SENSORS AND TRANSDUCERS

A transducer is a device that converts one form of energy or physical quantity into another, in accordance with some defined relationship. Where a transducer is the sensing element, which responds directly to the physical quantity to be measured and this forms part of an instrumentation or control system, then the transducer is often referred to as a sensor.

In data acquisition systems, transducers sense physical phenomena and provide electrical signals that the system can accept. For example, thermocouples, resistive temperature detectors (RTD's), thermistors, and IC sensors convert temperature into an analog voltage signal, while flow transducers produce digital pulse trains whose frequency depends on the speed of flow.

Two defined categories of transducer exist:

- Active transducers convert non-electrical energy into an electrical output signal. They do not require external excitation to operate. Thermocouples are an example of an active transducer.
- Passive transducers change an electrical network value, such as resistance, inductance or capacitance, according to changes in the physical quantity being measured. Strain gauges (resistive change to stress) and LVDT's (inductance change to displacement) are two examples to this. To be able to detect such changes, passive devices require external excitation.

Transducer Characteristics

Transducers are classified according to the physical quantity they measure (e.g. temperature, force etc). Beyond the obvious selection of the type of transducer required to measure a particular physical quantity and any cost considerations, the characteristics which are most important in determining a transducers applicability for a given application are as follows:

- Accuracy
- Sensitivity
- Repeatability
- Range

Accuracy

When a range of measurements is made of any process it is essential to know the accuracy of the readings and if this is maintained over the entire range. The accuracy of a transducer describes how close a measurement is to the actual value of the process variable being measured. It describes the maximum error that can be expected from a measurement taken at any point within the operating range of the transducer. Manufacturers usually provide the accuracy of a transducer as a percentage error over the operating range of the transducer, such as ± 1% between 20 0C and 120 0C, or as a rating (i.e. ± 1 0C) over the operating range of the transducer.

Sensitivity

Sensitivity is defined as the amount of change in the output signal from a transducer to a specified change in the input variable being measured. Highly sensitive devices, such as thermistors, may change resistance by as much as 5% per 0C, while devices with low sensitivity, such as thermocouples, may produce an output voltage that changes by only 5 mV per 0C.

Repeatability

If two or more measurements are made of a process variable at the identical state, a transducer's repeatability indicates how close the repeated measurements will be. The ability to generate almost identical output responses to the same physical input throughout its working life is an indication of the transducers reliability and is usually related to the cost of the transducer.

Range

A transducer is usually constructed to operate within a specified range. The range is defined as the minimum and maximum measurable values of a process variable between which the defined limits of all other specified transducer characteristics (i.e. sensitivity, accuracy etc) are met. A thermocouple, for example, could well work outside its specified operating range of 0 0C to 500 0C, however its sensitivity outside this range may be too small to produce accurate or repeatable measurements.

There are several variables that affect the accuracy, sensitivity and repeatability of the measurements being made:

- In the process of measuring a physical quantity, the transducer disturbs the system being monitored. As an example, a temperature measuring transducer lowers the temperature of the system being monitored, while energy is used to heat its own mass.
- Transducers are responsive to unwanted noise in the same way that a record players magnetic cartridge is sensitive to the alternating magnetic field of the mains transformer (giving rise to 'mains hum').
- Some transducers are subject to excitation signals that alter its response to the input physical quantity being measured. As an example, an RTD's excitation current can result in self-heating of the device, thereby changing its resistance.

Resistance Temperature Detectors (RTD's)

Characteristics of RTD's

Resistance temperature detectors (RTD's) are temperature sensors generally made from a pure (or lightly doped) metal whose resistance increases with increasing temperature (positive resistance temperature coefficient).

Most RTD devices are either wire wound or metal film. Wire wound devices are essentially a length of wire wound on a neutral core and housed in a protective sleeve. Metal film RTD's are devices in which the resistive element is laid down on a ceramic substrate as a zigzag metallic track a few micrometers thick. The resistance is precisely controlled by laser trimming of the metal track. The large reduction in size, with increased resistance, that this construction allows, gives a much lower thermal inertia, resulting in faster response and good sensitivity. These devices generally cost less than the wire wound RTD's.

The most popular RTD is the platinum film PT100 (DIN 43760 Standard), with a nominal resistance of 100 W ± 0.1 W at 00C. Platinum is usually used for RTD's because of its stability over a wide temperature range (-270 0C to 650 0C) and its fairly linear resistance characteristics. Tungsten is sometimes used in very high temperature applications. High resistance (1000 W) nickel RTD's are also available. Provided that the RTD element is not mechanically stressed (this also changes the resistance of a conductor), and is not contaminated by impurities, the devices are stable over a long period, reliable and accurate.

Linearity of RTD's

In comparison to other temperature measuring devices such as thermocouples and thermistors, the change in resistance of an RTD with respect to temperature is relatively linear over a wide temperature range, exhibiting only a very slight curve over the working temperature range. Although a more accurate relationship can be calculated using curve fitting - the Callendar-Van Dusen polynomial equations are often used - it is not usually required. Since the error introduced by approximating the relationship between resistance and temperature as linear is not significant, manufacturers commonly define the temperature coefficient of RTD's, known as alpha (a), by the expression:

$$Alpha\ (\alpha) = \frac{R_{100} \quad R_0}{100xR}\ \Omega/\Omega/^{\circ}C$$

where:

R_0 = Resistance at 0°C

R_{100} = Resistance at 100°C

This represents the change in the resistance of the RTD from 0˚C to 100˚C, divided by the resistance at 0˚C, divided by 100˚C.

From the expression of alpha (α) it is easily derived that the resistance R_T of an RTD, at temperature T can be found from the expression:

$R_T = R_0(1+\alpha T)$

where

R_0 = resistance at 0˚C

For example, the PT100 (DIN 43760 Standard), with nominal resistance of

100 Ω ± 0.1 Ω at 0˚C has an alpha (α) of 0.00385 Ω / Ω / ˚C.
Its resistance at 100˚C will therefore be 138.5 Ω.

Measurement Circuits and Considerations for RTD's

Two-Wire RTD Measurement

Since the RTD is a passive resistive device, it requires an excitation current to produce a measurable voltage across it. Figure 1 shows a two-wire RTD excited by a constant current source, I_{EX} and connected to a measuring device.

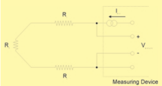

Figure 1 Two- Wire RTD Measurement

Any resistance, R_L, in the lead wires between the measuring device and the RTD will cause a voltage drop on the leads equal to (R_L x I_{EX}) volts. The voltage drop on the wire leads will add to the voltage drop across the RTD, and depending on the value of the lead wire resistance compared to the resistance of the RTD, may result in a significant error in the calculated temperature.

Consider an example where the lead resistance of each wire is 0.5 Ω. For a 100 ω RTD with an alpha (α) of 0.385 Ω/˚C, the lead resistance corresponds to a temperature error of 2.6˚C (1 .0Ω/0.385Ω/˚C).

This indicates that if voltage measurements are made using the same two wires which carry the excitation current, the resistance of the RTD must be large enough, or the lead wire resistances small enough, that voltage drops due to the lead wire resistances are negligible. This is usually true where the leads are no longer than a few (<3) meters for a 100 Ω RTD.

Four-Wire RTD Measurement

A better method of excitation and measurement, especially when the wire lead lengths are greater than a few meters in length, is the four-wire RTD configuration shown in Figure 2.

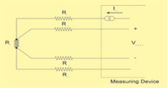

Figure 2 Four-Wire RTD Measurement

RTD's are commonly packaged with four (4) leads, two current leads to provide the excitation current for the device, and two voltage leads for measurement of the voltage developed. This configuration eliminates the voltage drops caused by excitation current through the lead resistances (R_{L1} and R_{L4}). Since negligible current flows in the voltage lead resistances (R_{L2} and R_{L3}) only the voltage drop across the resistance RT of the RTD is measured.

Three-Wire RTD Measurement

A reduction in cost is possible with the elimination of one of the wire leads. In the three-wire configuration shown in Figure 3, only one lead RL1 adds an error to the RTD voltage measured.

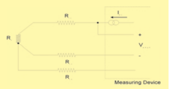

Figure 3 Three-Wire RTD Measurement

Self-Heating

Another consequence of current excitation of the RTD, is the possible effect that internal heating of the device may have on the accuracy of the actual temperature measurements being made. The degree of self heating depends on the medium in which the RTD is being used, and is typically specified as the rise in temperature for each mW of power dissipated for a given medium (i.e. still air).

For a PT100 RTD device, the self-heating coefficient is 0.2°C/mW in still air, although this will vary depending on the construction of the RTD housing and its thermal properties. With an excitation current of 0.75mA the power to be dissipated by the device is 56 μW [$(0.75 \times 10^{-3})^2$ x 100] corresponding to a arise in the temperature of the device due to self-heating of 0.011°C (56 μW x 0.2).

Inaccuracies in the temperature measurement due to self-heating problems, can be greatly reduced by:

- Minimizing the excitation power
- Exciting the RTD's only when a measurement is taken
- Calibrating out steady state errors