Basic Principles of Measurements

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ME 361: Instrumentation and Measuremen
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One thing you learn in science is that
there is no perfect answer, no perfect measure.

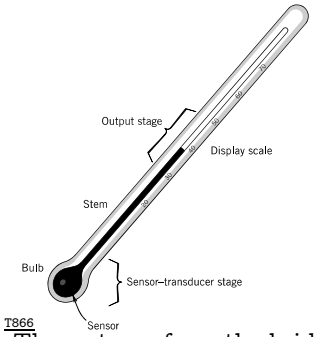
A. O. Beckman

Measurement

- A measuring instrument transforms a measurand, i.e., a physical variable to be measured, to provide comprehensible output.
- Measuring instruments are designed to generate a fixed and reproducible magnitude of the measurand which is expressed by a number followed by the matching unit, e.g., a length of 2.5 m.
- Measurement provides quantitative information on the actual state of the measurand that otherwise could only be estimated.
- Scope of applications of measurements:
  - To maintain quality control and quality assurance in production;
  - To comply with and enforcing laws and regulations;
  - To conduct basic/applied research and development, in science and engineering;
  - To develop, maintain and compare international and national physical reference standards, reference materials, and also to achieve traceability to national standards.

- *ISO/IEC Guide 99:2007 International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)*, defines measurement as:
  process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity.
- Measurement is an experimental science and most experiments are classified into following four categories:
  1. *Variational experiments*: carried out with an objective to establish the mathematical relations between the experiment's variables.
  2. *Validation experiments*: carried out to validate a specific hypothesis.
  3. *Pedagogical experiments*: aimed to demonstrate something that is already known.
  4. *Exploration experiments*: conducted to explore an idea or possible theory.

General Measurement System



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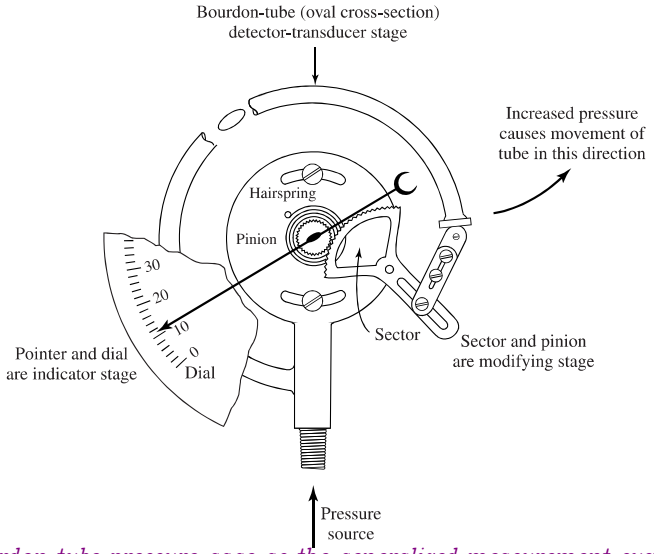
1. Detector-transducer or sensor stage
2. Intermediate or signal conditioning stage
3. Terminating or readout stage
4. Feedback control stage (optional)

These stages form the bridge between the input to the measurement system and the system output, a quantity that is used to infer the value of the physical variable measured. The relationship between the input information and the system output is established by a calibration.



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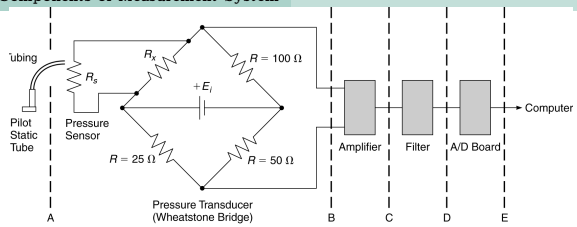
Bourdon-tube pressure gage as the generalized measurement system.



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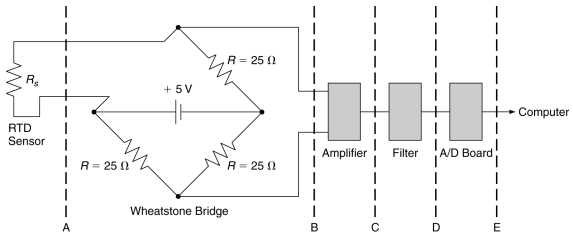
Pressure measurement system



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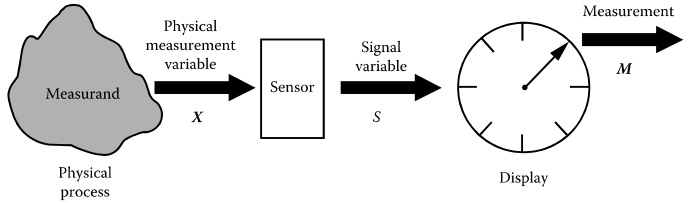
Temperature measurement system



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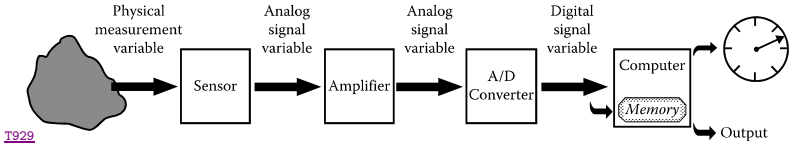
Simple instrument model



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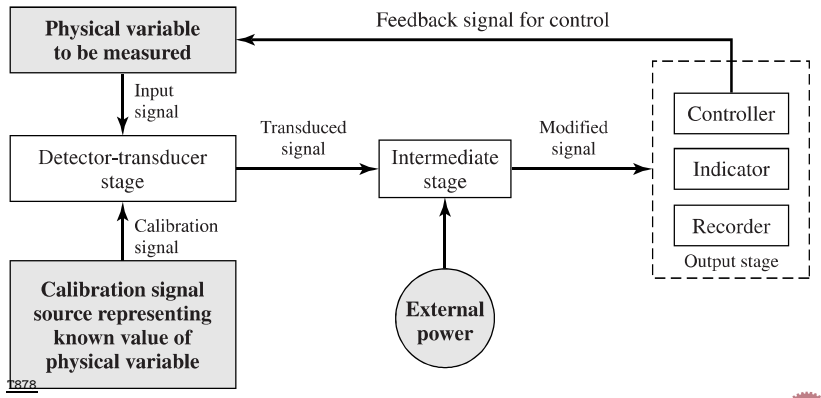
Instrument model with amplifier, ADC, and computer output

Components of a General Measurement System



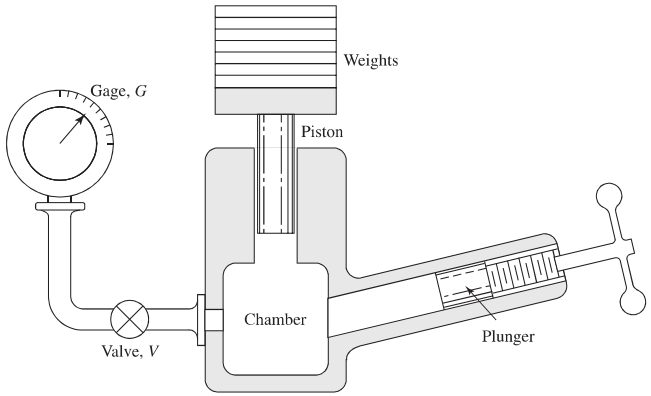
1. Sensor-Transducer stage: *Sensor* is directly affected by the measurand, while *transducer* transducers the sensed information to provide an output quantity having a specified relation to the input quantity. Examples of sensors-transducer include thermocouple, strain gauge, manometer, load-cell, etc.
2. Intermediate or signal processing stage: transduced signal is modified by one or more basic operations, such as amplification, filtering, differentiation, integrating or averaging, etc.
3. Terminating or readout stage: acts to indicate, record or control the variable being measured. Output may be *analogue* or *digital*.
4. Feedback control stage: In those measurement systems involved in process control, feedback control stage contains a controller that interprets the measured signal and makes a decision regarding the control of the process.

Sensor-Transducer Stage

- Sensor: is a physical element that employs some natural phenomenon to sense the physical variable to be measured; e.g. accelerometer, barometer, gyroscope.
- Transducer: converts the sensed information into a detectable signal; e.g. thermistor, thermocouple etc.
- Three basic phenomenon in effect in any sensor operation:
  1. Change (or the absolute value) in the measurand causes an equivalent change in the sensor property, e.g., displacement, voltage, resistance, capacitance, inductance, magnetic flux, etc.
  2. Change in the sensor property is converted into a more usable form, e.g., temperature change results in the change in generated voltage by a thermocouple.
  3. Exposure of sensor to the effects of measurement environment may lead to some exchange of energy to cause loading effect; e.g., a thermometer when inserted into a cup of tea takes some heat from it to cause a difference between true and indicated values.

Calibration

- Calibration affords the opportunity to check the instrument against a known standard and subsequently to reduce errors in accuracy.
- Calibration procedures involve a comparison of the particular instrument with either:
  1. a primary standard,
  2. a secondary standard with a higher accuracy that the instrument to be calibrated, or
  3. a known input source.
- Example: Calibration of a flow-meter
  - Comparison with a standard flow-measurement facility.
  - Comparison with a flow-meter of known accuracy, which is higher than the instrument to be calibrated.
  - Using indirect measurements e.g. weighing certain amount of water in a tank and recording the time elapsed for this quantity to flow.



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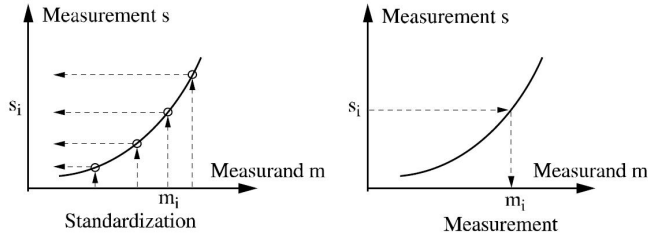
Pressure gauge calibration using dead-weight tester



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- When a measurement system is calibrated, its indicated value is compared directly with a reference value. This reference value forms the basis of the comparison and is known as the standard.
- Measurement traceability refers to the unbroken chain of calibrations linking an instrument or standard to primary standards.
- Accreditation means that a calibration laboratory in a specific field has been independently assessed and audited to show that it is competent to carry out specific tests and calibrations in that field.

Hierarchy of Standards

Primary standard	Maintained as absolute unit standard
Transfer standard	Used to calibrate local standards
Local standard	Used to calibrate working standards
Working standard	Used to calibrate local instruments

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Example of a Temperature Standard Traceability

Standard		
Level	Method	Uncertainty [°C][a]
Primary	Fixed thermodynamic points	0
Transfer	Platinum resistance thermometer	±0.005
Working	Platinum resistance thermometer	±0.05
Local	Thermocouple	±0.5

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Base SI units

There are seven base units of the SI, in terms of which all physical quantities can be expressed.

SI		
Quantity	SI unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin or degree Celsius	K or °C
Luminous intensity	candela	cd
Amount of substance	mole	mol

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All measurements can be expressed using combinations of the seven base units (and angle if needed). These combinations are called derived units.

Derived units - examples

Quantity	Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Speed	metre per second	$m\ s^{-1}$ or m/s
Acceleration	metre per second per second	$m\ s^{-2}$ or m/s^2
Force	newton	N
Energy	joule	J
Power	watt	W

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