Mechanical Measurements

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Fundamental Measuring Process

- Measurand (Input)
- Process of comparison (Measurement)
- Result (Readout)
- Standard
Generalized Measuring System

**Signal conditioner**

Modifies transduced signal into form usable by final stage. Usually increases amplitude and/or power, depending on requirement. May also selectively filter unwanted components and convert signal into pulsed form.

**Senses desired input to exclusion of all others and provides analogous output**

**Provide an indication or recording in form that can be evaluated by an unaided human sense or by a computer or controller**

**Sensor-transducer**

Calibration input

Mearurand

**Transduced signal (analogous to input)**

**Analogous driving signal**

**Indicator**

**Recorder**

**Processor**

**Controller**
Types of Input Quantities – Time Relationship

Static

Dynamic
- Steady-state periodic
- Nonrepetitive or transient
  - Single pulse or aperiodic
  - Continuous or random
Error Classification

- Bias errors or systematic errors
- Precision or random errors
- Illegitimate errors
Bias errors or systematic errors

- Errors occurring despite stable experimental conditions
- Calibration errors
- Certain types of consistently recurring human error
- Errors of technique
- Loading errors
- Limitation of system resolution
- E.g.: triaxial compression test
Loading error

It results from the influence exerted by the act of measurement on the physical system being tested. It is basic that the measuring process inevitably alters the characteristics of both the source of the measured quantity and the measuring system itself, from which it must follow that there will always be some difference between the measured indication and the corresponding to-be-measured quantity.
Precision or random errors

- Errors stemming from varying environmental conditions
- Certain types of human errors
- Errors resulting from variations in definition
- Errors derived from insufficient sensitivity of the measuring system
Illegitimate errors

- Blunders or mistakes
- Computational errors
- Chaotic errors
  - Extreme vibration
  - Mechanical shock of the equipment
  - Pickup of extraneous noise
Measuring System Response

Response is a measure of a system’s fidelity to purpose.

It may be defined as an evaluation of the system’s ability to faithfully sense, transmit, and present all the pertinent information included in the measurand and to exclude all else.
Response Characteristics of the System

- Amplitude response
- Frequency response
- Phase response
- Slew rate
Amplitude Response

- Amplitude response is governed by the system’s ability to treat all input amplitude uniformly.

- No system exists that is capable of responding faithfully over an unlimited range of amplitudes – all system can be overdriven.
Gain vs. input voltage for an amplifier section of a commercially available strain measuring system (for frequency = 1 kHz)
Usable range restricted to the horizontal portion
Frequency Response

Good frequency response is obtained when a system treats all frequency components with equal faithfulness.

Changing the frequency of the input signal should not alter the system’s output magnitude so long as the input amplitude remains unchanged (100 Hz, 500 Hz, etc.)
There must be some limit to the range over which good frequency response may be expected.

This is true for any dynamic system, regardless of its quality.
Frequencies above 10 kHz are attenuated and an input below this limit only is amplified in the correct relative proportion.

Frequency response curve for an amplifier section of a commercially available strain measuring system ($e_i = 10$ mV)
Phase Response

- Phase response is of importance primarily for the complex wave only.
- Time is required for the transmission of a signal through any measuring system.
- Often when a simple sine-wave voltage is amplified by a single stage of amplification, the output trails the input by approximately 180° or one-half cycle.
- For two stages, the shift may be 360°.
Phase lag vs. frequency for the same amplifier
For single-sine-wave input, any shift would normally be unimportant.

The shape being shown was actually formed a few microseconds or a few milliseconds after being generated is of no consequence.
For the complex wave made up of numerous harmonic components:

- Each component is delayed by a different amount.
- The harmonic components would then emerge from the system in phase relations different from when they entered.
- The whole waveform and its amplitudes would be changed, a result of poor phase response.
Delay, Rise Time, and Slew Rate

- Actually another form of frequency response
- The time delay, $\Delta t$, after the step is applied but before proper output magnitude is reached is known as delay, or rise time.
- It is a magnitude of the system’s ability to handle transients
Response of a typical system to a pulse-type input; $\Delta t$ is the rise time
**Slew rate** is the *maximum* rate of change that the system can handle.

In electrical terms, it is *de/dt*, or volts per unit of time.
Sensors

\[ I_{out} = f(I_{in}) \]

Transfer efficiency = \[ \frac{I_{out}}{I_{in}} \]

Sensitivity = \[ \eta = \frac{dI_{out}}{dI_{in}} \]
Loading of the Signal Source

- Energy will always be taken from the signal source by the measuring system.
- The information source will always be changed by the act of measurement.
- This effect is referred to as *loading*.
- The smaller the load placed on the signal source by the measuring system, the better.
While the first-stage detector-transducer loads the input source, the second stage loads the first stage, and finally the third stage loads the second stage.

A measure of the quality of the first stage is its ability to provide a usable output without draining an undue amount of energy from the signal.
1. Pressure causes the section of the flattened tube to tend toward a more circular form.
2. This causes the free end A to move outward.
3. The resulting motion is transmitted by link B to sector gear C.
4. Then to pinion D and cause the indicator hand to move over the scale.

Essentials of a Bourdon-tube pressure gage
Bourdon-Tube Pressure Gage

The tube serves as the primary detector-transducer, changing pressure into near linear displacement.

The linkage-gear arrangement acts as a secondary transducer and as an amplifier, yielding a magnitude output.
Schematic representation of a strain-gage load cell. The block forms the primary detector-transducer and the gages are secondary transducers.
Classification of First-Stage Devices

- Class I. First-stage element used as detector only
- Class II. First-stage elements used as a detector and signal transducer
- Class III. First-stage elements used as detector with two transducer stages
Mechanical

B. Elastic member
   Load cells
      Tension/compression Force to linear displacement
      Bending Force to linear displacement
      Torsion Torque to angular displacement
      Proving ring Force to linear displacement
      Diaphragm Pressure to displacement
      Liquid Column Pressure to displacement

D. Thermal
   Thermocouple Temperature to electric current
Electrical

A. Resistive
   Contacting  Displacement to resistance change
   Variable-length conductor  Displacement to resistance change
   Variable-area conductor  Displacement to resistance change
   Variable dimensions of conductor  Strain to resistance change

D. Piezoelectric  Displacement to voltage and/or voltage to displacement

E. Photoelectric
   Photovoltaic  Light intensity to voltage
   Photoresistive  Light intensity to resistance change
   Photoemissive  Light intensity to current
Relative Advantages of Electrical Elements

- Amplification or attenuation can be easily obtained
- Mass-inertia effects are minimized
- The effects of friction are minimized
- An output power of almost any magnitude can be provided
- Remote indication of recording is feasible
- The transducers are commonly susceptible to miniaturization