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Flow Measurement Using RTDs

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Abstract- In many processing industries, it is essential to measure either the flow rate or just to know whether the flow or no flow conditions exists. The change in resistance measures the prevailing temperature differential in the flow pipe. The temperature difference could be related to flow rate or flow or no-flow conditions. This may be achieved by the selection of right sensor, signal conditioning circuit and display.

Keywords: Flow Or No Flow Conditions, Temperature differential, sensor, signal conditioning and display

I.INTRODUCTION

The flow rate can be measured using venturimeter, orifice meter, turbine flow meter and ultrasonic flow meter. However, just to know the flow or No-flow conditions in the flow, the simplest reliable system developed is based on the thermal dispersion principle

II.THERMAL DISPERSION PRINCIPLE

The typical sensing element contains two thermowell-protected precision platinum Resistance Temperature Detectors (RTDs). When placed in the process stream, one RTD is heated and the other RTD sense the process temperature. The temperature difference between the two RTDs is related to the process flow rate as well as the properties of the process media. Higher flow rates or denser media cause increased cooling of the heated RTD and a reduction in the RTD temperature difference. Thermal dispersion technology to provide the highest reliability in flow, level and temperature detection. The sensing element is composed of two matched RTD's. One RTD is preferentially heated. The other RTD is unheated and thermally isolated to provide continuous process condition temperature and baseline indication. At no flow or under dry conditions, the temperature differential between the two RTDs is greatest. For flow / no flow detection, No-flow conditions produce a large signal. As flow increases, the heated RTD is cooled and proportionally reduces temperature differential. Changes in flow velocity directly affect this rate of heat [11]

The acronym "RTD" is derived from the term "Resistance Temperature Detector". The most stable, linear and repeatable RTD is made of platinum metal. The temperature coefficient of the RTD element is positive. An approximation of the platinum RTD resistance change over temperature can be calculated by using the constant 0.00385Ω/Ω/°C. This constant is easily used to calculate the absolute resistance of the RTD at temperature. [2]

Equation

$$RTD(T) = RTD_0 + T \times RT\,D_0 \times 0.00385\Omega/\Omega/°C$$

where:

RTD(T) is the resistance value of the RTD element at temperature T^oC

RTD_0 is the specified resistance of the RTD element at 0°C and, T^oC is the temperature environment that the RTD is placed. The RTD element resistance is extremely low when compared to the resistance of a NTC thermistor element, which ranges up to 1 MΩ at 25°C. Typical specified 0°C values for RTDs are 50, 100, 200, 500, 1000 or 2000Ω. Of these options, the 100Ω platinum RTD is the most stable over time and linear over temperature. If the RTD element is excited with a current reference at a level that does not create an error due to self-heating, the accuracy can be ±4.3°C over its entire temperature range of -200°C to 800°C. If a higher accuracy temperature measurement is required, the linearity formula below (Calendar-Van Dusen Equation) can be used in a calculation in the controller engine or be used to generate a look-up table.

$$RTD\,(T) = RTD_0\,[1 + AT + BT^2 - (100CT^3 + CT^4)$$

where:

RTD(T) is the resistance of the RTD element at temperature,

RTD_0 is the specified resistance of the RTD element at 0°C, T is the temperature that is applied to the RTD element (Celsius) and, A, B, and C are constants derived from resistance measurements at 0°C, 100°C and 260°C.

III.SENSOR FABRICATION TECHNOLOGY

Realization of a thin film sensor involves the deposition of a sensing film on a suitable substrate. There could be combination of metals and insulating materials needs to be deposited on one another depending upon the application or sensing requirements. [3]

Film Deposition Methods for Sensor Fabrication

Based on the thickness of the deposited film and the technology used to deposit these films, fabrication technology is broadly divided into two categories like i) thick film technology and ii) thin film technology, details of which are given below.

IV.THICK FILM TECHNOLOGY

Thick film technology uses pastes or "inks" with fine particles (5μ average diameter) of common or noble metals dispersed in an organic vehicle, along with a glass frit that binds them. Depending on the dispersed particles, the paste can be conductive, resistive or dielectric. Those pastes are screen printed on a substrate according to pattern involving width lines from 10 μ to 200μ. The printed film is dried by heating at about 150 °C to remove the organic solvent that provided the low viscosity needed for the paste to squeeze through the open areas in the screen. The substrate with the deposited film is then fired on a conveyor belt furnace, usually in the air atmosphere, so that the metal powder sinters and glass frit melts, thereby bonding the film to the substrate. The result is 10μ to 25μ thick film, impermeable to many substances but relatively porous for specific chemical or biological agents. Thick film components have a printed tolerance of about ±10% to ± 20%, but they can be later trimmed to within ±0.2% to ±0.5% through selective abrasion or laser evaporation.

Thick film technology finds at least three different uses in sensors. It has been used for years to fabricate hybrid circuits offering improved performance compared to monolithic integrated circuits for signal conditioning and processing. Thick film circuits and some sensors can be integrated in the same package, which improves the reliability (strong connections), permit functional trimming and reduces cost. It is also used to create support structures or substrates onto which a sensing material is deposited.

Some thick film pastes directly responds to physical and chemical quantities. There are pastes – some developed for sensing applications- with high temperature coefficients of resistance useful for temperature sensing, piezo-resistive pastes, magneto-resistive pastes, pastes with high Seeback coefficient among others. Pastes based on organic polymers and metal oxides such as SnO_2 can detect humidity and gases because of adsorption and absorption. Using thick film technology, it is straightforward to define the inter-digitated structures required for those sensors. Thick film sensors with ceramic substrate withstand high temperatures, can be driven with relatively large voltages and currents, can integrate heaters and can resist corrosion. Because the paste is fired into the ceramic, thick film sensors are compact and sturdy. The printing process is quite inexpensive, which permits competitive low volume fabrication. [4-6]

V.THIN FILM TECHNOLOGY

Thin films (generally less than 1 micron thick) are obtained, in general by vacuum deposition on a substrate. Sensor and circuit patterns are defined by masks and transferred by photolithography, similar to monolithic IC fabrication. Even though their names may suggest that the only difference between thick film and thin film technology is in film thickness, they are quite different technologies. In fact, metallized thin films may become thicker than some thick films. The properties of thin film differ from the bulk material.

Common materials in thin film circuits are nichrome for resistors, gold for conductors, and silicon dioxide for dielectrics. Many thin film sensors are resistive.Piezo-resistors use nichrome and poly crystalline silicon, conductivity sensors use platinum, strain gauge based sensors use platinum – tungsten alloys, and gas sensors use zinc oxide.

NI MULTISIM

The National Instruments Electronics Workbench Group (formerly Electronics Workbench) equips the professional printed circuit board (PCB) designer with world-class tools for schematic capture, interactive simulation, board layout, and integrated test. [7]

VI.SOURCES OF ERRORS AND CORRECTION

RTDs are externally powered sensors and based on the variation of resistance with temperature. The accuracy of platinum Resistance Thermometer (PRT) temperature measurement is largely determined by the number of leads used between the probe and the instrument. Two leads are often acceptable in the case of short cable runs; three leads compensating for lead resistance variations give improved accuracy; and four leads provide the greatest precision.

Self-heating of RTD also causes measurement inaccuracy. The maximum excitation current is determined by the self-heating within the RTD and this limits the maximum signal for a required measurement temperature range. To produce a higher-level signal for indication and recording, a separate signal conditioner is needed.

Noise interference can have a significant effect on accuracy. Shielded twisted pair signal cable minimizes noise interference on measuring circuit. For long cable runs a 4-20m A current transmitter may be used.

RTD elements are, in fact very vulnerable to contamination of all kinds, and must be used only in hermetically sealed probes for any industry application. Moisture, dirt or any seriously affect the accuracy of RTD. [1]

TABLE 1. RTD ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages
Very Accurate and Stable	Expensive Solution
Fairly Linear to ±4%C	Requires Current Excitation
Good Repeatability	Danger of Self-Heating
	Low Resistive Element

Common elements, such as Resistance Temperature Detectors (RTDs), thermistors, thermocouples or diodes are used to sense absolute temperatures, as well as changes in temperature. Of these technologies, the platinum RTD temperature sensing element is the most accurate and stable over time and temperature.

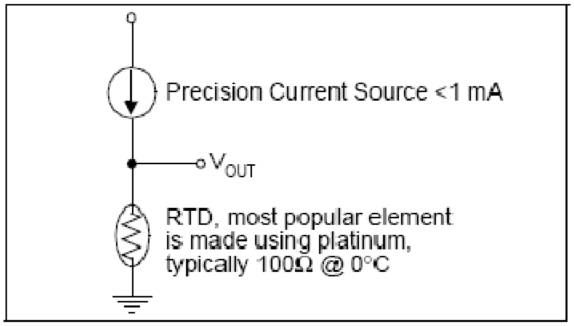

Figure-1. Current excitation.

VII.RTD CURRENT EXCITATION CIRCUIT

For best linearity, the RTD sensing element requires a stable current reference for excitation. In this circuit, a voltage reference, along with two operational amplifiers, are used to generate a floating 1 mA current source.

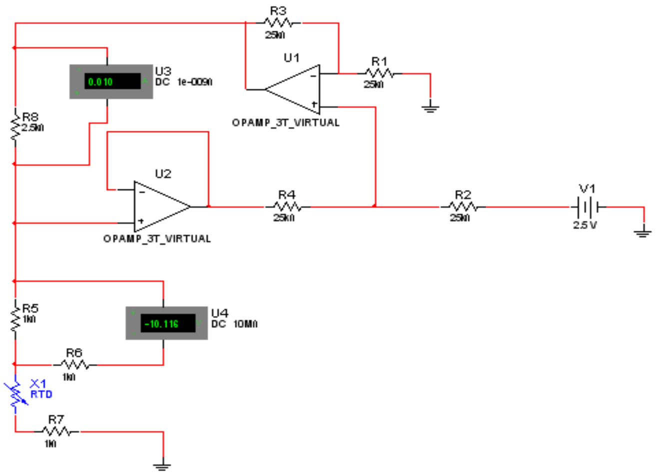

Figure 2. A Current Source For The RTD element can be constructed in a single-supply environment from two operational amplifiers and a precision voltage reference.

This is accomplished by applying a 2.5V precision voltage reference to R_4 of the circuit. Since R_4 is equal to R_3, and the non-inverting input to U1 is high impedance, the voltage drop across these two resistors is equal. The voltage between R_3 and R_4 is applied to the non-inverting input of U1. That voltage is gained by $(1 + R_2/R_1)$ to the output of the amplifier and the top of the reference resistor, R_{REF}. If $R_1 = R_2$, the voltage at the output of U1 is equal to:

EQUATION

$$V_{OUTU1} = \left(1 + {}^{R_2}\!/_{R_1}\right) \times \left(V_{REF} - V_{R4}\right)$$

$$V_{OUTU1} = 2 \times V_{REF} - V_{R4}$$

Where:

V_{OUTU1} is the voltage at the output of U1 and

V_{R4} is the voltage drop across R_4.

The voltage at the output of U1 is equal to:

EQUATION

$$V_{OUTU1} = V_{REF} - V_{R4} - V_{R3}$$

This same voltage appears at the inverting input of U2 and across to the non-inverting input of U2.

Solving these equations, the voltage drop across the reference resistor, R_{REF}, is equal to:

$$V_{RREF} = V_{OUTA1} - V_{OUTA2}$$

$$V_{RREF} = 2 \times \left(V_{REF} - V_{R4}\right) - \left(V_{REF} - V_{R4} - V_{R3}\right)$$

$$V_{RREF} = V_{REF}$$

where:

V_{RREF} is the voltage across the reference resistor, R_{REF} and, V_{R3} is the voltage drop across R_3

The current through R_{REF} is equal to:

EQUATION

$$I_{RTD} = V_{REF} / R_{REF}$$

This circuit generates a current source that is ratio metric to the voltage reference. The same voltage reference can be used in other portions of the circuit, such as the analog-to-digital (A/D) converter reference. Absolute errors in the circuit will occur as a consequence of the absolute voltage of the reference, the initial offset voltages of the operational amplifiers, the output swing of U1, mismatches between the resistors, the absolute resistance value of R_{REF} and the RTD element. Errors due to temperature changes in the circuit will occur as a consequence of the temperature drift of the same elements listed above. The primary error sources over temperature are the voltage reference, offset drift of the operational amplifiers and the RTD element.

VIII.RTD SIGNAL-CONDITIONING PATH

Changes in resistance of the RTD element over temperature are usually digitized through an A/D conversion. The current excitation circuit, is used to excite the RTD element. With this style of excitation, the magnitude of the current source can be tuned to 1 mA or less by adjusting R_{REF}. The voltage drop across the RTD element is sensed by U3, then gained and filtered by U4. With this circuit, a 3-wire RTD element is selected. This configuration minimizes errors due wire resistance and wire resistance drift over temperature.

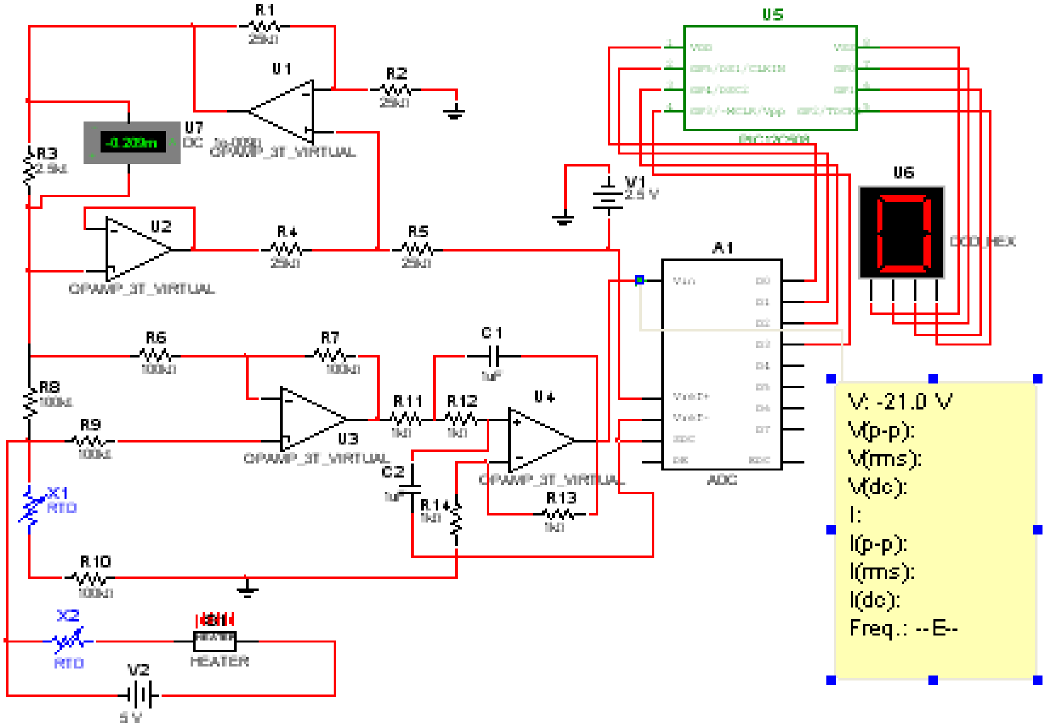

Figure 5. Simulated Circuit of flow switch

IX.CONCLUSION

1. No-flow conditions produce a large signal.
2. As flow increases, the heated RTD is cooled and proportionally reduces the temperature differential.
3. Changes in flow velocity directly affect this rate of heat dissipation.
4. An electronic circuit normalizes the differential measurement with the process media temperature and converts the RTD temperature/resistance differential into a DC voltage signal.

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