



## Sample: Engineering - Sensors and Transducers

### Problem 2

2. The input range of a particular sensor is from 0 to 6 units and its output modelled by the equation:  $O = f(I) = 1 + 2I + 0.05I^2 - 0.00833I^3$ . Ideally the output should be related to the input by the ideal straight line equation (ISL) of the form  $O = kI + a$ .

- (a) Give the law of the Ideal Straight Line for the sensor.
- (b) Plot a graph of the non linearity,  $N(I)$ , against input,  $I$ .
- (c) From the graph, determine the maximum non-linearity of the sensor, expressed as a percentage of output span.
- (d) Attempt to determine the maximum percentage non-linearity mathematically.

### Solution

- (a) There is no requirement to use linear regression so we can assume that straight line equation is  $O = f_l(I) = 1 + 2I$ .
- (b) According to (a), non-linearity is related to the input by the equation  $N(I) = 0.05I^2 - 0.00833I^3$ .

Graph of the non-linearity is shown on figure 1.

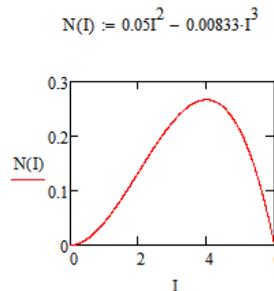


Fig. 1 - Graph of the non-linearity  $N(I) = 0.05I^2 - 0.00833I^3$

- (c) Maximum non linearity is 0.27 units or  $\frac{0.27}{6} \cdot 100\% = 4.5\%$ .
- (d) Mathematically maximum non-linearity is extrema of the function  $N(I)$  (see fig. 1).

So:

$$N(I) = 0.05I^2 - 0.00833I^3 \text{ (function),}$$

$$N'(I) = 0.1I - 0.025I^2 \text{ (differentiate),}$$

$$0 = (0.1 - 0.025I)I \text{ (set } N'(I) = 0),$$

$$I_1 = 0, I_2 = 4,$$

Maximum of the function  $N(I)$  is:

$$N(4) = 0.05 \cdot 4^2 - 0.00833 \cdot 4^3 = 0.267 \text{ units or } \frac{0.267}{6} \cdot 100\% = 4.45\%$$

**Answer** (a)  $O = f_l(I) = 1 + 2I$ ; (b) (c) fig. 2.1;  $N(I) = 0.05I^2 - 0.00833I^3$ ; (d) 4.45 %



Problem 3

(a) A temperature control process has a first-order response with a step response time of 12 seconds. In selecting a temperature sensor for the control system for the process, for what maximum value of sensor time-constant would you be looking?

(b) If your requirement is for a sensor suitable for a heavy industrial application, with a linear characteristic, working in temperatures up to 300°C, what type of sensor would you recommend? Draw the symbol for the sensor and show its interfacing circuit.

Solution

(a) Value of sensor time-constant is important if you need efficient dynamic temperature sensing. Let step response time  $t_r = 5\tau_s$ , where  $\tau_s$  - time-constant of a temperature control process.

Then system temperature changes by equation  $\Theta(t) = (100)e^{-\frac{t}{12/5}} = (100)e^{-\frac{t}{2.4}}$ , where 100(100%) - steady-state value of the temperature in percent.

Output of measurement system is  $\Theta'(t, \tau) = \Theta(t) \left(1 - e^{-\frac{t}{\tau}}\right)$ .

Where  $\tau$  - value of sensor time-constant, which we will vary to answer the question.

In the figure 2(a), are shown graphs of temperature in temperature control process and values, measured with sensors (time constant varies from 0.1 s to 10 s). In the figure 1(a), are shown graphs of error in temperature evaluation (time constants are 0.1s and 0.5s).

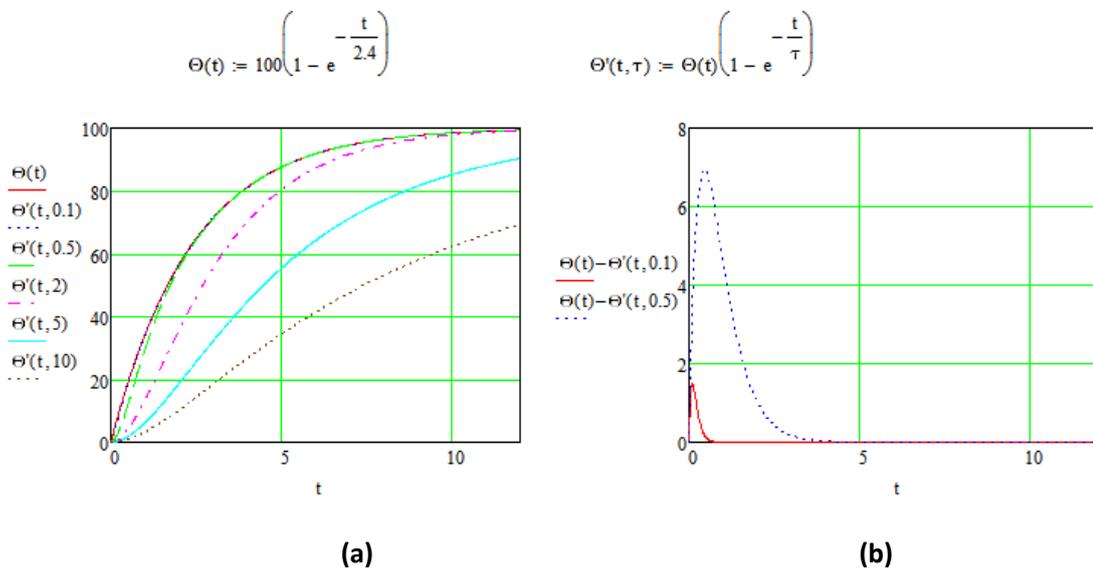


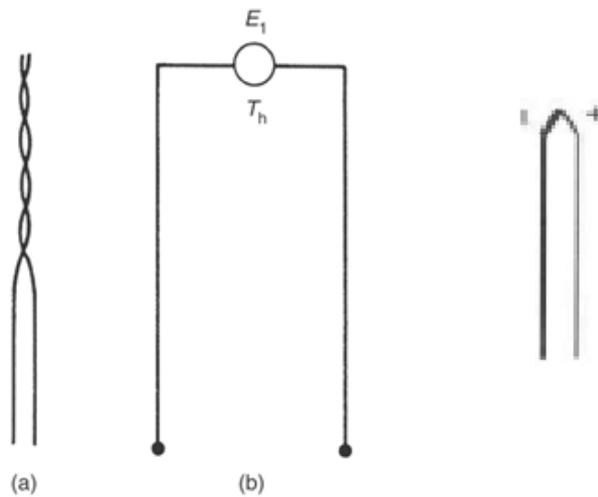
Figure 2

So if it is necessary to have dynamic error less than 2%, we'll find sensor with time constant 0.1s and less.

For example, time constant of thermocouple made with exposed butt welded 0.001 inch dia. wire = .003 sec.

(b) Chromel-constantan thermocouples (type E) give the highest measurement sensitivity of  $68 \text{ mV}/^\circ\text{C}$ , with an inaccuracy of 0.5% and a useful measuring range of  $-200^\circ\text{C}$  up to  $900^\circ\text{C}$ .

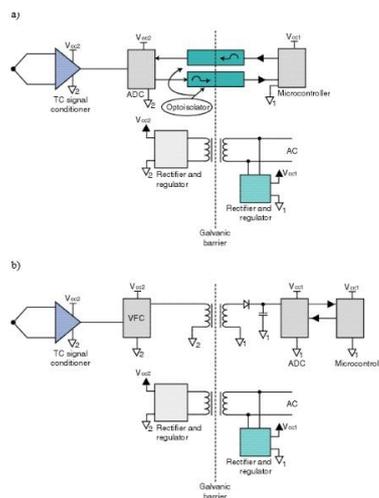
A typical thermocouple, made from one chromel wire and one constantan wire, is shown in Figure 3

**Figure 3**

(a) Thermocouple and (b) equivalent circuit.

Galvanic isolation is an important feature in many industrial applications. Because thermocouples are really just long loops of wire, they will often pick up high levels of common-mode noise. In some applications, the thermocouples may be bonded to equipment that is at line voltage (or higher).

In this case, galvanic isolation is required to keep high-voltage AC out of data acquisition system. This type of isolation is usually accomplished in one of two ways—using either an opto-isolator or a transformer. Both systems require the thermocouple signal conditioner to allow its ground to float with respect to earth ground. Figure 4a and 4b outlines these schemes.

**Figure 4**

Galvanic isolation using opto-isolation (a) and using a VFC and a transformer (b).

**Answer** (a) 0.1 s; (b) Chromel-constantan thermocouples (type E)



## Problem 4

4. In a flow control loop in a process for which you are specifying a flow sensor, it is undesirable to insert any sensing device into the actual flow because of interference with the flow. Due to the corrosive nature and high pressure and temperature of the flow, only stainless steel pipes can be used anywhere in the system. The liquid is non-conductive. Recommend a flow sensor and explain its operating principle.

**Answer**

We may use liquid flow sensor, that is based on Doppler effect.

The waves that can be used for measurement can be ultrasonic. Figure 5 shows the principle of the method, using in this example the simpler system of a receiver transducer downstream of the transmitter. This makes the velocity of the received wave equal to the natural velocity (in a still liquid) plus the liquid velocity. The change in wavelength is proportional to liquid velocity, and the absolute value of liquid velocity can be calculated with relative ease.

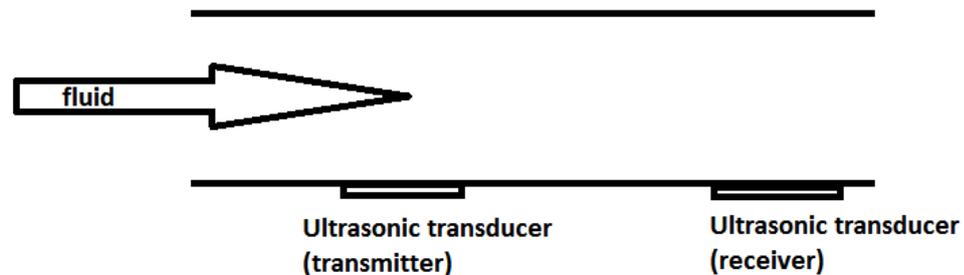


Figure 5

We may also use temperature at the sensors varies depending upon the mass flow.

Thermal mass flow meters generally use combinations of heated elements and temperature sensors to measure the difference between static and flowing heat transfer to a fluid and infer its flow with a knowledge of the fluid's specific heat and density. The fluid temperature is also measured and compensated for. If the density and specific heat characteristics of the fluid are constant, the meter can provide a direct mass flow readout, and does not need any additional pressure temperature compensation over their specified range.



Problem 5

5. You have been asked to recommend a suitable type of linear position control sensor that is to be used in an explosive environment. For this reason, unsafe electrical contacts must be avoided. The sensors will be installed in locations that are hazardous to access except when the plant is shut down annually for maintenance. The span required is 5 cm. The sensor case must not permit any ingress of dust or of water.

State what type of position sensor you would recommend and give your reasons. Sketch both the recommended sensor and circuit, and explain its operation. Comment on how signal conditioning requirements can now be met. Identify the durability required in respect of dust and water ingress.

**Answer** I recommend linear variable differential transformer (LVDT), which is now the most commonly used sensor for distance in the range of millimeters to centimeters. The principle is illustrated by the circuit diagram shown in Figure 6. The device consists basically of three fixed coils, one of which is connected to an AC supply. The other two coils are connected to a phase-sensitive detector, and as a core of ferromagnetic material moves in the coil axis, the output from the detector will be proportional to the distance of the core from one end of the coils. As the name suggests, the output from the phase-sensitive detector will be fairly linearly proportional to distance, and there are considerable advantages as compared to other types of distance sensors, as follows.

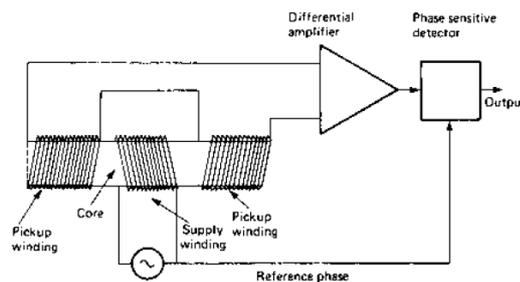


Figure 5

Linear variable differential transformer (LVDT)

For example AC-Operated LVDT Position Sensors for Hazardous Locations ATEX Approved HLR 750 Series are hermetically sealed, constructed entirely of stainless steel for environmental robustness, they feature a through-bore design which makes the LVDTs' cores accessible from both ends for better mechanical support and core guidance and facilitates cleanout in dusty or dirty locations.



## Problem 6

6. A customer has approached your company for advice on updating its automatic weighing facility. (This is similar to the type shown in FIGURE 7 of Lesson ICP - 1 - 6.) The customer's present system has a load cell with foil strain gauges. These are connected to a Wheatstone bridge and then to an instrumentation amplifier. This sensing system is old and has become unreliable.

Explain to the customer what modern developments in strain gauge technology are available. Include an explanation of gauge factor and possible temperature effects.

### Answer

The oldest and most widely used strain gauge alloy is constantan. It has adequately high strain sensitivity or gauge factor, which is relatively to strain level and temperature.

It must be noted, however, that constantan tends to exhibit continuous drift at temperatures above +150°F (+65°C).

Modified Karma, or K alloy, with its wide areas of application, represents an important member in the family of strain gauge alloys. This alloy is characterized by good fatigue life and excellent stability, and is the preferred choice for accurate static strain measurements over long periods of time (months or years) at room temperature, or lesser periods at elevated temperature. It is recommended for extended static strain measurements over the temperature range from 269° C to +260°. For short periods, encapsulated K-alloy strain gauges can be exposed to temperatures as high as +400°C. An inert atmosphere will improve stability and extend the useful gauge life at high temperatures.

An important property shared by modified Karma strain gauge alloys is their responsiveness to special processing for self-temperature-compensation. Self-temperature-compensated strain gauges are designed to produce minimum thermal output (temperature-induced apparent strain) over the temperature range from about -45° to +200° C.

Today, most strain gauges and load cells use a simple DC voltage to excite the resistive bridge elements. This time-proven method is adequate for many applications, but it requires the measurement instrument to process a wide bandwidth of electrical signals, which may include noise.

Taking advantage of the fact that the actual bridge elements are simply resistors, we can obtain higher performance when the elements are excited by an AC signal. This technique works in much the same way as amplitude-modulated (AM) radio and allows the measurement instrument (the receiver) to "tune out" all other frequencies except the one of interest (the frequency of the AC excitation signal). The AC excitation is a known frequency ( $f_c$ ), so when the resulting force-modulated signal is decoded, only a small bandwidth of electrical signals around  $f_c$  must be considered. All other signals in surrounding frequencies are ignored, including noise ([http://www.sensormag.com/sensors/force-strain-load-torque/solving-tough-strain-gauge-problems-990?page\\_id=1](http://www.sensormag.com/sensors/force-strain-load-torque/solving-tough-strain-gauge-problems-990?page_id=1)).

Semiconductor strain gauges have the great advantage over metallic strain gauges of a gauge factor of typically 400. Because of the high resistivity of silicon, semiconductor strain gauges can be made very small. Semiconductor strain gauges are even more prone to temperature variations than metallic gauges. Special doping can make them less temperature sensitive but this reduces the gauge factor to about 100.