing and the software signal conditioning is done using the LABVIEW 2014 tool.

The rest of the paper is organized as follows. In Section II, we provide a brief description of RTD Characteristics. InSection III, we introduce description of NI 9219 Hardware used. Proposed work is described in Section IV.Section V deals with important Results and Discussion. Finally, we conclude this paper in Section VI.

II. RESISTANCE TEMPERATURE DETECTOR

A platinum resistance temperature detector (RTD) is a device with a typical resistance of 100 Ω at 0 °C. It consists of a thin film of platinum on a plastic film [4]. Typical elements used for RTDs include nickel (Ni) and copper (Cu), but platinum (Pt) is by far themost common because of its wide temperature range, accuracy, and stability as shown in Fig.1. Its resistance varies with temperature and it can typically measure temperatures up to 850°C [2]. The relationship between resistance and temperature is relatively linear.

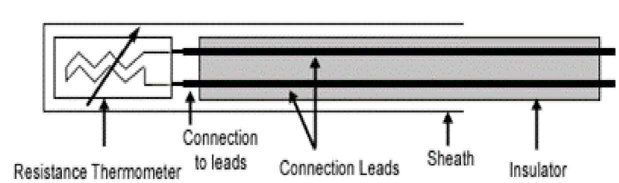

Fig.1 Physical Architecture of RTD

A. Relationship between Resistance and Temperature

The temperature coefficient, called alpha (α), differs between RTD curves. Alpha is most commonly defined as shown in equation (1),

$$\alpha(\Omega/\Omega/°C) = (R\,100 - R0)/(R0 * 100°\,C) \quad (1)$$

where, R100 is the resistance of the RTD at 100° C,
R0 is the resistance of the RTD at 0° C.
Fig. 2 displays a typical resistance-temperature curve for a 100 Ω platinum RTD.

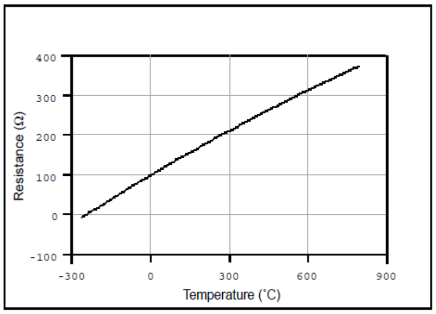

Fig. 2 Resistance-Temperature Curve for a 100 Ω Platinum RTD, α = 0.00385

The Callendar-Van Dusen equation is commonly used to approximate the RTD curve as in equation (2)

$$Rt = R0[1 + At + Bt^2 + C(t - 100)^3] \quad (2)$$

Where, Rt is the resistance of the RTD at temperature t,
R0 is the resistance of the RTD at 0° C,
A, B, and C are the Callendar-Van Dusen coefficients shown in Table I and t is the temperature (°C).

For temperatures above 0° C, the equation (2) reduces to a quadratic equation (3). If we pass a known current, I_{ex} , through the RTD and measure the output voltage developed across the RTD, V_0, then t can be estimated by,

$$t = \frac{2(V_0 - I_{EX}\,R_0)}{I_{EX}\,R_0[A+\sqrt{A^2+4B(V_0-I_{EX}\,R_0)/I_{EX}\,R_0}]} \quad (3)$$

where , V0 is the measured RTD voltage and
Iex is the excitation current.

TABLE I

CALLENDAR-VAN DUSEN COEFFICIENTS CORRESPONDING TO COMMON RTDS

Standard	Temperature Coefficient (α)	A	B	C*
DIN 43760	0.003850	3.9080×10^{-3}	-5.8019×10^{-7}	-4.2735×10^{-12}
American	0.003911	3.9692×10^{-3}	-5.8495×10^{-7}	-4.2325×10^{-12}
ITS-90	0.003926	3.9848×10^{-3}	-5.870×10^{-7}	-4.0000×10^{-12}

B. RTD Calibration

When using RTDs, the temperature is computed from the measured RTD resistance. Depending on the temperature range and accuracy we can use simple linear fit, quadratic or cubic equations, or a rational polynomial function.

For the case of measurements between 0°C and 100°C, a linear approximation can be used as in equation (4).

$$T = (R/R_0 - 1) / \alpha \quad (4)$$

where $R_0 = 100$, and $\alpha = 0.00385$

The average error over the interval ±0.38°C can be minimized to ±0.19°C by shifting the equation a little, as in equation (5),

$$T = (R/R_0 - 1)/\alpha - 0.19 \quad (5)$$

A quadratic fit provides a much greater accuracy in the range of 0°C to 200°C and provides an rms error over the range of only 0.014°C, and a maximum error of only 0.036°C. The equation for a European standard 100Ω RTD is shown in equation (6),

$$T = -244.83 + R\,(2.3419 + .0010664\,R) \quad (6)$$

A cubic fit equation over the range of -100°C to +600°C provides an RMS error of only 0.038°C over the entire range, and 0.026°C in the range of 0°C to 400°C as shown in equation (7),

$$T = -247.29 + R\,(2.3992 + R\,(.00063962 + 1.0241E\text{-}6\,R)) \quad (7)$$

Fitting the RTD data over its full range (-200 to +850°C) produces the formula (8) for computing temperature from RTD resistance,

$$T = C_0 + \frac{R(C_1+R(C_2+R(C_3+C_4R)))}{1+R(C_5+R(C_6+C_7R))} \quad (8)$$

Using the rational polynomial function results in an average absolute error of only 0.015°C over the full temperature range.

C. Accuracy of Various Approximations

The average absolute errors for the above approximations to the Temperature vs. Resistance RTD curve are summarized in Table II.

TABLE II

TEMPERATURE RANGE AND AVERAGE ERROR OF VARIOUS APPROXIMATIONS

Equation	Temperature Range	Average Error
Linear1	0 -- +100°C	±0.12°C
Linear2	-200 -- +850°C	±25°C
Quadratic	0 -- +200°C	±0.11°C
Quadratic	-200 -- +850°C	±3.2°C
Cubic	-100 -- +600°C	±0.03°C
Cubic	-200 -- +850°C	±0.31°C
Rational Polynomial	-200 -- +850°C	±0.015°C

III. HARDWARE DESCRIPTION

The NI DAQ 9219 hardware has four 6 spring-terminal connectors that provide connections for four analog input channels. The signal name and terminal assignments by mode are explained in reference [9]. In Fig.3, the lead wire resistance does not affect these modes because a negligible amount of current flows across the HI and LO terminals due to the high input impedance of the ADC[6].

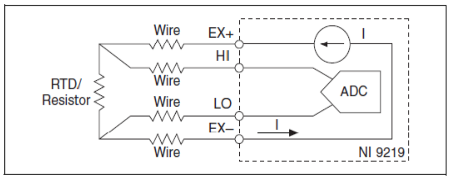

Fig.3. 4-Wire Resistance and 4-Wire RTD mode

The 3-Wire RTD modecompensates for lead wire resistance in hardware if all the lead wires have the same resistance whereas in 2-Wire Resistance mode, lead wire resistance is not compensated[8]. The NI 9219 applies a gain of 2x to the voltage across the negative lead wire and the ADC uses this voltage as the negative reference to cancel the resistance error across the positive lead wire.

IV.PROPOSED WORK

The proposed work includes temperature measurement, signal conditioning and analysis of static and dynamic resistance characteristics of RTD. The hardware setup of the proposed work is shown in Fig.4.

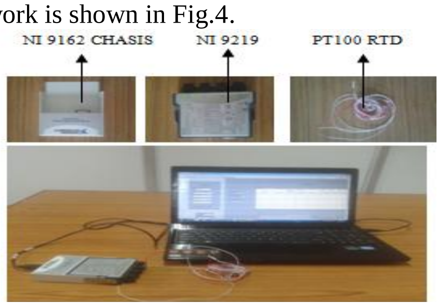

Fig.4 Hardware setup

The RTD is used to measure the corresponding resistance change with respect to the temperature and the acquisition of resistance from RTD is done using LabVIEW through NI DAQ 9219 as shown in Fig.5

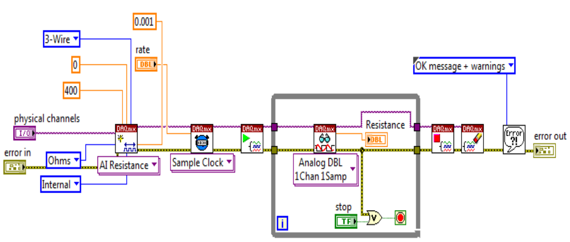

Fig.5 Block Diagram for Acquiring Resistance

The acquired resistance is converted to temperature using linear fit, cubic fit, quadratic fit and rational polynomial equation as shown in Fig.6.

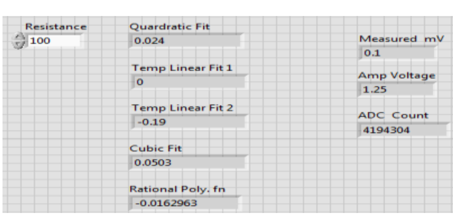

Fig.6 Front Panel_resistance_to_temp

A. STATIC TEMPERATURE MEASUREMENT

The performance criterion for the measurement of quantities that remain constant, or vary only quite slowly is called static measurement. The static characteristics of instruments are related with steady state response. The input parameters such as physical channel in which RTD isconnected to and the type of RTD wire configuration accompanied with number ofreadings, sampling rate, actual temperature are configured. In order to begin the execution, the actual temperature must be equal to the true temperature. Then, the process is initiated and the corresponding status is indicated using the status indicator. After taking the required number of readings, the average for each of the measured resistance, amplified voltage, ADC count and various approximations to convert resistance to temperature is calculated and tabulated. Finally, the waveform graph is plotted for the analysis of static temperature measurement.

B. DYNAMIC TEMPERATURE MEASUREMENT

The set of criteria defined for the instruments, which are changes rapidly with time, is called 'dynamic characteristics. It is used to compare the dynamic properties.Configure the input parameters such as physical channel in which RTD is connected to and the RTD wire configuration accompanied with sampling rate, start and end temperature. The start temp button is used to collect the data. Initially, the resistance for an average of 30 samples is calculated. Then the starting temperature is determined and the data acquisition process is carried outuntil the RTD reaches the end temperature. The values such as number of samples collected, 63.2% end temp, resistance, actual temperature, start and end resistance & temperature, elapsed time, time constant and gain values are computed. Finally, the waveform graph is plotted for the analysis of dynamic characteristics of temperature measurement.

V. RESULTS AND DISCUSSION

In this section, the static and dynamic temperature measurements VI are developed and simulated using LabVIEW.

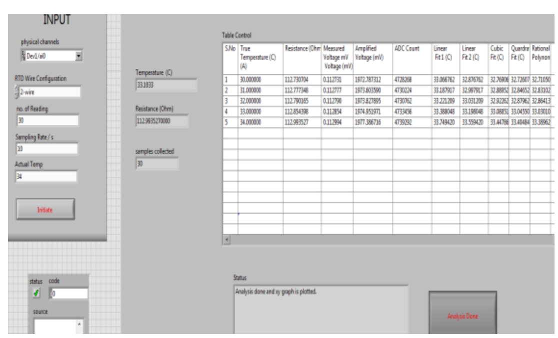

Fig.7 Front Panel of Static Temperature Measurement

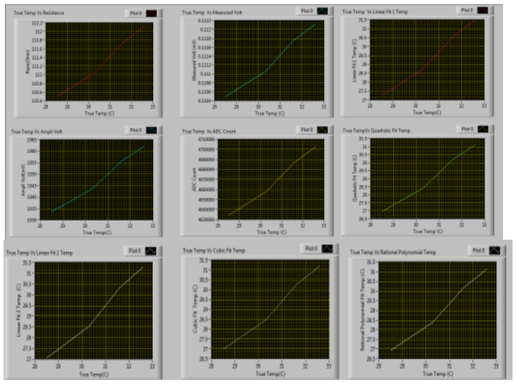

Fig.8 Front Panel-Waveform Graph of Static Temperature Measurement

Procedure for static temperature measurement

- The input parameters such as physical channel in which RTD is connected to and the RTD wire configuration accompanied with number of readings, sampling rate, actual temperature are initialized as shown in the Fig.7.
- Then the initiate button is clicked for the data acquisition.
- The status of the execution is shown using the status indicator and the readings are tabulated when the required numbers of samples are collected.
- Finally, the analysis done button is clicked and the graph is plotted for various approximations methods as shown in Fig.8.
- The results are analyzed and it is found that the rational polynomial function shows better accuracy and high linearity compared to other approximation techniques.

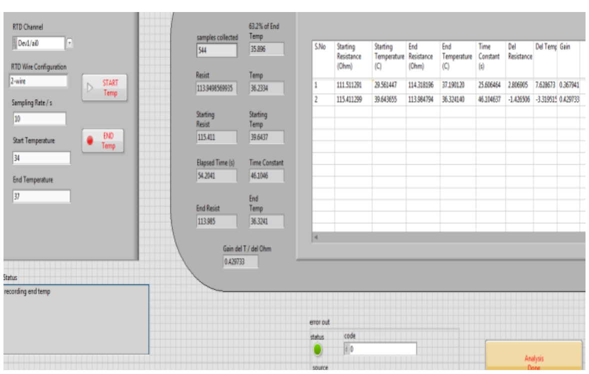

Fig.9 Front Panel of Dynamic Temperature Measurement

Procedure for Dynamic Temperature Measurement

- Configure the input parameters such as physical channel in which RTD is connected to and the RTD wire configuration accompanied with sampling rate, start and end temperature as shown in Fig.9.
- Click the start temp button to collect the data and the Status indicator is used to display the current status of the execution.
- Initially, the resistance for the average of the 30 samples is measured to find the average starting temperature and the data acquisition is done continuously until the RTD reaches the 63.2% of end temperature.
- When the end temperature is reached, click the end temp button.
- Then, the average of start and end resistance & temperature, time constant and gain values are computed.
- The gain value is estimated to be positive and results in higher efficiency and the waveform graph is plotted for the corresponding readings as in Fig.10.

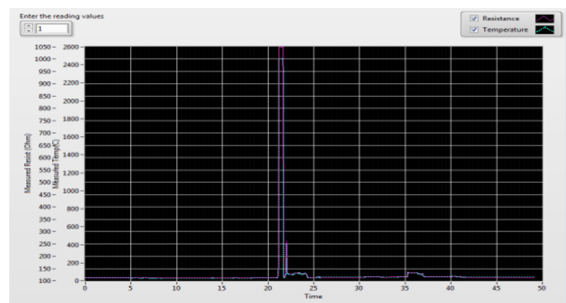

Fig.10 Front Panel-Waveform Graph of Dynamic Temperature Measurement

Thus, from the results of static and dynamic temperature measurement,it is observed that the rational polynomial equation in static temperature measurement exhibits high linearity than other approximation techniques and the dynamic temperature measurement yields better gain value and hence results in improved performance.

VII. CONCLUSION AND FUTURE WORK

The temperature was measured using the RTD & the software signal conditioning stages are done using LabVIEW 2014 tool which includes voltage/current excitation, amplification and linearization. The 4 wire RTD provides good interchangeable configuration and cancels out the lead resistance effectively compared to other RTD wire configuration. It is observed that the best suited way for static temperature measurement of RTD is by using Rational Polynomial equation as it provides high linearity compared to other techniques. In dynamic temperature measurement, the software signal conditioning yields high gain and improved efficiency than the traditional method.
The future work is to implement the signal conditioning stages of RTD in an embedded based FPGA hardware in order to obtain increased data acquisition rate and to enhance the performance.

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