

Temperature Measurement of Coal Pipe of Coal Mills by a Modified Bridge Circuit



Karunamoy Chatterjee, Tapan Maity, Subrata Chattopadhyay

Abstract—In our earlier work we proposed a method to measure the temperature of the coal pipe of Coal Mills in PF Boiler by a continuous basis, In order to achieve, accurate measurements of coal pipe temperature, using the resistive transducers like resistance temperature detector (RTD), the small resistance changes linearly with temperature, but resistance measurement by using RTD using normal Wheatstone bridge circuit would have errors for the stray capacitance presents in between bridge nodal points and the ground. Hence, by the use of a modified operational amplifier based Wheatstone bridge network, these effects can be minimized. The bridge performance has been studied experimentally with RTD. It has been observed good linearity, repeatability and variable sensitivity over the wide range of temperature.

Keywords— RTD, stray capacitance, op amp based bridge network.

I. INTRODUCTION

The most important variables is temperature and it is always needed to measure and control for any process. The temperature is measured by the different types of temperature measuring transducers such as thermometer, thermistor, thermocouples, radiation pyrometers etc. [9,10,11]. These types of temperature transducers may long lasting and user friendly but using that transducer, we need to require various environmental as well as experimental precautions during the measurement of process temperature. The resistance of a resistive transducer is generally changing very small for the temperature changes and the stray capacitance between the ground and the bridge nodal points introduce error as it is comparable with the impedance of the sensor which is used for measurement. Therefore, for minimization of that error, a modified operational amplifier based AC Wheatstone Bridge has been designed. Over the years many scientist and researcher measured temperature using electronic circuits, Wheatstone’s bridge in different configurations etc. The coal pipe temperature has been measured in continuous basis for PF boiler system [1]. In [2], measurement of resistance has been reported using a self-balancing bridge directly by the accuracy of 1 percent.

Wheatstone bridge [2] is a standard topology for determining the induced voltage across the forth arm of the bridge circuit. Some other measuring circuits techniques are also available in [3, 4]. The method discussed in [5] which keeps the error below 0.1% using lead wire resistances of higher range. Enhancement of bridge sensitivity employing Wheatstone’s bridge for strain and temperature measurement is demonstrated by Shreem Ghosh et. al. in [8]. K.V. Santhosh et.al. has designed an adaptive calibrated circuit using RTD with an optimized Artificial Neural Network for temperature measurement [12]. In [14,6,7], [15], a look up table has been made created for the calibration of RTD. In [13] some methods and techniques of temperature measurement are discussed. In the present case the nodal points of the bridge output lead wires has been considered at virtual ground condition and as due to this the stray capacitance between the bridge output lead wires and also between any output lead wire and may always be considered very less. Identical bridge equations for the modified AC Wheatstone bridge network have been developed as we get for the conventional AC Wheatstone bridge network. Thus it has been observed that regular measurement is possible by this modified AC Wheatstone bridge network.

II. BLOCK DIAGRAM OF THE SYSTEM

The block diagram of the temperature measuring method has been shown in fig.1. It contains process tank, RTD, Wheatstone bridge, some signal conditioning circuit and a voltmeter. Process tank is a cylindrical type hotspot, whose temperature will be sensed by the temperature sensor RTD. A PT-100 RTD is used for this purpose. Here, for the measurement of change in resistance of the RTD, a modified operational amplifier based measurement system has been developed. For the signal to be rectified a bridge rectifier may be used. If the ripple persists the filter may be suggested for connection. A voltmeter is used to measure the obtained voltage signal.

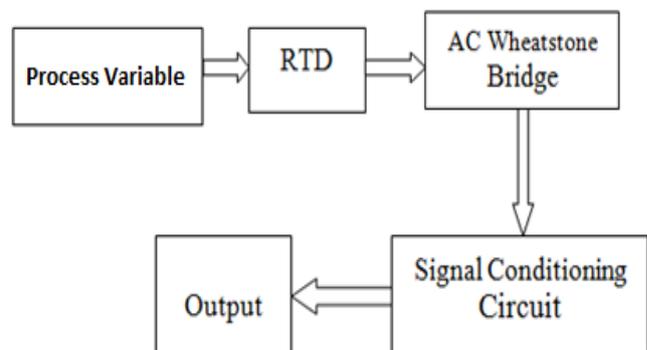


Fig.1. Block diagram of the system

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III.METHOD OF APPROACH

The Figure2 shows the circuit diagram of “Modified AC Wheatstone Bridge Network using RTD”. Here the bridge circuit consists of four resistances. A (230v to 9v) step down transformer. One RTD (PT100) is connected in an arm of the bridge. The general AC Wheatstone bridge network is modified by connecting two operational amplifiers A1 and A2 which are very high gain and the non-inverting terminals has been added to the circuit common or ground terminal.

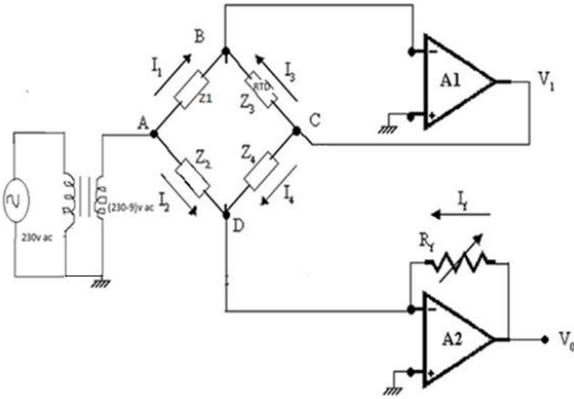


Fig.2. Modified AC Wheatstone Bridge Network

Therefore, the bridge output nodal points B and D have been considered at the same potentials. These lead that the effect of stray capacitance that will present between them and also stray inductance of the inductive coil may be assumed to be very less. Since B and D are at virtual ground, so for the Ac supply voltage $V = V_m \sin \omega t$, currents through the bridge impedances Z_1, Z_2, Z_3 and Z_4 are respectively given by,

$$I_1 = \frac{V}{Z_1}, I_2 = \frac{V}{Z_2}, I_3 = \frac{V_1}{Z_3}, I_4 = \frac{V_1}{Z_4} \quad (1)$$

Where, V_1 is the output voltage of the operational amplifier A_1 .

If V_0 be the output voltage of the operational amplifier A_2 then the current through its feedback resistance path is given by,

$$I_f = \frac{V_0}{R_f} \quad (2)$$

From the Kirchhoff's current law,

$$I_1 + I_3 = 0 \quad (3)$$

$$I_2 + I_4 + I_f = 0 \quad (4)$$

From the equation (1) and (3),

$$\frac{V}{Z_1} + \frac{V_1}{Z_3} = 0 \quad \text{Or, } V_1 = -\left(\frac{Z_3}{Z_1}\right)V \quad (5)$$

From the equations (1), (2) and (4),

$$\frac{V}{Z_2} + \frac{V_1}{Z_4} + \frac{V_0}{R_f} = 0 \quad (6)$$

From the equations (5) and (6)

$$V_0 = \frac{R_f}{Z_1 Z_2 Z_4} (Z_2 Z_3 - Z_1 Z_4) V \quad (7)$$

At balance condition of the bridge, $V_0 = 0$

$$\text{i.e. } Z_2 Z_3 = Z_1 Z_4 \quad (8)$$

The condition for balance is same as of the general Wheatstone bridge network.

Modified bridge network as shown in Figure.2 is applied and is designed a network with circuit component as shown in Figure.3, where

$$Z_1 = \frac{R_1}{1 + j\omega R_1 C_1}, Z_2 = \frac{R_2}{1 + j\omega R_2 C_2}, Z_3 = R_0 + \Delta R, Z_4 = R_4$$

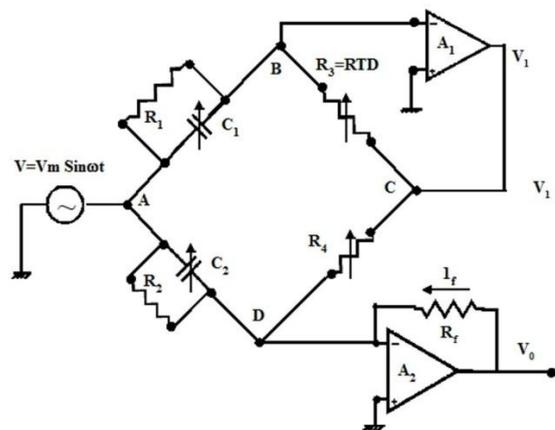


Fig.3. Modified AC Wheatstone Bridge Network using RTD

Here R_0 is the value of the resistance of the RTD for the very less value of a process variable and ΔR is the resistance change for the change of the variable above the very less value.

Hence, we get out put voltage of the bridge from the equation no. (7) and it can be written as following

$$V_0 = \frac{R_f V}{R_1 R_2 R_4} [R_2 R_x (1 + j\omega R_1 C_1) - R_1 R_4 (1 + j\omega R_2 C_2)]$$

(9) Where,

Or,

$$V_0 = \frac{R_f V}{R_1 R_2 R_4} [(R_2 R_x - R_1 R_4) + j\omega(R_2 R_x R_1 C_1 - R_1 R_4 R_2 C_2)]$$

(10)

Where V_0 and V are the RMS values of the output and supply voltage signal respectively of the bridge and R_0 is the sensor resistance for the less value of variable Then, $V_0 = 0$ for $R_x = R_0$.

Therefore equating real and imaginary part

$$R_2 R_0 - R_1 R_4 = 0$$

(11)

$$R_2 R_0 R_1 C_1 - R_1 R_4 R_2 C_2 = 0$$

(12)

Hence from equating (10), (11), (12) the bridge output voltage for a change in resistance ΔR of the resistive transducer (RTD) by the change in process variable above the minimum value is given by

$$V_0 = \frac{R_f V}{R_1 R_2 R_4} [R_2 (R_0 + \Delta R) - R_1 R_4 + j\omega\{R_2 (R_0 + \Delta R) R_1 C_1 - R_1 R_4 R_2 C_2\}]$$

Or,

$$V_0 = \frac{R_f V}{R_1 R_2 R_4} [R_2 R_0 + R_2 \Delta R - R_1 R_4 + j\omega(R_2 R_0 R_1 C_1 + R_2 \Delta R R_1 C_1 - R_1 R_4 R_2 C_2)]$$

Or,

$$V_0 = \frac{R_f V}{R_1 R_2 R_4} [R_2 \Delta R (1 + j\omega R_1 C_1)]$$

(13)

Or,

$$V_0 = \frac{R_f (1 + j\omega R_1 C_1) V}{R_1 R_4} \Delta R$$

(14)

Hence if RMS value of output voltage be V_0 , then

$$V_0 \propto \Delta R$$

(15)

It implies that the output voltage is exactly linearly related to the change in process variable with bridge sensitivity factor R_f .

From RTD characteristics the change in resistance (ΔR) can be represented by the following equation

$$\Delta R = R_0 \alpha \Delta T$$

(16)

R_0 — RTD resistance at minimum value of process variable
 α — Temperature co-efficient of resistance of RTD
 ΔT — Change in temperature

Using equation (14) and (16), the bridge input voltage due to change of temperature (ΔT) is given by

$$V_0 = \frac{R_f (1 + j\omega R_1 C_1) V}{R_1 R_4} R_0 \alpha \Delta T$$

(17)

$$\text{Or, } V_0 = K \Delta T$$

(18)

Therefore, $V_0 \propto \Delta T$

(19)

$$\text{Where } K = \frac{R_f (1 + j\omega R_1 C_1) V}{R_1 R_4} R_0 \alpha$$

Hence the output voltage V_0 is directly proportional in the change of temperature of the process plant.

IV. ERROR ANALYSIS

The introduction of error for the drifting of zero and drifting of gain of the OPAMPS which we can minimize by choosing noise free OPAMPS and selecting a stabilised sinusoidal signal for exaction purpose.

From equation (18),

$$\Delta T = \frac{V_0}{K}$$

ΔT_1 is the relative measurement error and it is expressed in percentage (%). It has been calculated by the following equation,

$$\text{Relative Measurement Error } (\Delta T_1) = \frac{\left(\frac{V_0}{K} - \Delta T\right)}{\Delta T} \times 100\%$$

(20)

Where ΔT is the temperature change and the output voltage which has been measured is as V_0 .

In terms of percentage of maximum range, it changes in (ΔT_2) this has been defined as

$$\text{Relative Measurement Error } (\Delta T_2) = \frac{\left(\frac{V_0}{K} - \Delta T\right)}{\Delta T_{\max}} \times 100\%$$

(21)

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The actual values may be obtained and relative measurement error (ΔT_3) from the linearity may then be defined as

$$\text{Relative Measurement Error}(\Delta T_3) = \frac{(V_{0_{actual}} - V_0)}{(V_{0_{actual}})_{Max}} \times 100\% \quad (22)$$

Where $V_{0_{actual}}$ is the actual value obtained from the best fit linear curve for the given temperature change ΔT and V_0 is the corresponding observed value.

V. EXPERIMENTAL ANALYSIS

The circuit diagram of the modified bridge is designed by considering the parallel combination of resistor and capacitor in the branch of Z_1 and Z_2 . The other two branches are connected with a resistor and the RTD is shown in Figure 3.

The experimental setup for modified AC Wheatstone bridge network is shown in Figure 3 with selected value of R_f . The bridge components of the network had the following specifications:

R_1, R_2, R_4 = Variable resistance taken from decade box.

C_1, C_2 = Variable decade capacitor, (0.1, 0.01, 0.001 μ F decades) No.98722, Make: H. Tinsley & Co. Ltd.

R_3 = RTD [PT 100]

R_f = 1 k Ω , 3W, W/W potentiometer

The 9V, 50Hz AC power supply is provided to the circuit using a step down transformer.

The initial minimum bridge balance condition is obtained using oscilloscope and multimeter for a particular value of R_f [202.3 Ω] by varying the potentiometer R_1, R_2, R_4 and

variable capacitor C_1, C_2 using RTD [PT 100] in place of R_3 at room temperature. Then the RTD is placed in a hot spot and temperature measurement is started. The bridge output voltages for different values of ΔT is measured for a particular value of bridge sensitivity factor R_f . An experimental characteristic graph has been plotted for the bridge output voltage against the change in temperature [ΔT] for different values of bridge sensitivity factor R_f is shown in Figure 4. From the experimental data, the best fit linear characteristic is drawn by using MS Office Excel worksheet software as shown in the same Figure 4. Now the percentage error from this linear characteristic is calculated

by using the equation (20). The percentage deviation is found to lie within +/- 2% as shown in Figure 5.

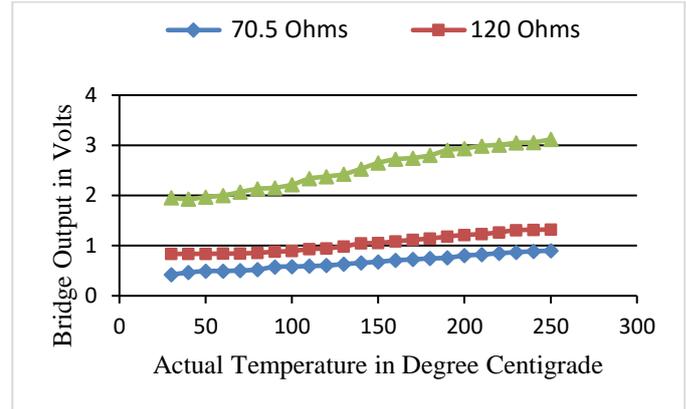


Fig. 4. RTD Characteristics with Modified AC bridge network for different values of the bridge sensitivity factor resistance [R_f]

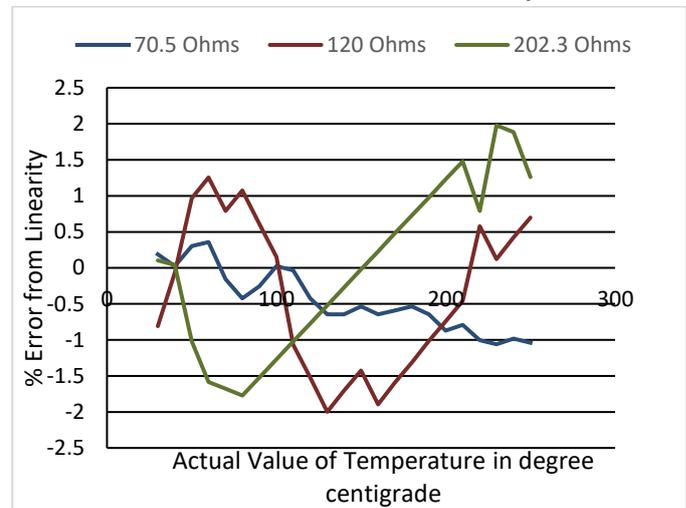


Fig.5. % error curves of Temperature for different values of the bridge sensitivity factor resistance [R_f]

VI. DESIGN METHOD

In the boiler design, pulverized coals are forced to flows within the long coal-pipe with the help of hot air and we cannot predict the flow profile of pulverized coal through coal pipe. Again there is no arrangement to get update the coal pipe temperature also. As a consequent, coal pipe get choked for the improper coal flow and it is not known for a long time. Once the coal pipe is being choked we may require huge manpower with huge cost to de-choke the coal pipe and as a result loss of power generation and it also directly make impact on the economic matter of our power plant. Therefore, by measuring the coal pipe temperature in regular basis, it is possible to minimize the losses. Automation has been developed for the measurement of coal pipe temperature and the automation has been adopted by the modified bridge network. A scanner has been used for the channel scanning purpose and the data logger will serve the purpose of channel scanning. RTD output signal has been scanned by that data logger.

Here, four numbers of coal mill has been taken for consideration and individual mill will have four coal pipes, therefore, we measured 16 numbers of coal pipe temperature. We procured 16 numbers of RTD and all are surface mounted. RTD has been fixed on the individual coal pipe very carefully before entering at the burner area. a central control junction box has been created where All RTDs signals have been connected and then it has been fed to the temperature scanner unit. After that a communication between Data logger or Temperature Scanner to DCS system through a single pair cable has been established. To

provide uninterrupted measurement of process value i.e., coal pipe temperature a programme or logic has been developed on DCS software. A graphical representation of all of those 16 numbers of coal pipe temperature for plant operators has been configured as well as an alarms for low temperature i.e., temperature has been given. Final development of the bridge network with other required hardware has been shown in Fig.6.

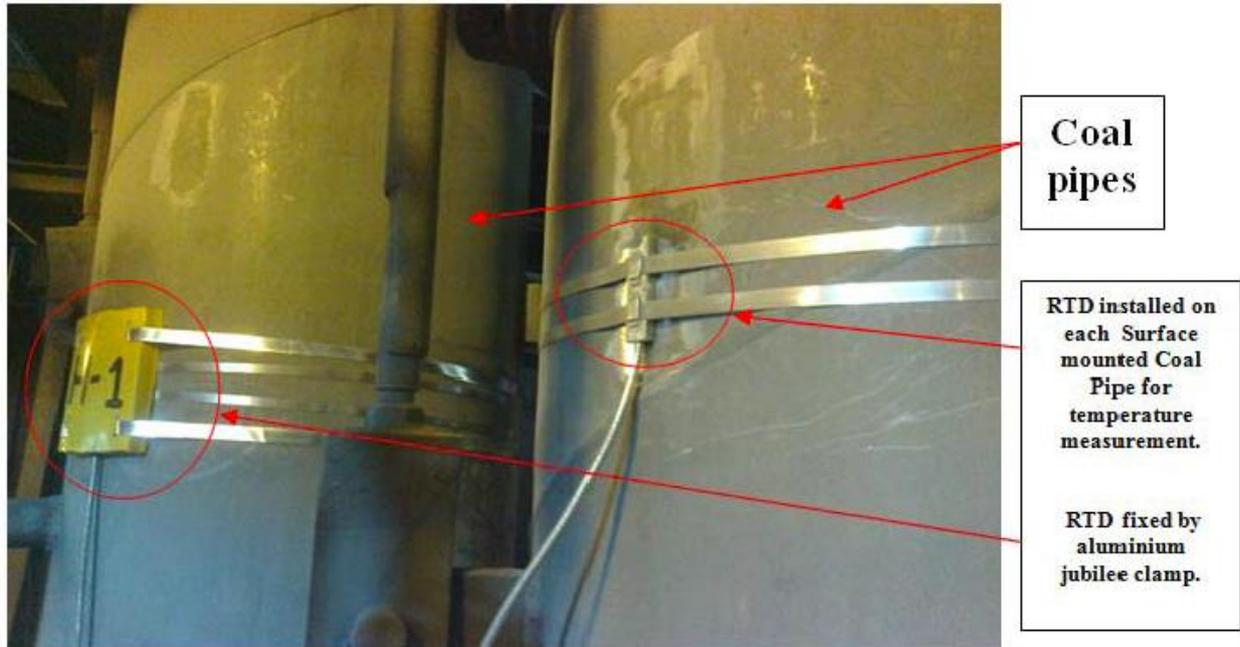


Fig.6 RTD mounted coal pipe for Temperature measurement

VII. DISCUSSION

The bridge characteristics graph has been shown in Figure 4. It has been found quite good linearity with the variation of temperature. At the time of experiment, we found the same results with very good repeatability.

As developed system produces an amplified output, so, we need not require to use bridge amplifier or an instrumentation amplifier. Hence, we can directly be directly rectify and filtered the output voltage to produce a DC voltage signal.

To obtain the optimum sensitivity, The maximum excitation voltage of the RTD connected in the arm BC in Figure 2 depends upon maximum output voltage of the op-amp A1. As a result a good sensitivity, repeatability and linearity have been observed during the experiment with this modified ac Wheatstone bridge network.

VIII. CONCLUSION

Uninterrupted power supply is a basic demand in this new age. It can be provided by modernization of the power houses. The availability of the equipments is essential for uninterrupted power generation in the power plants. Each and every small parameter plays a vital role. In this study, the temperature of coal pipe has been measured and monitored for a long time without any interruption. It is found that if the temperature of the coal pipe becomes less than 65°C, the alarm is enunciated in the control room and

the necessary corrective measures can be taken without any delay. Thus, the choking of the coal pipe can be prevented by continuous monitoring of the temperature of the coal pipes. This directly increases the availability of coal mill for uninterrupted power supply. Hence, the best efficiency of the boiler can be achieved by maintaining proper coal flow to it.

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REFERENCES

1. Karunamoy Chatterjee, Sankar Narayan Mahato, Subrata Chattopadhyay, "Measurement and Control of Coal Pipe Temperature of Coal Mills of PF Boiler," International Journal of Engineering and Technology (IJET), Vol 8 No 4 Aug-Sep 2016.
2. S. C. Wheatstone, "An account of several new instruments and processes for determining the constants of a voltaic circuit," Philos. Trans. R. SOC. Land., vol. 133, no. 1843, pp. 303-329.
3. M. Rehman, M.T. Ahmed, M. Arif, "A Self-balancing bridge for in-circuit measurement", in Proc. of the IEEE, Inst & Meas., Vol. 73, 1985, pp. 1680-1682.
4. Karl F. Anderson, "The New Current Loop: An Instrumentation and Measurement Circuit Topology", IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 5, October 1997.

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5. S. Pradhan, S. Sen, "An improved lead compensation technique for three wire resistance temperature detectors", IEEE Tran on Inst. & Meas., 48, 5, 1999, pp. 903-905.
6. S. C. Bera and D. N. Kole, "Study of a Modified AC Bridge Technique for Loss Angle Measurement of a Dielectric Material", Sensors & Transducers Journal, Vol. 96, Issue 9, September 2008, pp. 104-111.
7. Subrata Chattopadhyay, Mahuya Baneerji and Sagarika Pal, "Modified AC Wheatstone Bridge Network for Accurate Measurement of Pressure Using Strain Gauge Type Pressure Sensor", Sensors & Transducers Journal, Vol. 136, Issue 1, January 2012, pp. 25-34.
8. Shreem Ghosh, Aninda Mukherjee, Kunal Sahoo, Sunit Kumar Sen, Arindam Sarkar, "A Novel Sensitivity Enhancement Technique Employing Wheatstone's Bridge for Strain and Temperature Measurement", 978-1-4799-4445-3/15/\$31.00 ©2015 IEEE.
9. E. O. Doebelin, "Measurement System Application and Design", 4th Edition, McGraw Hill Publishing Company, 1990.
10. D. V. S Murthy, "Transducer and Instrumentation", 2nd Edition, Prentice-Hall of India Pvt. Ltd., New Delhi, 1995.
11. Curtis D. Johnson, "Process Control Instrumentation Technology", 8th Edition, Prentice-Hall of India Pvt. Ltd., New Delhi, 2006.
12. K.V. Santhosh and B.K. Roy, "An Adaptive Calibration Circuit for RTD Using Optimized ANN" Proceedings of 7th International Conference on Intelligent Systems and Control (ISCO 2013), 978-1-4673-4603-0/12/\$31.00102012 IEEE.
13. Jiaoyue Lio, Lin Ma and Juqing Yang, "Methods and Techniques of Temperature Measurement", 978-1-4244-8165-1/11/\$26.00 ©2011 IEEE.
14. Najidah Hambali, Shahrizal Saat, Mohd Ashraf Ahmad, Mohd Syakirin Ramli, Muhamad Akmal Ishak, "Computerbased System for Calibration of Temperature Transmitter using RTD", Proc. 3rd International Conference on information Management, innovation Management and industrial Engineering, Kunming, China, November 2010.
15. Najidah Hambali, Shahrizal Saat, Mohd Syakirin Ram Ii, Mustaqim Hazmi, "Automatic Detection Computer-based (ADCob) System for Temperature Measurement Calibration of RTD", Proc. international Conference on Electrical, Control and Computer Engineering, Pahang, Malaysia, June, 2011.

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