MCE380: Measurements and Instrumentation Lab

Chapter 1: Introduction

Topics:
Instrument Static Performance and Calibration
Standards, Units and Dimensional Consistency Checks

Reference: Holman, CH1 and 2.

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Introductory Reading Assignment

Read about the following topics in Doebelin, Chapter 1 (posted on course website and in CSU ECR):
`http://academic.csuohio.edu/richter_h/mce380/`
`http://scholar.csuohio.edu/search/r?SEARCH=mce+380`

- Why study measurement systems?
- Classification of measurement applications

Read the whole of Holman, Chapter 1 plus Chapter 2 up to 2.6.
Visit the NIST (National Institute of Standards and Technology page dealing with accuracy and precision:
`http://physics.nist.gov/Pubs/guidelines/appd.1.html`

Read up to D.1.2.

Some Basic Concepts

- An instrument or measurement system can be viewed as a box having an input and an output.
- The input is the *measurand* and the output is the *measurement* or *readout*. The system translates measurand to readout according to some physical *transduction principle*.
- A physical transformation is involved when going from measurand to readout. For example, a mercury thermometer translates temperature to linear displacement according to thermal expansion laws. A *scale* or *calibration curve* is used to transform displacement into temperature readout. We will call the intermediate variable *sensor output*.
- What are the measurand and sensor output in a conventional tire pressure gauge? What is the transduction principle? -Look at Fig. 2.1 in Holman. Why is the cross section of the tube oval?

Static Sensitivity

- The *static sensitivity* or *sensitivity* refers to the proportionality constant between input (measurement) and sensor output when the instrument or system operates in steady (static or quasi-static) conditions.
- For example, if a clinical thermometer has the 98°F mark one inch below the 100°F mark, it has a sensitivity of 0.5 in/°F.
- If an instrument has the same sensivity for all ranges of the measurand, we say it is *linear*. Real instruments are linear only within a range.
- It is important to realize that the sensitivity applies to static or near-static operation. Suppose a mercury thermometer is switched back and forth between a bath of ice and water at 80° F. If we switch every ten minutes, the readings will have stabilized and the calibration will be correct. If we switch every second, our calibration will be useless.

Accuracy

Accuracy is a measure of the deviation between readout and measurand. To determine the accuracy of an instrument, we need a second instrument with significantly higher accuracy. The more accurate instrument provides the “true” value of the measurand.

The accuracy is specified in either absolute or percentage terms in a commercial instrument. Go to:

`http://www.casio.com/products/Timepiece/Classic/A168W-1/`

and find the accuracy of this watch. Compare it with this one:

`http://www.tagheuer-timing.com/_imgtiming/Specifications/en/CP520.pdf`

(express both as percentage)

Sometimes people use the term “precision” when they mean “accuracy” (like Tag Heuer).

Accuracy can be improved by using *calibration*. It all depends on the *repeatability* of the instrument. That is, it doesn’t matter if we get distorted readings, so long we always get the same readings for the same measurands. We can always calibrate.

Precision

Precision is a measure of the variability of readouts produced by an instrument when measuring the same measurand. Using a very precise scale to weigh the same paper clip over and over will not always give the same readout.

Although the weight of the clip does not change significantly over the measurement period, a number of *random errors* cause the readout to change. For example, vibration transmitted to the base of the scale from people walking around could be responsible for some of the spread.

Repeatability is another word for precision.

Always check definitions when reading a document dealing with measurements.

Precision may be quantified using statistics like the standard deviation, the range, etc. Details later.

Eliminating Non-Random Errors: Calibration

Raw measurements may contain nonlinearity (distortion) and offsets, in addition to randomness. We can deal with offsets and nonlinearity by performing *calibration*.

The degree of accuracy improvement obtainable by calibration depends on the precision (repeatability) of the instrument.

A calibration curve or equation can be used to translate the sensor output into readout, or to correct the readout.

Example: Fotonic® sensor calibration curve. We have this non-contact position sensor in the lab. It determines the distance of the optical probe to a reflective target. The physical principle involved in the design of the sensor implies that there is a nonlinear relationship between distance and voltage (sensor output). In the following example, we obtain a calibration curve to convert voltage to distance readout.

Optical Reflective Sensor Calibration

MTI-2000 Fotonic™ Sensor

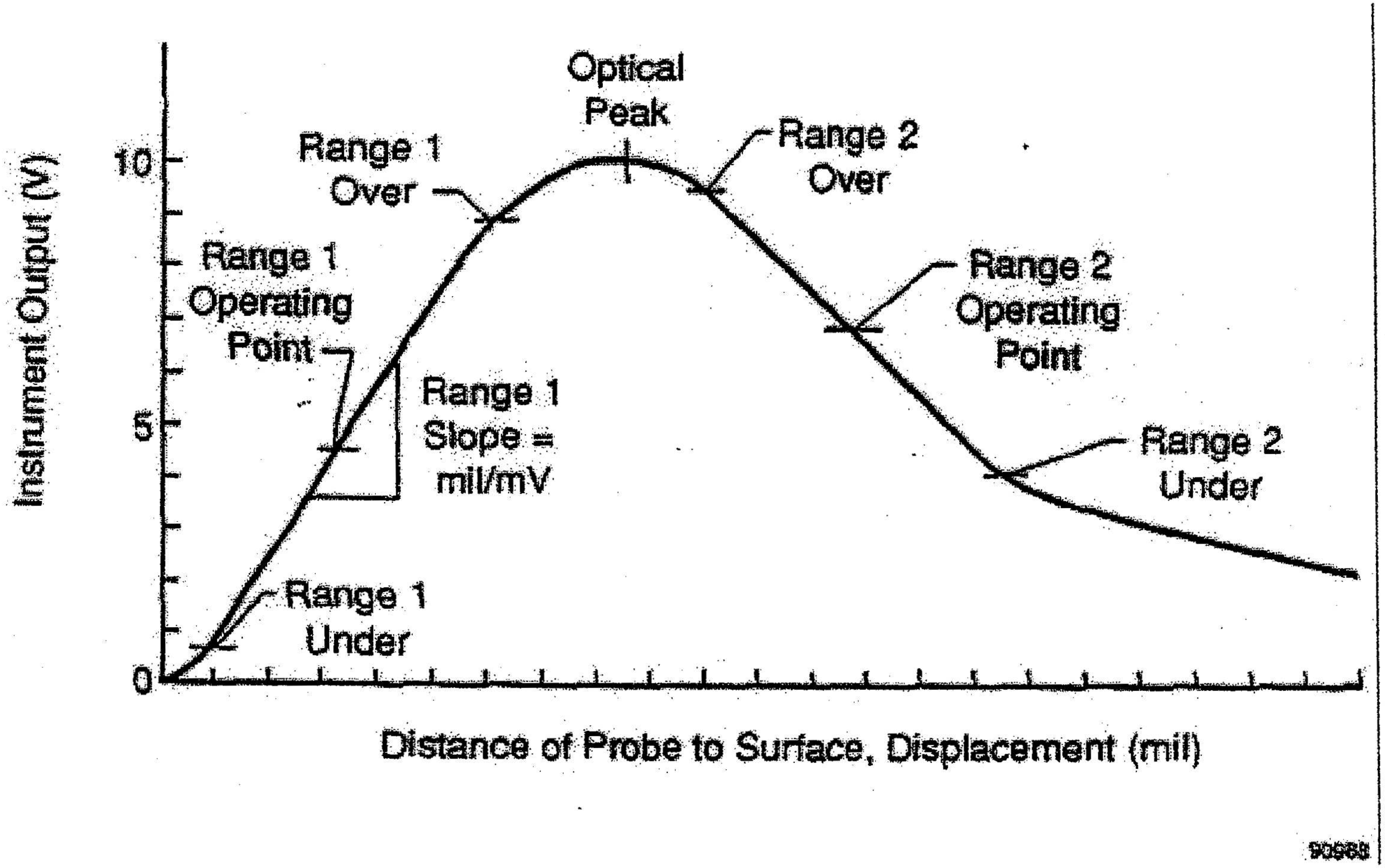

Figure 3.2: Typical Calibration Curve

Data for Homework 1

Obtain the sensitivity and a calibration equation for Range 1 and Range 2 for the Fotonic® sensor. We'll use a special micrometer to determine the "true" probe-target distance. Collected data will be posted in the course website. Observe any obvious systematic and random errors occuring during the calibration.

Which instrument is better?

A thermometer gives the following readings when immersed repeatedly in boiling water:
212.35,211.87,212.23,211.99,211.66,212.42,211.54,211.50,212.29,211.99
(degrees Fahrenheit)

A thermocouple gives the following voltages:
12.01,11.99,12.00,11.98,11.98,11.97,12.02,12.03,12.01,11.99

(millivolts).

Metrology Standards and Units

Read Holman, Additionally, feel free to read about the history and development of measurement standards:
`http://www.bipm.org/en/si/base_units/`
The *Bureau International des Poids et Mesures* (BIPM) is an international organization dating back to 1875 and located near Paris. The task of the BIPM is to ensure world-wide uniformity of measurements and their traceability to the International System of Units (SI). Definitions like

The kelvin is 1/273.16 of the temperature of the triple point of water

are decided upon at the BIPM conventions.

Formula Verification By Dimensional Check

A good way to detect errors in formula derivations is to check the consistency of the various dimensions. For example, let's check if the following formula contains dimensional errors:

$$Q = \frac{A_2}{\sqrt{1 - (\frac{A_2}{A_1})^2}} \sqrt{\frac{2g_c}{\rho}(p_1 - p_2)}$$

where Q is flowrate in m^3/s, A_1 and A_2 are areas in m^2, g_c=1 (dimensionless) and p_1 and p_2 are pressures in Pa.

Then find the value of g_c so that we can use ft^3/s for Q, ft^2 for A_1 and A_2, psi for p_1 and p_2 and lb/ft^3 for ρ.

Exercises

Refer to Table 2.6 in Holman

1. Decompose 1 Farad into fundamental units (kg, m, s, C).
2. Look up the viscosity of the Mobil 1 5W-30 motor oil at 40°C in centiStokes and express it in SI units. Use Mobil Oil's web page.