Measurement System Principles

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1 The System

- Input:- The Sensor
  1. Strain gage; wire (SR-4) or semiconductor
  2. Thermometer; liquid in glass, thermocouple (approximately linear), resistance thermometer; wire or semiconductor (thermistor, nonlinear)
  3. Piezoelectric (force) transducer
- Intermediate:- The signal conditioner
  1. Amplifier
  2. Analog to digital convertor
  3. Thermocouple reference junction or equvalent compensator
  4. Bridge circuit, *e.g.*, strain gage; multi-arm
- Output:- Display or storage
  1. Digital panel display
  2. Analog dial and needle
  3. Computer database
  4. Set of measured variables for a system controller
  5. Oscilloscope face

2 Some Important Topics

- Binary codes, arithmetic (10's and 2's complement), range, resolution, precision and accuracy
- Root Mean Square Voltage depends on periodic waveform.
- It is used with respect to power, either to do work or as a signal to drive an instrument system.
- $P = E^2/R, \quad E \equiv V_{rms}$, (see 04-01-11)
- $$V_{rms} = \frac{1}{(T/2)} \int_0^{T/2} [v(t)]^2 dt$$

  Note that for a sinusoidal wave we use the interval to $T/4$ because of symmetry.

- Question (today's 1% prize):- What's the V_{rms} of a DC signal?

- Answer:- It depends. If it's raw power we are intyerested in, it's just the DC voltage. If it's an AC "ripple" *on* the DC that carries the signal information we want then it's the V_{rms} of the AC-DC=signal, *i.e.* DC RMS voltage is zero!

- If we are interested in output as a function of input, that is a direct problem.

- If we want to know input as a function of output, we call it an inverse problem.

- If we want an instrument to exhibit a certain range of output according to a specified range of input this is a design problem and we must determine the so-called design (variables) parameters.

3 System Stage and Unifying Physical Principle

Unifying physical principles (UFP) are the phenomenæ that govern sensing (sensor) and signal modification (conditioning). These are implicit in the equations I've been feeding to you and sometimes explaining only partially. Let's use the example of a simple one-strain gage tensile/compression element force transducer.

- **Stage 1 Input**:- Equilibrium input forces, $+T$ and $-T$ applied to either end of a steel bar with a strain gage on it

- **UFP**:- Hooke's Law, $\epsilon \propto \sigma$, strain is proportional to stress, $\epsilon = \sigma/E$ where E is Young's modulus

- **Stage 2 Input**:- …is Stage 1 output.

- **UFP**:- $R = R(\epsilon)$, change in gage resistance is due to change in length due to strain. This is a reasonably linear relationship $\Delta R = k\epsilon$ where k is some constant

- **Stage 3 Input**:- …is Stage 2 output.

- **UFP**:- Wheatstone bridge circuit, Ohm's Law, Kichhoff's node and branch laws to compute out-of-balance voltage of bridge.

- **Stage 4 Input**:- …is Stage 3 output.

- **UFP**:- Thévenin's theorem. The ideal situation we strive to attain is 0 output impedance and ∞ input impedance to achieve 0 signal current thereby minimizing the the disturbance (attenuation) of the desired signal. Think about trying to measure the temperature of a very small glass of hot water with a very big thermometer. The cold thermometer would tend to depress the equilibrium temperature thereby giving a low reading. Avoiding all this is what "signal conditioning" is about. Zero output impedance=*big* glass. Infinite input impedance=*tiny* thermometer.

4 Our Favourite Example

The mutiarm strain gage bridge was used over and over again to illustrate, via specific numerical examples, the way that UFP affects instrument input/output relations and how this leads to a choice of design parameters to let us design and make an instrument to suit some application, *e.g.*, force/torque range and displacement (linear or angular) requirement -*vs*- optimal output to signal conditioner (intermediate) stage.

5 Statistics

For those in MECH 262 there will be some questions on some of the following topics.

- Building a decision tree to enumerate "experiment" outcome probability with discrete (finitely countable) outcomes when repeated a large number of times (infinite?); the Law of Large Numbers. Throwing dice, spinning roulette wheels, *etc.*
- Modeling probability using assumed binomial and Poisson's distribution behaviour; rotten eggs, bad light bulbs, *etc.*
- Normal (Gaussian) probability distribution, its characterization by mean (maximum) probability and standard deviation; its spread-outness. No modeling examples or questions for now.
- Simple (single) regression; straight line "curve" fitting to scattered data in a least squares sense; no double or normal squared distance regression problems on mid-term. Maybe on final exam however.

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