Theory and Design for Measurements

Reference Texts

- Theory and Design for Mechanical Measurements, Richard S. Figliola, Wiley

Measurement methods

- Introduction
  - Relationship between real value and the value actually measured?
- General Measurement System
- Experimental Test Plan
- Calibration
- Standards
- Presenting Data

General Measurement System

- Sensor-transducer stage
  - Convert the sensed information into a detectable signal
- Signal conditioning stage
  - Modifies to a desired magnitude
- Output stage
  - Indicates or records the value measure
- Feedback control stage
  - Interprets the measured signal and make a decision regarding the control process

General Measurement System

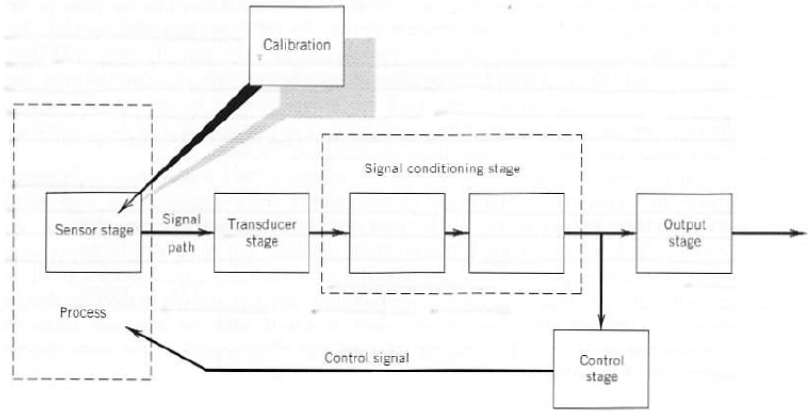
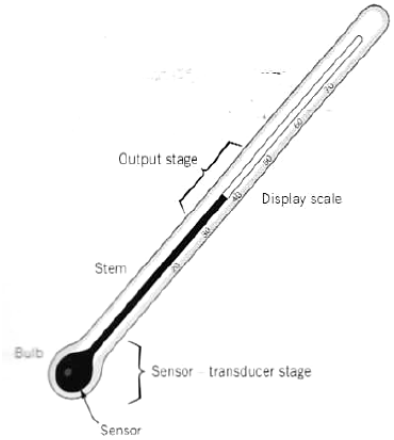


Figure 1.1 Components of a general measurement system.

Measurement System



Experimental Test Plan

- Parameter Design Plan
  - Test objective and identification of process variables and parameters
- System and Tolerance Design Plan
  - Selected of measurement technique, equipment and test procedure
- Data Reduction Design Plan
  - Analyze, present and use the anticipated datas

Experimental Test Plan

- Variable
  - Independent variable: A variable that can be changed independently of other variables
  - Dependent variable: A variable that is affected by changes in one or more other variables
  - Extraneous variable: Variables that cannot be controlled during measurement, but that affect the value of the variable measured
- Parameters
  - Control parameter: A parameter that has an affect on the behavior of the measured varible
- Noise is random variation of the value of the measured signal as a consequence of the variation of extraneous variable
- Interference imposes undesirable deterministic trends on the measured value

Variables

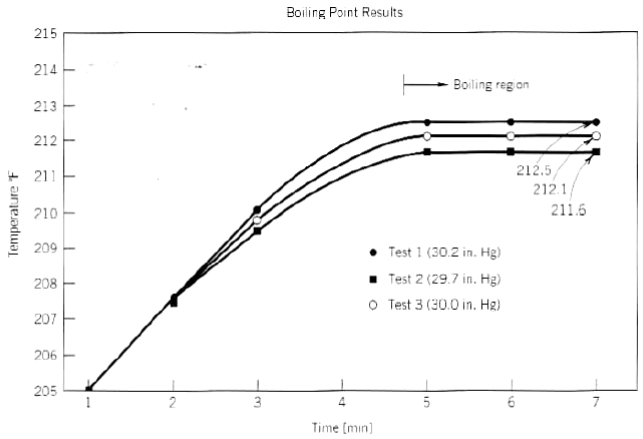


Figure 1.3 Results of a boiling point test for water.

Noise and Interference

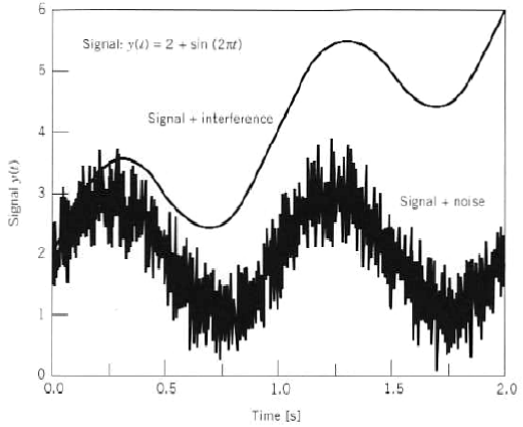


Figure 1.4 Effects of noise and interference superimposed on the signal $y(t) = 2 + \sin 2\pi t$.

Experimental Test Plan

- Random Tests
- Replication and Repetition
- Concomitant Methods

Pressure Calibration System

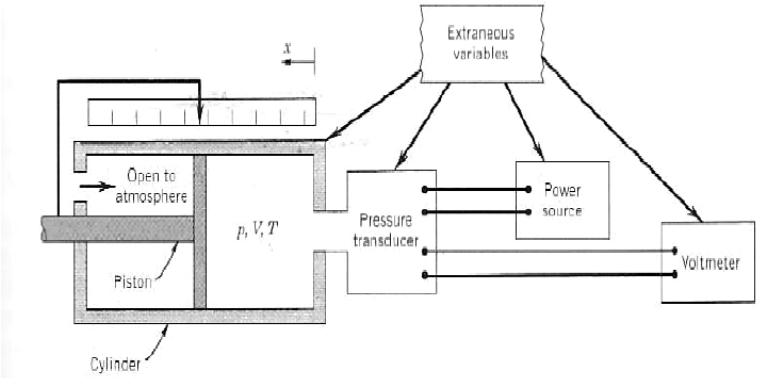


Figure 1.5 Pressure calibration system.

Calibration

- Static Calibration
- Dynamic Calibration
- Static Sensitivity
- Range
- Resolution
- Accuracy and Error

Static Calibration

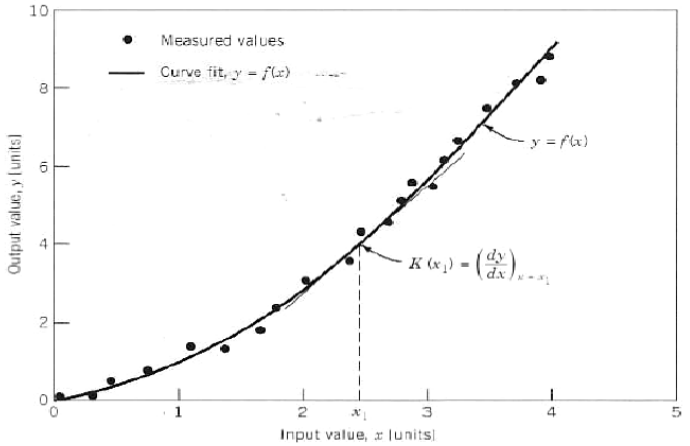


Figure 1.6 Representative static calibration curve.

Accuracy and Error

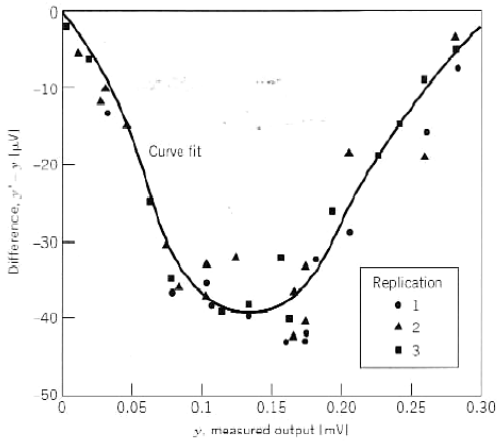


Figure 1.7 Calibration curve in the form of a deviation plot for a temperature sensor.

Precision, Accuracy and Discrepancy

- ค่าความแม่นยำ (Precision)

  คือ ความแม่นยำในการวัดหลายๆ ครั้ง กล่าวคือ มี discrepancy มากหรือน้อย ซึ่งขึ้นอยู่กับ ความละเอียดของเครื่องมือ และ ความชำนาญของผู้ใช้

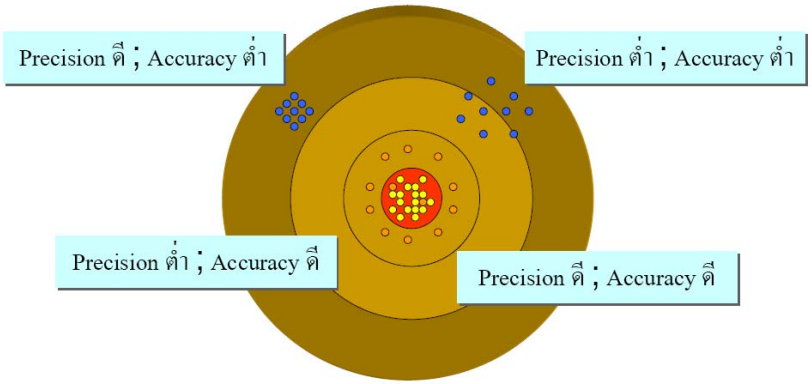
- ค่าความถูกต้อง (Accuracy)

  คือ ความถูกต้องของค่าการวัดที่ได้ว่า ใกล้เคียง กับค่าจริงเพียงใด accuracy

- ค่าความแตกต่าง (Discrepancy)

  คือ ค่าแตกต่างของการวัด 2 ครั้งในปริมาณเดียวกันเมื่อมีการขจัด systematic errors ออกไปแล้ว

Precision and Accuracy



Calibration

- Random and systematic errors and Uncertainty
- Sequential test
- Random Test

Random and systematic errors

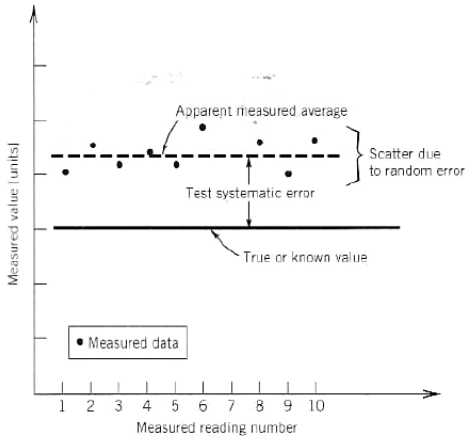


Figure 1.9 Effects of random and systematic errors on calibration readings.

Sensor Data

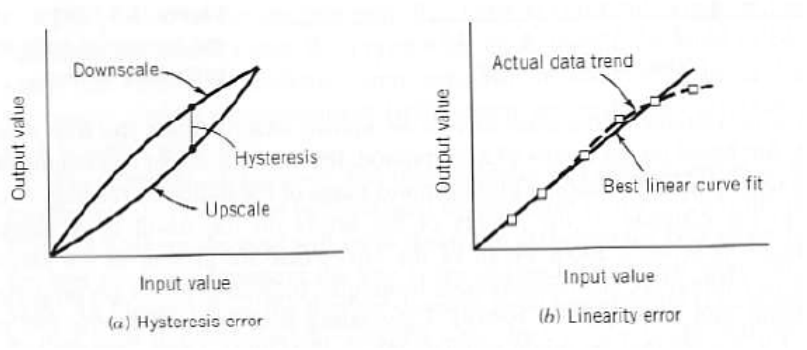
Table 1.1 Manufacturer's Specifications: Typical Pressure Transducer

Operation	
Input range	0–1000 cm H_2O
Excitation	±15 V dc
Output range	0–5 V
Performance	
Linearity error	±0.5% FSO
Hysteresis error	Less than ±0.15% FSO
Sensitivity error	±0.25% of reading
Thermal sensitivity error	±0.02% /°C of reading
Thermal zero drift	±0.02% /°C FSO
Temperature range	0–50 °C

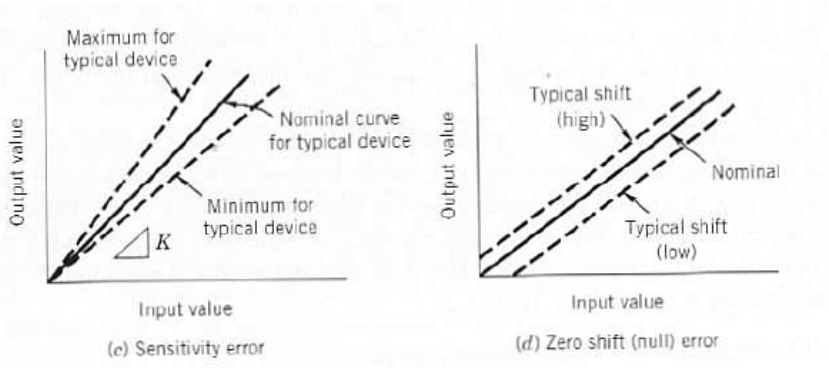
Calibration: Error

- Hysteresis Error
- Linearity Error
- Sensitivity Error
- Zero shift Error
- Repeatability Error
- Overall Instrument Error

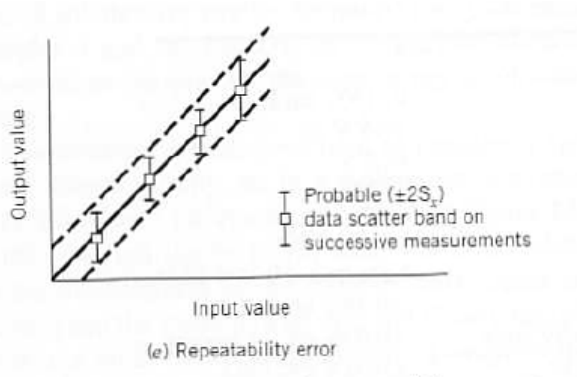
Hysteresis and Linearity Errors



Sensitivity and Null Errors



Repeatability Error



Sources of Error in Measurements

- Natural errors
- Instrument errors
- Personal errors

Types of Errors

- Systematic errors
  - สาเหตุเกิดจากองค์ประกอบของระบบการวัด ไม่ว่าจะเป็น สภาวะแวดล้อม เครื่องมือ และ ผู้ทำการรังวัด
  - มีขนาดเปลี่ยนไปตามสภาพของสภาวะดังกล่าว
  - มีลักษณะเป็นแบบสะสม (cumulative errors)
  - สามารถหาปริมาณและคำนวณตรวจแก้ได้
- Random errors
  - เป็นความคลาดเคลื่อนที่อยู่นอกเหนือการควบคุมของมนุษย์ (accidental errors)
  - มีขนาดและทิศทางไม่แน่นอน ไม่สามารถตรวจแก้ได้โดยตรง
  - การคำนวณปรับแก้อาศัยหลักการทางสถิติและทฤษฎีความน่าจะเป็น เช่น การหาค่าเฉลี่ย การคำนวณแบบ least square เป็นต้น

Table 1.6 Voltmeter Calibration Data

Increasing Input [mV]		Decreasing Input [mV]	
X	*Y*	*X*	*Y*
0.0	0.1	5.0	5.0
1.0	1.1	4.0	4.2
2.0	2.1	3.0	3.2
3.0	3.0	2.0	2.2
4.0	4.1	1.0	1.2
5.0	5.0	0.0	0.2

Standards

Its indicated value is compared directly with a reference value

- Dimension
  - define a physical variable that is used to describe some aspect physical system
- Unit
  - define a quantitative measure of dimension

Standards

- Primary Standard
- Transfer Standard
- Local Standard
- Working Standard

The National Institute of Standards and Technology (NIST)

Hierarchy of Standards

Table 1.3 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

* There may be additional intermediate standards between each hierarchy level.

Hierarchy of Standards:Temperature

Table 1.4 Example of a Temperature Standard Traceability

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

* Typical instrument systematic and random errors.

Standards

- Base Dimensions and their Units
  - Mass
  - Time and frequency
  - Length
  - Temperature
  - Current
  - Measure of Substance
  - Luminous Intensity

Standards

- Derived Units
  - Force
  - Energy
  - Power
  - Electrical Dimensions

Dimensions and Units

Table 1.2 Dimensions and Units*

Unit	Dimension: SI	Dimension: IP
Primary		
Length	meter (m)	inch (in)
Mass	kilogram (kg)	pound-mass (lb_m)
Time	second (s)	second (s)
Temperature	kelvin (K)	rankine (°R)
Current	ampere (A)	ampere (A)
Substance	mole (mol)	mole (mol)
Light intensity	candela (cd)	candela (cd)
Derived		
Force	newton (N)	pound-force (lb)
Voltage	volt (V)	volt (V)
Resistance	ohm (Ω)	ohm (Ω)
Capacitance	farad (F)	farad (F)
Inductance	henry (H)	henry (H)
Stress, Pressure	pascal (Pa)	pound-force/inch^2 (psi)
Energy	joule (J)	British thermal unit (BTU)
Power	watt (W)	foot pound-force (ft-lb)

*SI dimensions and units are the international standards. IP units are presented for convenience.

Standards: Time and frequency

One second is define as the time elapsed during 9,192,631,770 periods of the radiation emitted between two excitation levels of the fundamental state of cesium-133

$$1\,\text{Hz} = \frac{1\,\text{cycle}}{\text{second}} = \frac{2\pi\ \text{rad}}{1\,\text{s}}$$

Standards: Length

One meter is defined exactly as the length traveled by light in 1/299,792,458 of a second (velocity of light 299,792,458 m/s)

$$1\,\text{ft} = 0.3048\,\text{m}$$

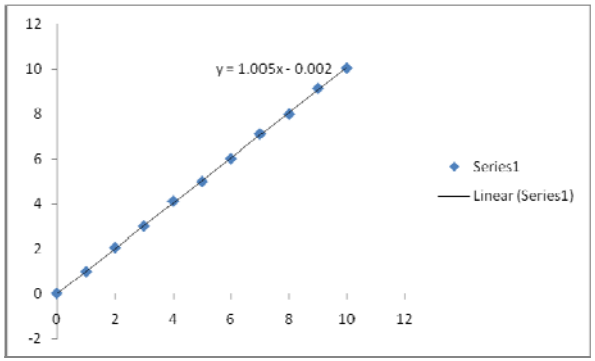
$$1\,\text{in} = 0.0254\,\text{m}$$

Voltmeter Calibration Data (Sequential Test)

Upscale		Downscale	
x (mV)	y(mV)	x (mV)	y(mV)
0	0	0	0.5
1	0.97	1	1.23
2	1.98	2	2.15
3	2.98	3	3.03
4	3.92	4	4.12
5	4.98	5	5.2
6	6	6	6.12
7	6.99	7	7.11
8	7.97	8	8.12
9	9.01	9	9.05
10	10.03	10	10.02

Voltmeter Calibration Data (Random Test)

x (mV)	y(mV)	%Error
0	0	0
1	0.97	3
2	2.05	-2.5
3	2.98	0.666667
4	4.1	-2.5
5	4.98	0.4
6	6	0
7	7.08	-1.14286
8	7.97	0.375
9	9.12	-1.33333
10	10.03	-0.3



Voltmeter Calibration Data (Random Test)

No.	x (mV)	y(mV)	%Error
1	5	4.85	3.0000
2	5	4.81	3.8000
3	5	4.9	2.0000
4	5	4.82	3.6000
5	5	4.83	3.4000
6	5	4.92	1.6000
7	5	4.86	2.8000
8	5	4.87	2.6000
9	5	4.91	1.8000
10	5	4.83	3.4000
	mean	4.86	2.8
	Sx	0.0392	0.7832