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Remote Multi-Point Temperature Measurement Using 3-wire Resistance Temperature Detectors

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ABSTRACT: Temperature is an important parameter for the operation and control of any process plant. Also the number of temperature points is, perhaps, the highest amongst all the process variables. Thus often multiple temperature points in similar applications are monitored together. Here in this paper, a multi-point temperature measurement scheme is described using 3-wire Resistance Temperature Detectors (RTD). The design includes Lead Wire Compensation for accurate and consistent measurement of temperature from remote place.

Keywords: Compensation, Lead, multisensor systems, resistance measurement, temperature measurement.

I. INTRODUCTION

Temperature is the principal process variable of serious concern to the process industries [1]. This is mainly due to two reasons – i) to establish proper operating condition and ii) to ensure proper safety of the parts. For example, temperature control is critical in chemical, petroleum, petrochemical, polymer, plastic, pharmaceutical, metallurgical, air-conditioning, power, food processing and many more industries. Temperature control also plays a critical role in the safe operation of such facilities. Temperature monitoring points in any such process plant are usually huge in number. It is also quite likely that many such temperature points may be grouped together (based on the type of sensors used, the temperature ranges, similar applications etc.) for monitoring purposes by a single instrument. For example, boiler temperatures, winding and bearing temperatures of large industrial motors are to name a few. It not only helps to make a comparative study amongst the similar temperature points easier but also cuts down the system cost by a considerable amount.Thermocouples and resistance temperature detectors are widely used temperature sensors in industries. Thermocouples are rugged and are suitable for high temperature applications. Common temperature ranges are within -101 to +1149^{o}C for base-metal thermocouples and within -18 to + 1700^{o}C for precious-metal thermocouples [2]. The temperature range of RTD is somewhat less than thermocouple and they are most suitable in the temperature range of -200 to 650^{o}C [3]. However, RTD is superior to thermocouple with respect to accuracy, sensitivity, repeatability, linearity and stability [4]. Also for practical applications, thermocouple needs a second sensor to read the ambient temperature for cold junction compensation which also affects measurement accuracy. Other than temperature, resistive transducers are also used in other process variable measurements like pressure, strain, displacement etc.

In spite of all the advantages of resistive sensors, they pose a serious problem when applied to multi-point monitoring where the corresponding sensors have to be multiplexed to the same instrument. The resistances of the switches used in the multiplexers add to the sensor resistances leading to erroneous measurements. Moreover, the variations in the ON resistance from switch to switch tend to add different resistances to the different leads of the sensor, making the standard lead resistance compensation techniques [5], [6] unsuitable. Recently, Pradhan and Sen developed a lead resistance compensation technique [7] that converts the resistance information into equivalent voltages and use circuits to cancel the drops across the lead resistances. The circuit of [7], reproduced here in Figure 1 for ready reference, is used in the present scheme for multiplexing information received from an array of resistive sensors.

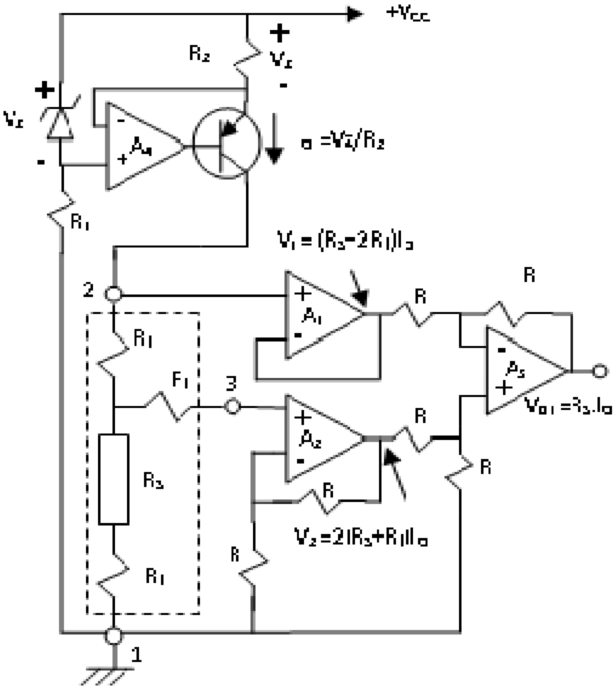

Fig.1 Lead Wire Compensation Circuit for 3-wire RTD

II. SIGNAL MULTIPLEXING

Multi-point measurement requires the signals to be multiplexed such that signal processing circuit should be common for all the sensors. Sensors giving direct voltage outputs like thermocouples are easy to multiplex. But resistance multiplexing is difficult due to the fact that the multiplexers themselves have channel resistances which will be added to that of the sensors. The problem can be avoided by converting the sensor resistances into equivalent voltage signals before multiplexing them to the measuring circuits.

The lead wire compensation scheme of Fig.1 converts information of sensor and lead resistances into suitable voltages before being processed by the electronics to produce a lead resistance free output. The RTD is excited with a constant current source (I_O) built around the op-amp A4. The voltage drop V_1 at terminal 2 of the RTD is buffered through the op-amp A_1 and that at terminal 3 is doubled through the amplifier A_2 to generate V_2. Finally the output voltage V_{O1} is extracted by subtracting V1 from V2 by the amplifier A3, rendering V_{O1} independent of lead wire resistances.

The expressions for V_1, V_2 and V_{O1} are identical as in [7] and are repeated below for the sake of completeness.

$$V_1 = (R_S + 2R_1).I_o \qquad (1)$$

$$V_2 = 2.(R_S + R_1).I_o \qquad (2)$$

$$V_{O1} = (V_2 - V_1) = R_S.I_o \qquad (3)$$

Equation (3) indicates that output voltage (V_{O1}) is proportional to the sensor resistance (R_S) as I_O is a constant.

An 8-channel multiplexing scheme for multi-point temperature measurement based on this circuit is proposed in this paper. The scheme is shown in Fig.2. Three 8-channel analog multiplexers driven by a common 3-bit selection input are used. While multiplexer #1 is used to direct the excitation current to the sensor currently being scanned, multiplexers #2 and #3 select respectively the voltages of leads 2 and 3 of the same sensor. Common selection inputs thus ensure the inclusion of only one sensor to the measuring circuit at a time. The selection inputs can be driven by a 3-bit binary counter or by three output port bits in a microprocessor based system. The channel resistance of multiplexer #1 has no effect on the performance as it is switching the output of the current source to different sensors. Multiplexers #2 and #3 connect the voltage outputs from nodes 2 and 3 of the sensor circuits to the non-inverting inputs of the amplifiers A_1 and A_2 respectively, having very high input impedances. Therefore, neither the switch resistances nor their variations from channel to channel have any effect on the circuit operation. Analog multiplexers used are CD4051s.

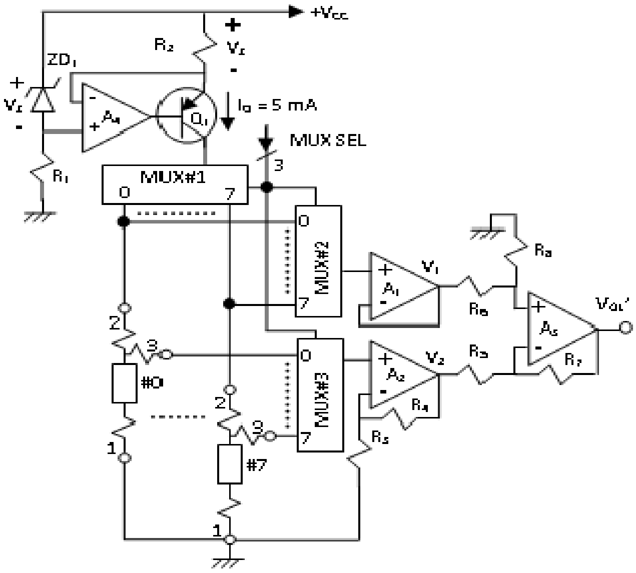

Fig.2 Multi-point Temperature Measurement Scheme

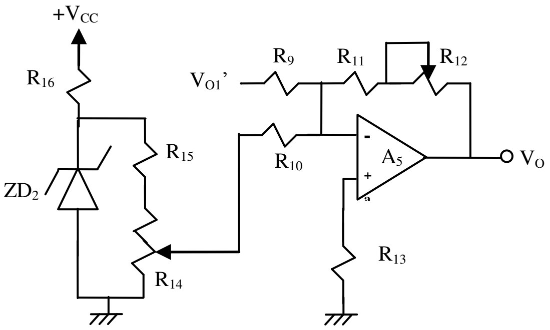

Fig.3 Adjustment of Non-Zero Output Voltage At 0^o C For Temperature Measurement Using RTD

The output V_{O1} as in Fig.1, being proportional to the sensor resistance RS, is not zero when the process temperature measured is 0 OC. An additional adder circuit as shown in Fig.3 is thus added to cancel the said non-zero value. Also as the adder circuit has a negative gain, the op-amp A3 is reversed in Fig.2 to make the final output (VO) positive. Now VO is suitable to display the temperature by a direct reading instrument.

The accuracy of the system depends primarily on the constant current source. Thus it is constructed using a stable reference (LM336-2.5V) and a low drift amplifier (OP-07). In fact, all the other amplifiers and voltage references used in the circuits are OP-07s and LM336-2.5Vs only. Also the gain of the amplifier A_2 should be exactly two for proper cancellation of the lead resistances. It is ensured by putting a matched resistance pair in place of R_3 and R_4.

III. EXPERIMENTAL RESULTS

PT100 RTD sensors are simulated through YOKOGAWA CA71 HANDY CAL Calibrator having simulation accuracy of ±(0.025% of full range + 0.1Ω for 0 to 400.00 Ω full range) [8]. Output voltage is also measured by the same calibrator having a measurement accuracy of ±(0.025% of reading + 0.2 mV for 0 to ±1.1000 V full range) [9]. Experiments are performed for different sensor resistances (corresponding to different process temperatures) in all the channels and different lead resistances added to each. A 5mA sensor excitation current is used as in [7]. Overall circuit gain is set at unity. For each channel, resistances corresponding to different sensor temperatures are simulated and voltages have been taken for four sets of lead resistances of 0 Ω, 10 Ω, 20 Ω, & 30 Ω. The data is presented in Table I.

From Table I it is observed that results are very close to the ideal ones. However, for quantitative analysis, worst case values for each simulated process temperature (sensor resistance) are taken from Table I and noted in Table II. It is seen from Table II that overall worst case error recorded is ±0.027%. Considering that there is a simulation accuracy of ±0.05% and measurement accuracy of ±0.052% of the calibrator, the worst case system error may be predicted as ±0.13%.

TABLE I

Measured output voltage in the circuit of fig.3. (sourcing and measurement accuracies of the calibrator are 0.05% and 0.045% of full range respectively).

Temperature(^{O}C)	**Sensor Res (Ω)**	**Ideal V_O (V)**	**Ch #**	**Measured V_O (V) for diff. Lead Resistances**			
				0 (Ω)	**10 (Ω)**	**20 (Ω)**	**30 (Ω)**
0	100.00	0.0000	0	0.0000	0.0000	0.0000	0.0002
			1	0.0001	0.0000	0.0001	0.0001
			2	0.0000	0.0000	0.0000	0.0002
			3	0.0000	0.0000	0.0000	0.0001
			4	0.0000	0.0001	0.0001	0.0002
			5	0.0000	0.0001	0.0001	0.0001
			6	0.0000	0.0001	0.0001	0.0002
			7	0.0001	0.0001	0.0001	0.0001
100	138.50	0.1925	0	0.1925	0.1925	0.1925	0.1926
			1	0.1925	0.1926	0.1925	0.1926
			2	0.1925	0.1926	0.1925	0.1927
			3	0.1925	0.1925	0.1925	0.1926
			4	0.1925	0.1926	0.1925	0.1926
			5	0.1926	0.1926	0.1926	0.1926
			6	0.1925	0.1925	0.1925	0.1927
			7	0.1926	0.1926	0.1925	0.1926
200	175.83	0.3792	0	0.3791	0.3792	0.3792	0.3793
			1	0.3792	0.3792	0.3792	0.3793
			2	0.3791	0.3792	0.3792	0.3793
			3	0.3792	0.3791	0.3791	0.3792
			4	0.3791	0.3792	0.3792	0.3793
			5	0.3792	0.3792	0.3792	0.3793
			6	0.3792	0.3792	0.3792	0.3793
			7	0.3792	0.3792	0.3792	0.3793
300	212.02	0.5601	0	0.5601	0.5601	0.5601	0.5602

			1	0.5601	0.5601	0.5601	0.5602
			2	0.5601	0.5601	0.5601	0.5602
			3	0.5601	0.5601	0.5600	0.5601
			4	0.5601	0.5601	0.5601	0.5602
			5	0.5601	0.5602	0.5601	0.5602
			6	0.5601	0.5601	0.5601	0.5602
			7	0.5601	0.5601	0.5601	0.5602
400	247.08	0.7354	0	0.7353	0.7353	0.7354	0.7354
			1	0.7354	0.7354	0.7353	0.7354
			2	0.7353	0.7353	0.7353	0.7355
			3	0.7353	0.7353	0.7352	0.7353
			4	0.7354	0.7354	0.7354	0.7355
			5	0.7354	0.7354	0.7353	0.7354
			6	0.7354	0.7354	0.7354	0.7355
			7	0.7354	0.7354	0.7354	0.7354

TABLE II

Deviations Of Output Voltage From The Ideal Ones And Error Estimation

Process Temperature	**Ideal Output Voltage, V_O' (V)**	**Measured Output Voltage, V_O (V)**		**Worst Case Deviation, ΔV (V)**	**% Error of Span, $\Delta V*100/V_O'(max)$**
		Min	Max		
0	0.0000	0.0000	0.0002	+0.0002	+0.027
100	0.1925	0.1925	0.1927	+0.0002	+0.027
200	0.3792	0.3791	0.3793	±0.0001	±0.014
300	0.5601	0.5601	0.5602	+0.0001	+0.014
400	0.7354	0.7353	0.7355	±0.0001	±0.014

From Table I it is observed that results are very close to the ideal ones. However, for quantitative analysis, worst case values for each simulated process temperature (sensor resistance) are taken from Table I and noted in Table II. It is seen from Table II that overall worst case error recorded is ±0.027%. Considering that there is a simulation accuracy of ±0.05% and measurement accuracy of ±0.052% of the calibrator, the worst case system error may be predicted as ±0.13%.

IV. CONCLUSION

The present remote multi-point temperature measurement technique is simple, uses low cost commonly available components and yet offers excellent measurement accuracy. This method can also be used for remote multi-point measurement for other process parameters where resistive sensor can be employed for basic sensing purpose, like pressure measurement by strain gauge etc.

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BIOGRAPHY

Sukes Maiti was born in West Bengal, India, in 1979. He received the B.E. degree in Instrumentation Engineering from the North Maharashtra University, Jalgaon, Maharashtra, India, in 2002 and M.Tech. degree in Biomedical Engineering from the VIT University, Vellore, India, in 2005.

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Saibal Pradhan was born in West Bengal, India, in 1965. He received the B.Sc. (Hon.) degree in physics and the B.Tech. and M.Tech. degrees in radio physics and electronics from the University of Calcutta, Kolkata, India, in 1987, 1990 and 1992 respectively. He received his PhD degree from Jadavpur University, Kolkata in 2007.

In 1992, he joined Industrial Instrumentation, Kolkata, where he became a Senior Executive Engineer. From 1998 to 2000, he worked for Fisher-Rosemount (India) Ltd., Kolkata. Then he joined the College of Engineering & Management, Kolaghat, India, as a Lecturer and became an Asst. Prof. in 2003. At present Dr. Pradhan is professor & Head of the Dept. of Applied Electronics & Instrumentation Engineering in College of Engineering & Management, Kolaghat. His research interests are in electronic process instrumentation, microprocessor applications and VLSI design.

Susanta Sen was born in Kolkata, India, on December 30, 1951. He received the B.Sc. (Hons.) degree in physics and B.Tech., M.Tech., and Ph.D. degrees in radio physics and electronics from the University of Calcutta, Kolkata in 1970, 1973, 1975 and 1983 respectively.

From 1976 to 1978, he worked as a C.S.I.R. Research Fellow. He joined the Institute of Radio Physics and Electronics, University of Calcutta, as a Lecturer in 1978 and became a Reader in 1985. Between 1986 and 1988, he was on leave at AT&T Bell Laboratories, Murray Hill, NJ. At Bell Labs, he pioneered the area of resonant tunneling bipolar transistors and their circuit applications. His present research interests are in optoelectronics, quantum electron devices, and electronics instrumentation. He became a Professor of Electronic Science at the University of Calcutta in 1989. Presently, he is a Professor in the Institute of Radio Physics and Electronics.

Dr. Sen is a Fellow of the Institution of Engineers (India) and a Life Member of the Computer Society of India.