Variables and Calibration

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Measurement Systems (Review)

- **Sensor**: Receives energy from the measured medium and produces an output that is a function of the measured quantity
- **Transducer**: Converts measured variable to a different energy form (usually electrical)
- **Variable Manipulation**: Conditions measured variable (amplification, filtering, etc.)
- **Data Transmission**: Makes measured variable available at another location
- **Data Presentation**: Records and/or displays measured variable
Example: Angular Position Measurement System

Sensor/Transducer → Potentiometer → Amplifier → Filter → A/D Converter → Output

Sarcos Dextrous Arm
Experimental Test Plan

- When you want to measure something, what is the plan?

- Test plan based on 3 steps:
  - Parameter design plan
  - System and tolerance design plan
  - Data reduction design plan

- Hint: good way to layout your project…
Measurement Variables

- **Independent variables:**
  - Can be changed independently of other variables

- **Dependent variables:**
  - Affected by changes in other variables

- **Controlled variables:**
  - Can be specified (controlled) during a measurement
  - Controlling variables allows us to find the relationship between the independent and dependent variables

- **Extraneous variables:**
  - Cannot be controlled during measurements
  - Affect measurement results

  - Angular position, temperature, excitation voltage
  - Potentiometer output voltage
  - Angular position, excitation voltage
  - Temperature, noise
Extraneous Variables

- Variations in extraneous variables result in:
  - Noise
    - Random (stochastic) variation in measured value
    - Requires statistical description
    - Examples:
      - Interstellar background noise
      - Random differences in strength of steel
  - Interference
    - Undesired non-random (deterministic) variation in measured value
    - Examples:
      - 60 Hz AC power line interference
      - 120 Hz fluorescent lighting interference
      - Accelerometer and gyroscope drift due to temperature fluctuations
Extraneous Variables

Signal: $y(t) = 2 + \sin (2\pi t)$

Signal + interference

Signal + noise
Random Tests

- Randomization
  - Measure in a random order
- Repetition
  - Estimate improves with number of measurements
- Replication
  - Duplicate set of measurements using similar conditions
- Concomitant Methods
  - Multiple ways to measure same phenomena
- More about this in Chapters 3 & 4
Calibration

- Correlate system output with a known input ("standard")
- **Objective:** Determine a functional relationship between input and output that will enable interpretation of output signals during a measurement
- Linear input-output relationship most desirable
- If nonlinear, choose between:
  - Linear curve fit over full range
  - Linear curve fits over subranges
  - Nonlinear curve fit over full range
Calibration

◆ Definitions:
  - Operating Range:
    • $r_i = x_{\text{max}} - x_{\text{min}}$
    • $r_o = y_{\text{max}} - y_{\text{min}} = \text{FSO ("full-scale-operating range")}$
  - Sensitivity:
    • Ratio of change in output to change in input
    • Slope of calibration curve
    • Can change with input if calibration is not linear
    • Also called “static sensitivity” or “static gain”
Calibration: Angular Position Measurement System

- **Objective:** Determine the relationship between joint angle and output voltage
- **Procedure:**
  - Move arm to a desired angle
  - Measure resulting voltage
  - Repeat & plot
- **Use functional relationship in subsequent measurements**
- **Beware of extrapolation**
Calibration: Static vs. Dynamic

- **Static Calibration:**
  - Variables remain constant during measurement
  - Done to determine steady-state relationship between input and output

- **Dynamic Calibration:**
  - Variables change during measurement (often sinusoid)
  - Done to determine frequency range of sensor
  - Characterizes dynamic capabilities of sensor
Accuracy vs. Precision

- Absolute error:
  \[ \varepsilon = x_{\text{true}} - x_{\text{measured}} \]

- Accuracy:
  - Measure of absolute error
  - Tells how well the true value is measured
  - Can be based on “true” value or an estimate of the true value:
  \[ A = \frac{|\varepsilon|}{x_{true}} \cdot 100\% \]

- Precision:
  - Measure of repeatability
  - Measure of variation among measurements

- A system can be very precise while not being very accurate due to systematic error
  - Random error causes random variation
  - Systematic error causes a bias, offset between the mean value and the true value
Accuracy vs. Precision

(a) High repeatability gives low random error but no direct indication of accuracy

(b) High accuracy means low random and systematic errors

(b) Systematic and random errors lead to poor accuracy
Accuracy vs. Precision

![Graph showing accuracy vs. precision](image)

- **Measured value [units]**
- **Measured reading number**

- **Apparent measured average**
- **Scatter due to random error**
- **Test systematic error**
- **True or known value**

**Measured data**
Instrument Errors

See Figliola, pp. 20-23 for definitions
# Trans-Tek 210-220 LVDT

## Transducer Specifications

<table>
<thead>
<tr>
<th>Model</th>
<th>Full Stroke</th>
<th>Max. Usable Stroke</th>
<th>Body Length</th>
<th>Core P/N</th>
<th>Core Length</th>
<th>Core Mass</th>
<th>Input Impedance</th>
<th>DC Input Resistance</th>
<th>Output Impedance</th>
<th>Phase Angle</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.65 (16.5)</td>
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<td>1.00 (25.4)</td>
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<td>205</td>
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<td>266</td>
<td>13</td>
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<td>0.95 (24.1)</td>
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<td>1.45 (36.8)</td>
<td>4.50 (114.3)</td>
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<td>7.50 (190.5)</td>
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<td>10.00 (254.0)</td>
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<tr>
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<td>8.45 (214.6)</td>
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</tbody>
</table>

**Specifications at reference frequency**

| Non-linearity | < ±0.25% FS (Best Fit Straight Line) |
| Sensitivity   | 0.50 V/V ±10% at FULL SCALE |
| Input Voltage | 28 V RMS, Max |
| Null Voltage  | < 1.0% Excitation Voltage |
| Temperature Coefficients | < ±0.001% FS/F Zero, < ±0.01% Reading/F Span |
| Outer Housing and Bore Liner | 300 Series Stainless Steel |
| Core          | Chrome Plated Iron/Nickel Alloy |
### Sensotec Model 415 Pressure Transducer

#### Performance

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (note 4)</td>
<td>+/-0.1% Full Scale</td>
</tr>
<tr>
<td>Non-Linearity and Hysteresis</td>
<td>+/-0.10% Best Fit Straight Line</td>
</tr>
<tr>
<td>Non-Repeatability</td>
<td>0.10% Best Fit Straight Line</td>
</tr>
<tr>
<td>Output</td>
<td>4-20 mA</td>
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<tr>
<td>Resolution</td>
<td>Infinite</td>
</tr>
</tbody>
</table>

#### Environmental

- Temperature, Operating: 
  -20° to 185°F
- Temperature, Compensated: 
  60° to 160°F
- Temperature, Effect: 
  Zero: 0.005% Full scale/°F
  Span: 0.007% Reading/°F

#### Electrical

- Excitation (acceptable): 9 to 32 VDC
- Insulation Resistance: 5,000 Megohm @ 50 VDC
- Electrical Termination (std): PTIH-10-6P or equiv. (Hermetic Stainless)
- Mating Connector (not incl.): PT06A-10-6S or equiv.
- Frequency Response: 300 Hz

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4. Accuracies stated are expected for Best Fit Straight Line for all errors including linearity, hysteresis & non-repeatability thru zero.
Standards

- What do you use to calibrate a device?
  - A standard
- Levels of standards:
  - Primary (international level)
  - Transfer (within a country)
  - Working (at a specific location, factory or lab)
  - Local (used to do actual measurements)
- Measurement devices given a certificate when calibrated.
- More on this in section 1.5