Xi'an Jiaotong-Liverpool University
西交利物浦大学

EEE220 Instrumentation and Control System

2018-19 Semester 2

Dr. Qing Liu

Email: qing.liu@xjtlu.edu.cn

Office: EE516

Department of Electrical and Electronic Engineering

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Course Information

Initial Assessment:

- **Coursework: 2 lab reports (15%, 7.5% each)**
  - Individual work (discussion allowed, plagiarism strictly prohibited)
  - Coursework should be submitted on ICE (e-copy)
  - Observe the deadlines, university policy applied for late submissions
- **Midterm test (15%)**
  - One-hour closed book exam (week 7)
- **Final Exam: (70%)**
  - Three-hour closed book exam during examination days (TBD)

Resit Assessment:

- **Resit Exam: (70%)**
  - Three-hour closed book exam after the end of semester 2 (TBD)
  - Marks of coursework will be carried forward when calculating the final marks

Module Information

- **Lecture**
  - Time: Monday 16:00-18:00 & Thursday 09:00-11:00 (Week 1-6, 8-14);
  - Venue: EE118
- **Lab**
  - Time: Thursday 11:00-13:00 & 14:00-18:00, week 3-4 (lab 1), week 11 (lab 2)
  - Venue: EE213 & EE215 (lab 1); EE305 & EE309 & EE311 (lab 2)
- **Tutorial**
  - Time: Thursday 13:00-14:30, week 6, 13
  - Venue: EE118

Contact Information

- **Instructor: Dr. Qing Liu**
  - Email: qing.liu@xjtlu.edu.cn
  - Office: EE516
  - Office hour: 1-5pm, Wednesday
  - Office telephone number: +86 (0512) 8816 1400
  - Homepage: http://www.xjtlu.edu.cn/en/departments/academic-departments/electrical-and-electronic-engineering/staff/qing-liu
  - TA: Shuyi Qu(shuyi.qu@xjtlu.edu.cn)

Course Goals

- ❑ Understanding of control system with instrumentation:
  - Why automatic control is useful for Electrical, Mechanical, Aerospace, Electronics, etc.
  - Recognize the elements of control system design and possess an appreciation of controls in the context of engineering design
- ❑ Understand basic ideas and concepts of signal measurement :
  - Sensor and signal analysis
- ❑ Know relevant mathematical theory in time & frequency domain
- ❑ Be able to solve simple control problems and design system
- ❑ Be aware of computational tools (Matlab)

Learning Outcomes

❑ Knowledge and Understanding

After successfully completion of the module, the students should be able to:

- Appreciate basic sensors/transducer specifications and their interpretation;
- Understand the behaviour of linear system, the derivation of mathematical models in differential equations, transfer function and state space representation;
- Familiarise the problem of instability and apply standard tests for stability;
- Appreciate the advantages and disadvantages of closed-loop feedback with regard to system response speed, sensitivity to parameters and disturbances, accuracy and stability;
- Understand the system requirements for a typical measurement system and some common factors that can affect its performance;
- Familiarise common types of system controller, and know how to select the most appropriate controller for a given problem;
- Appreciate how complete control schemes are implemented in hardware and software, and the problems of system integration.

Learning Outcomes (cont'd)

❑ Intellectual Abilities

- Model linear system in differential equations, transfer function representation, block diagrams and state space realization;
- Analyse dynamic and static characteristics of linear systems in both time and frequency domains;
- Design and tune controllers (e.g. PID controllers) for linear system with frequency domain methods;
- Optimise sensor arrangement to get effective value;
- Design a typical measurement system including the choice of transducer, associated signal conditioning and transmission path requirements.

❑ Practical Skills

- Analyse the dynamic and steady state performance of a system by analytic methods or computer aided simulation and design technique;
- Calculate suitable controller settings for a given problem;
- Combine control system with sensor and transducer;
- Possess practical experimental skills in data collection, analysis and interpretation.

Reference Books

- **Textbook**

- Richard C. Dorf, Robert H. Bishop (2016), Modern Control Systems (13th ed.), Pearson, ISBN-13: 9870131383

- **Reference Materials**

- W. Bolton (2015), Mechatronics electronic control systems in mechanical and electrical engineering, Pearson, ISBN: 9781292076683
- W. Bolton (1998), Measurement and Instrumentation Systems, Butterworth-Heinemann, ISBN-13: 978-0750631143
- Norman S. Nise (2011), Control Systems Engineering (6th ed.), Wiley, ISBN-13: 978-8126537280

- Matlab with Control System Toolbox

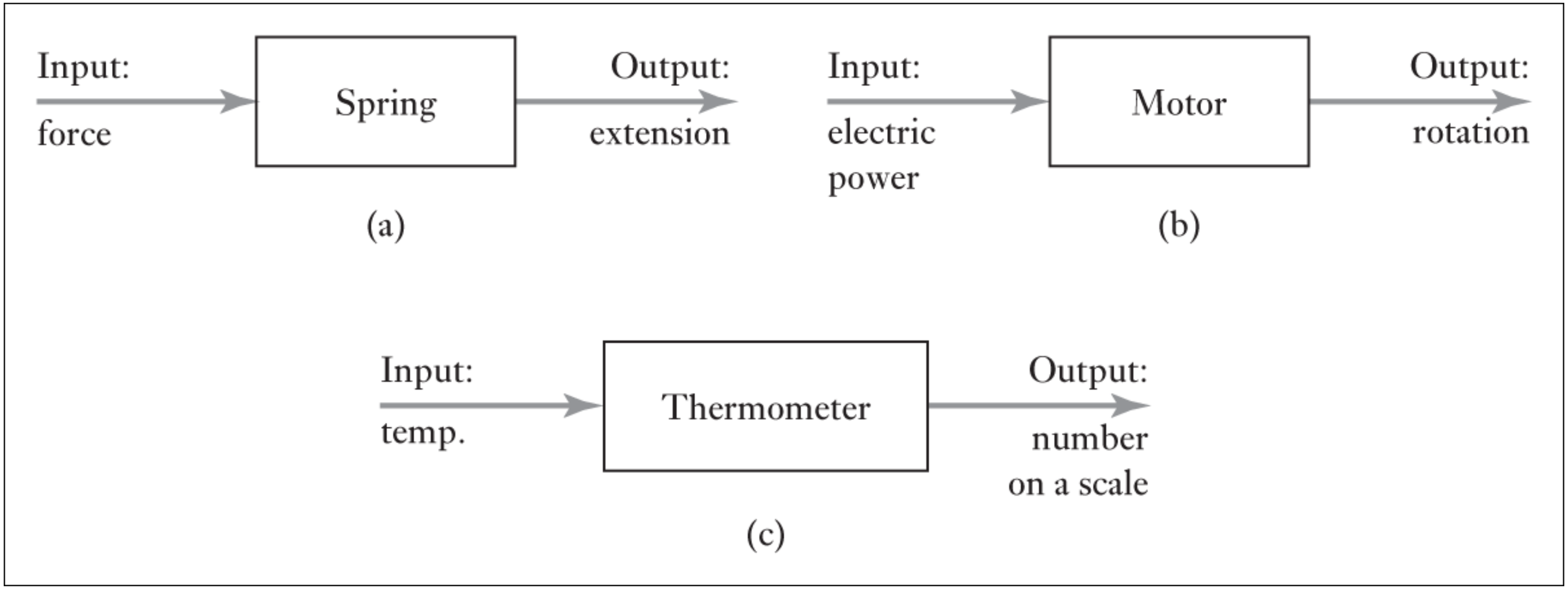
Lecture 1

Outline

- Instrumentation System: Definitions and Basic Concepts
- Static Characteristics of Sensor Performance
- Dynamic Characteristics of Sensor Performance

System

A **System** can be thought of as a box or block diagram which has an input and output where we are concerned not with what goes on inside the box but with only the relationship between the output and the input.



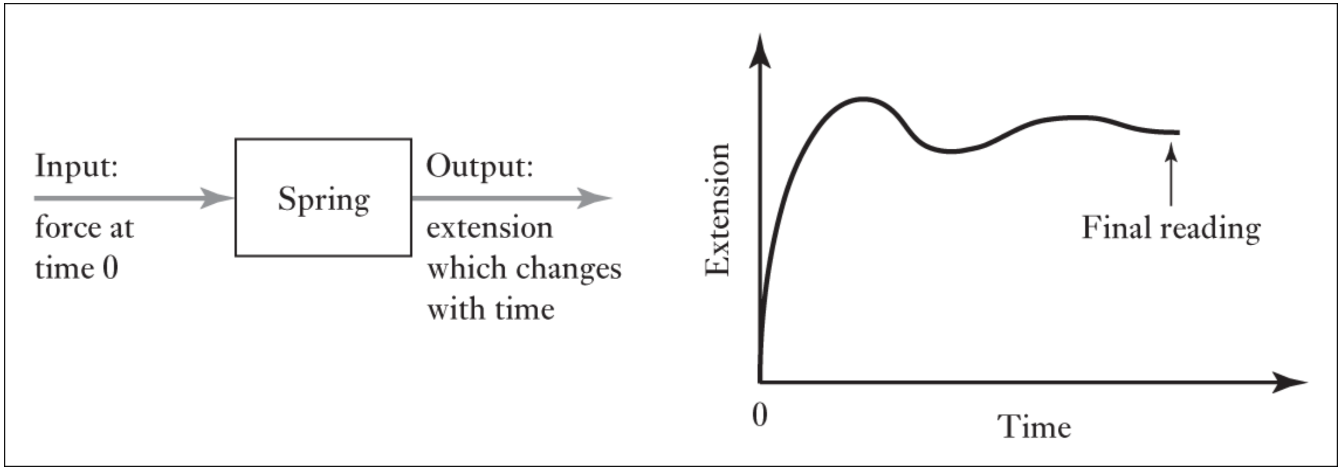
Examples of systems: (a) spring, (b) motor, (c) thermometer.

Modelling Systems

The response of any system to an input is not instantaneous. The response of systems are functions of time.

In order to know how systems behave when there are inputs to them, we need to devise models for systems which relate the output to the input, so that we can work out, for a given point, how the output will vary with time and what it will settle down to.

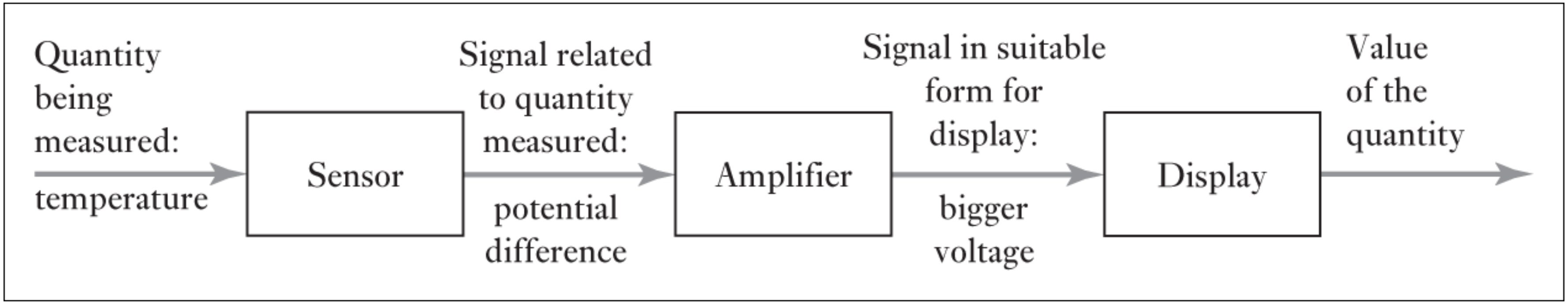
For example, for the spring system, $F = kx$ only describes the force (F)–extension (x) relationship when steady-state conditions occur. When the force is applied, oscillations will occur before the spring settles down to its steady-state extension value.



Instrumentation / Measurement System

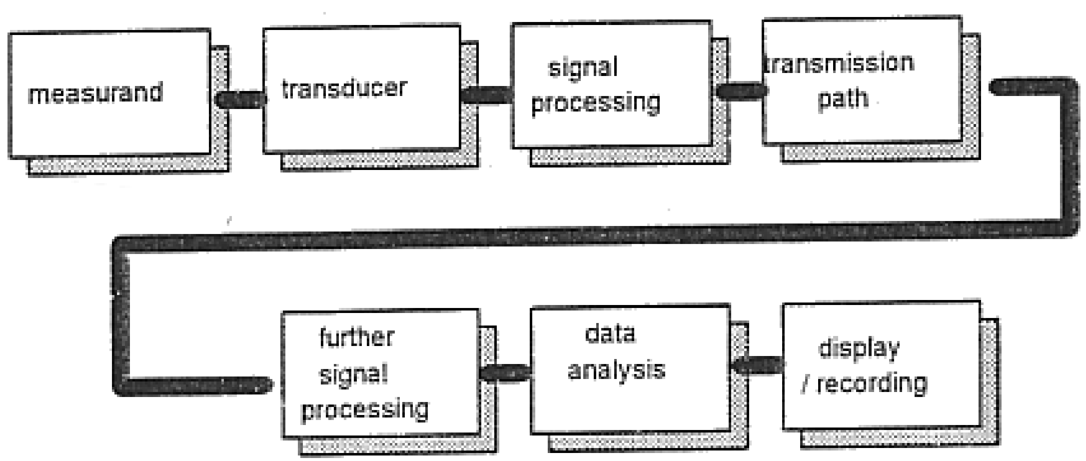
An **instrumentation / measurement system** can be thought of as a box which is used for making measurements. Generally, it is considered to be made of three basic elements:

1. A sensor responds to the quantity being measured by giving as its output a signal which is related to the quantity;
2. A signal conditioner takes the signal from the sensor and manipulates it in to a condition which is suitable either for display, record, transmission or use of control;
3. A display system displays the output from the signal conditioner.



Other concepts

An Instrumentation System



- Measurand

\- the physical quantity being measured, e.g. temperature, strain, displacement, air flow etc.

- Transmission Path

\- the medium used to transmit data, e.g. optical fiber, radio, electrical cables, pneumatic pipes etc.

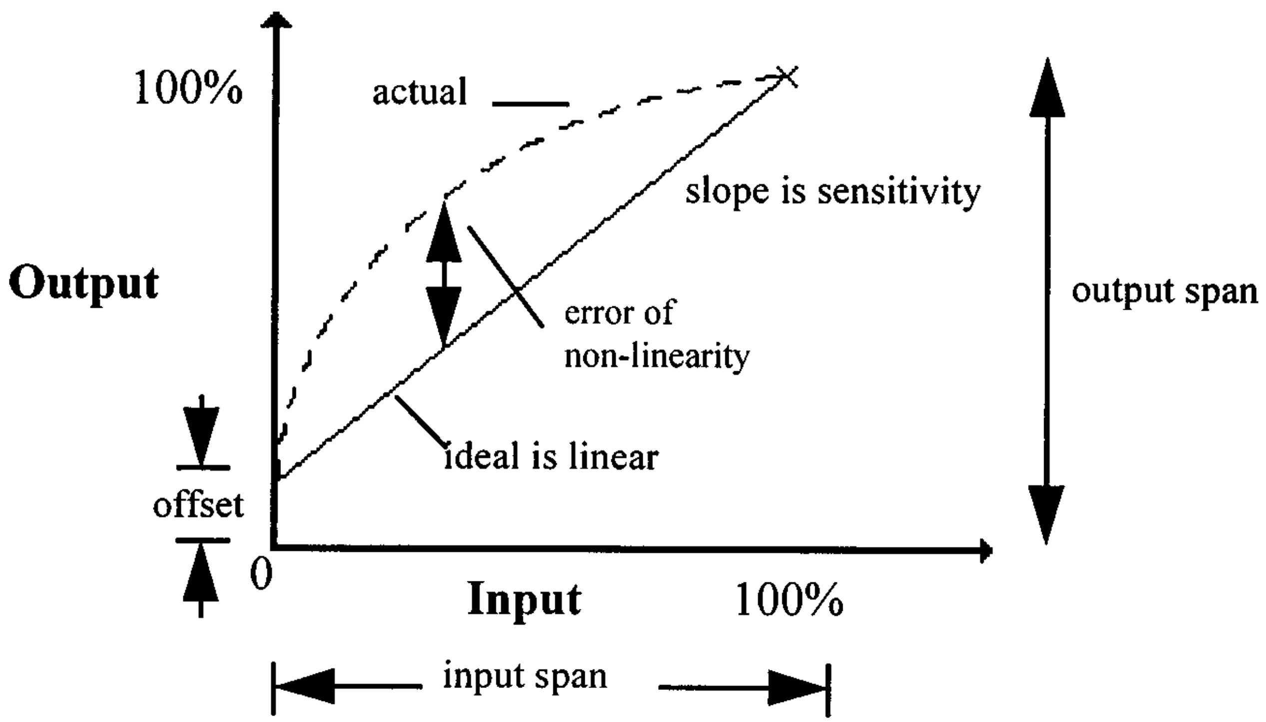
Sensors and Transducers

- The term sensor is used for an element which produces a signal relating to the quantity being measured, i.e., electrical resistance temperature element.
- The term transducer is often used in place of the term sensor. Transducers are defined as elements that when subject to some physical change experience a related change.

Thus sensors are transducers.

A measurement system may use transducers, in addition to the sensors, in other parts of the system, to covert signals in one form to another form.

Static Characteristics of Sensor Performance



- Range / span
- Error
- Accuracy
- Precision
- Sensitivity
- Resolution
- Hysteresis error
- Non-linearity error
- Repeatability/ reproducibility
- Dead band / time
- Etc.

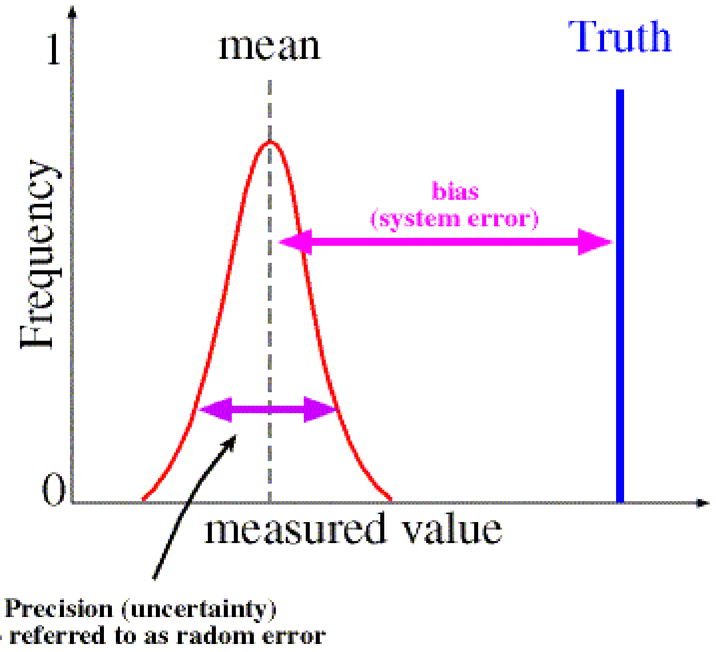
Factors Affecting Accuracy

- Transducer placement: the transducer must be located in an appropriate position and with an appropriate orientation to measure the measurand accurately;
- The introduction of a transducer may affect the measurand;
- The interconnection of the system may cause electrical loading effects;
- Other physical parameters may interact with the system and affect the measurement;
- The transducers themselves introduce a source of error.

Measurement Error: Systematic Error

- **Systematic Error (bias)** sources:
  - usually those that change the input–output response of a sensor resulting in mis-calibration
  - aging, damage or abuse of the sensor
  - measurement process itself changes the intended measurand
  - the transmission path
  - human observers

✓ Systematic error can be corrected by some methods if the error source is known.

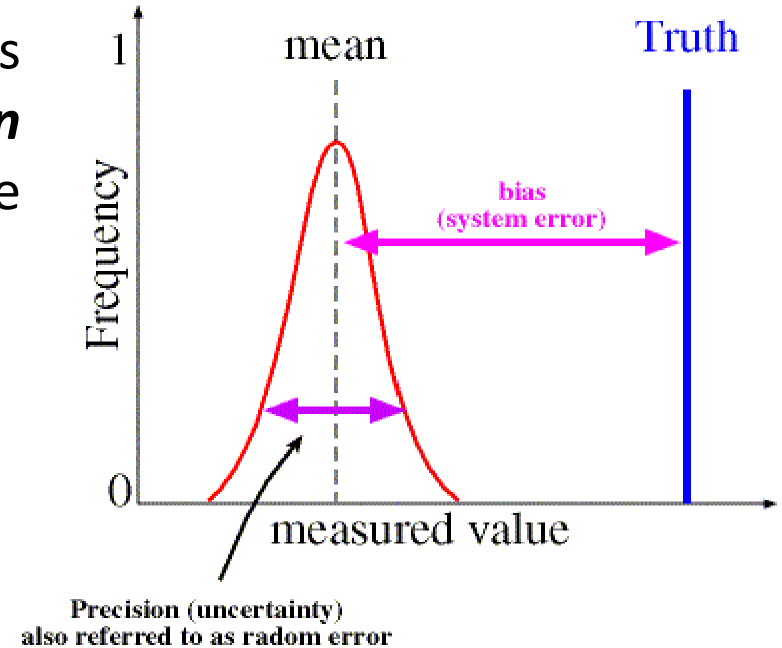


Measurement Error: Random Error

- **Random Error (noise)** sources:
  - usually unknown and unpredictable changes in the measurement
  - may occur in the measuring instruments or in the environmental conditions

Random error is often referred to as noise, and exhibit a ***Gaussian distribution*** when repeating a large number of measurements.

◆ Random error can NOT be completely eliminated.



Measurement Uncertainty

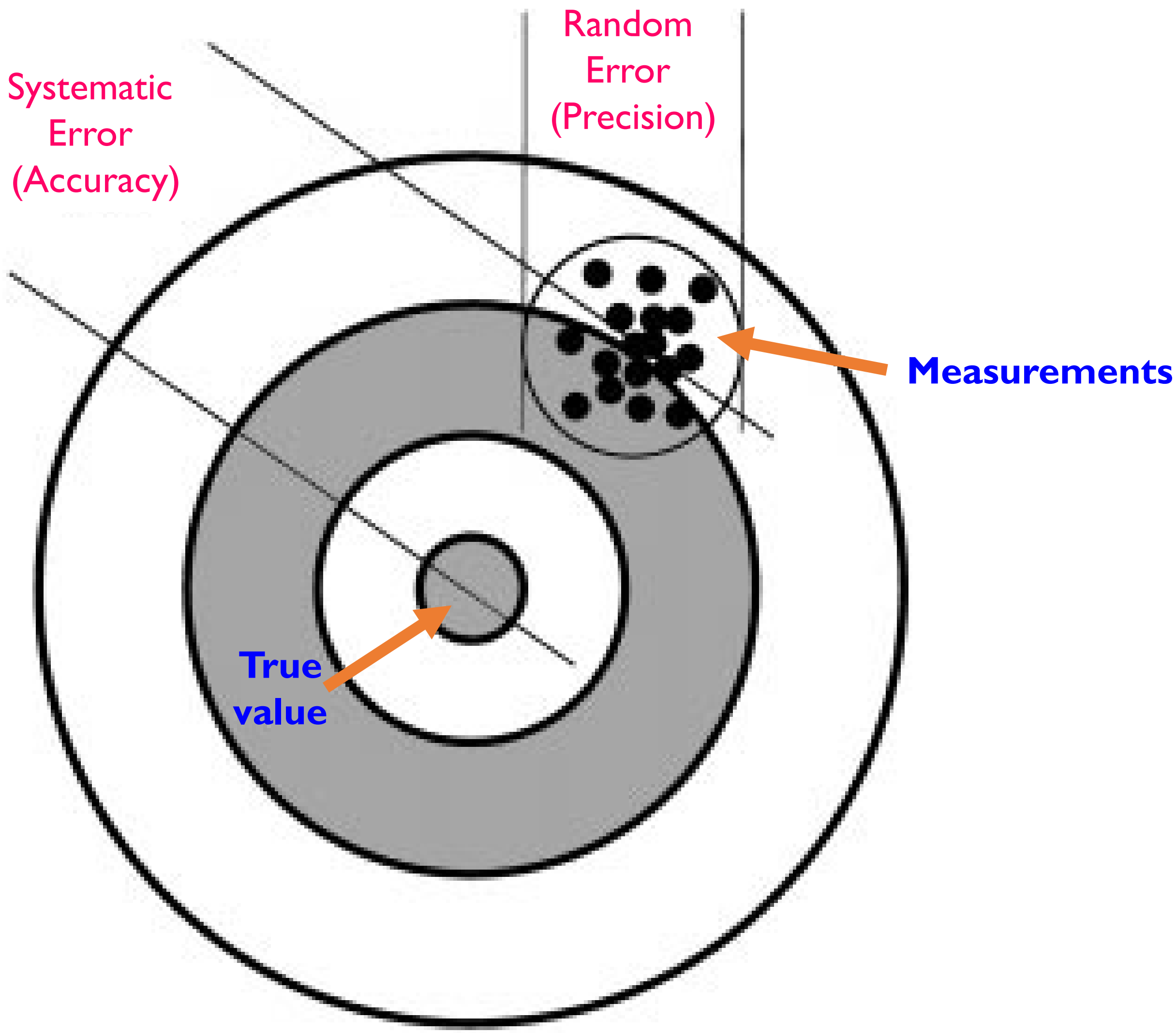
Accuracy:

- defined as the difference between the true value of the measurand and the measured value indicated by the instrument;
- determined by systematic error;
- usually expressed as a percentage of the full scale deflection (FSD) of the transducer or system.

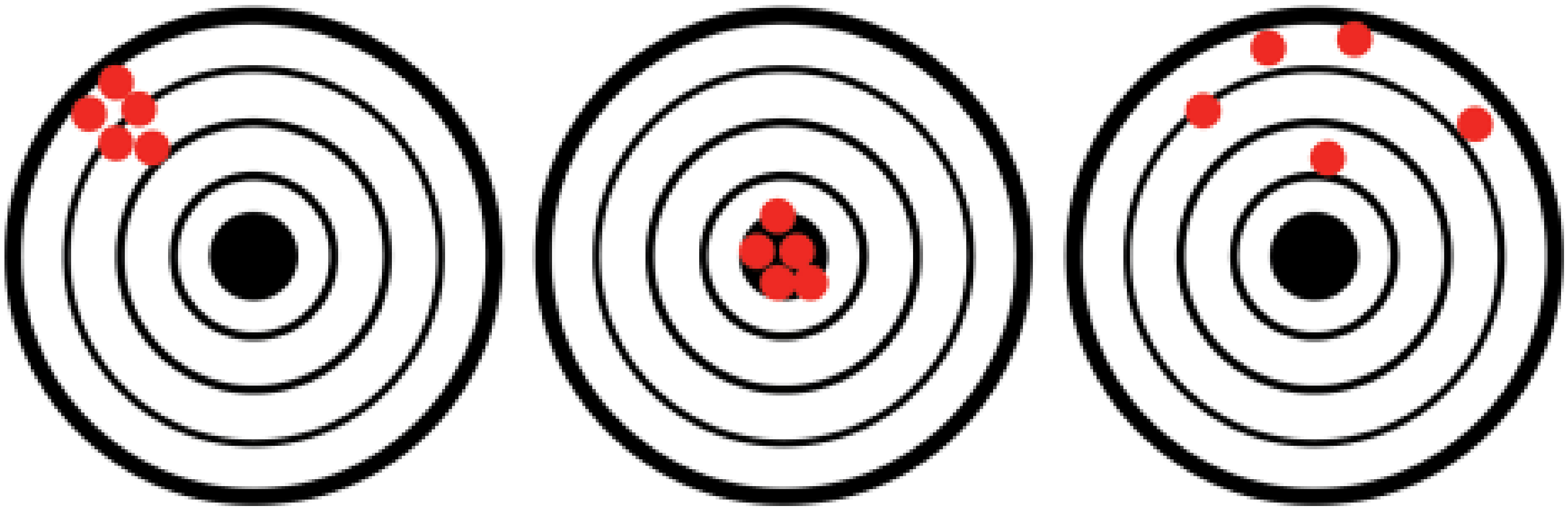
Precision:

- a term that describes an instrument's degree of freedom from random errors;
- normally quantified by the standard deviation δ that indicates the width of the Gaussian distribution;
- The smaller the standard deviation, the more precise the measurement.

Target Analogy of Measurement



Accuracy vs. Precision



Poor accuracy but good precision

Good accuracy and good precision

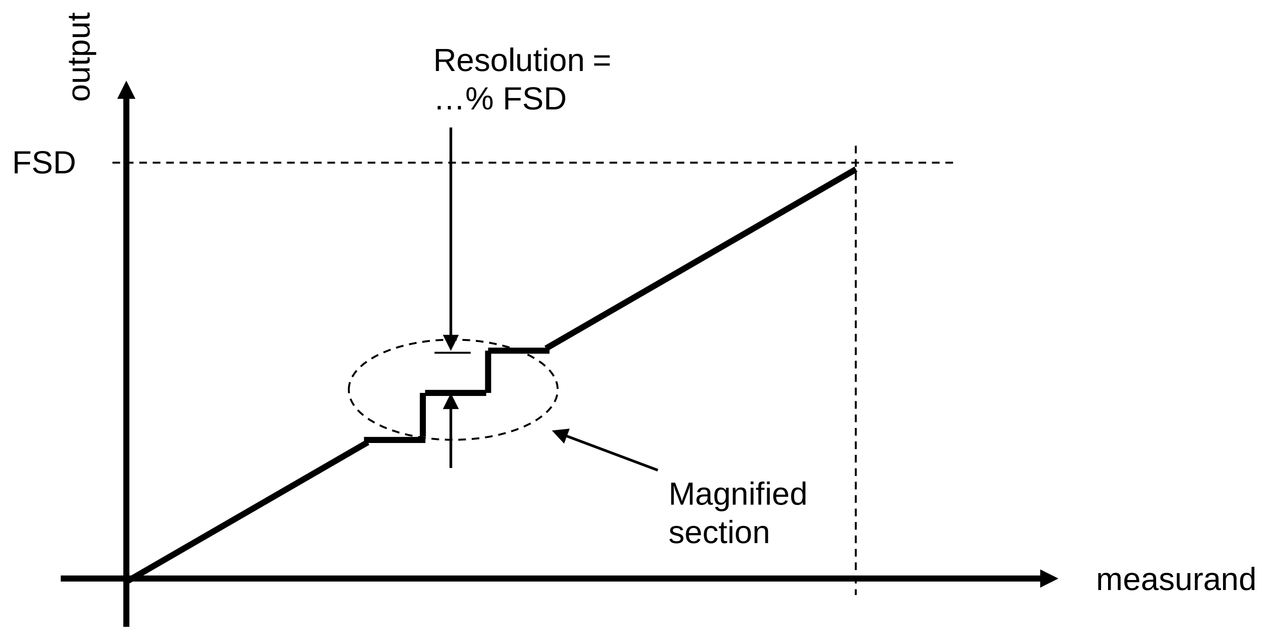
Poor accuracy and poor precision

Resolution

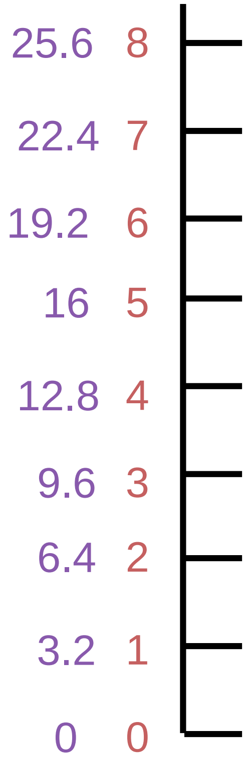
Resolution:

- is the smallest change in the measurand that can be measured;
- the resulting maximum error is **half** the resolution of the measurement.

FSD: Full Scale Deflection



Resolution and Maximum Error



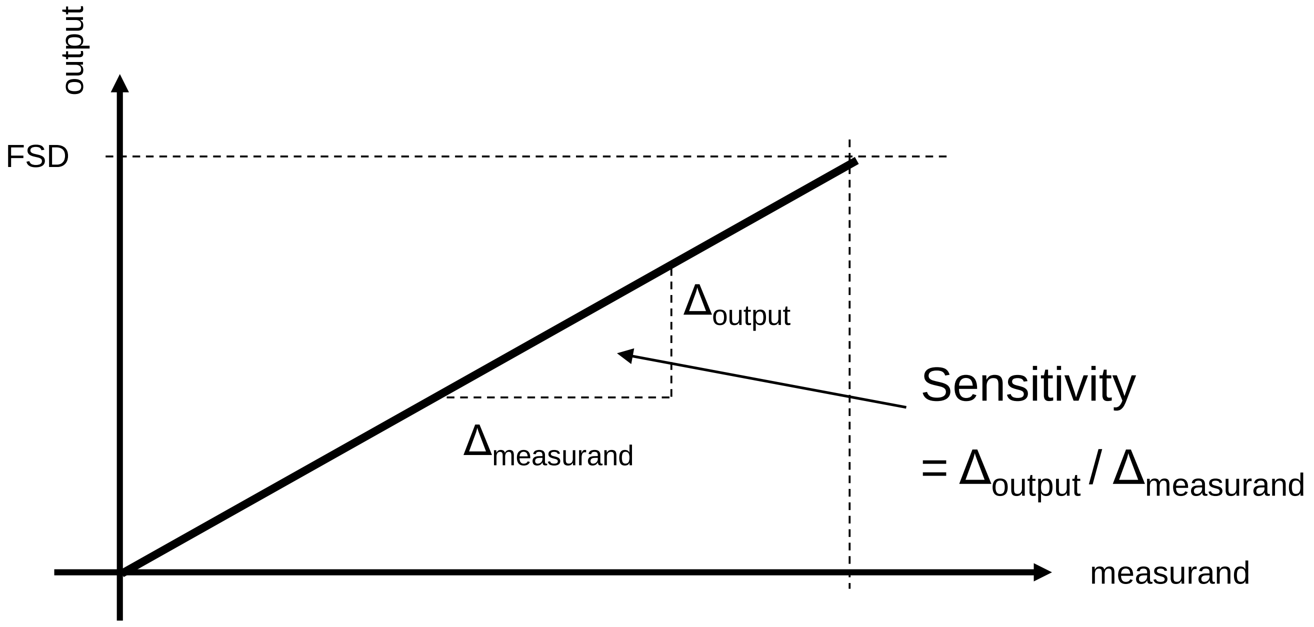
Unit (mm, ^{o}C, Volt etc.)

Resolution	True Value	Measurement	Error	
1	1.2	1	0.2	≤ 0.5
	3.6	4	0.4	
	7.5	7 or 8	0.5	
	…	…	…	
3.2	2.8	3.2	0.4	≤ 1.6
	17.5	16	1.5	
	24.8	25.6	0.8	
	…	…	…	

Sensitivity

Sensitivity:

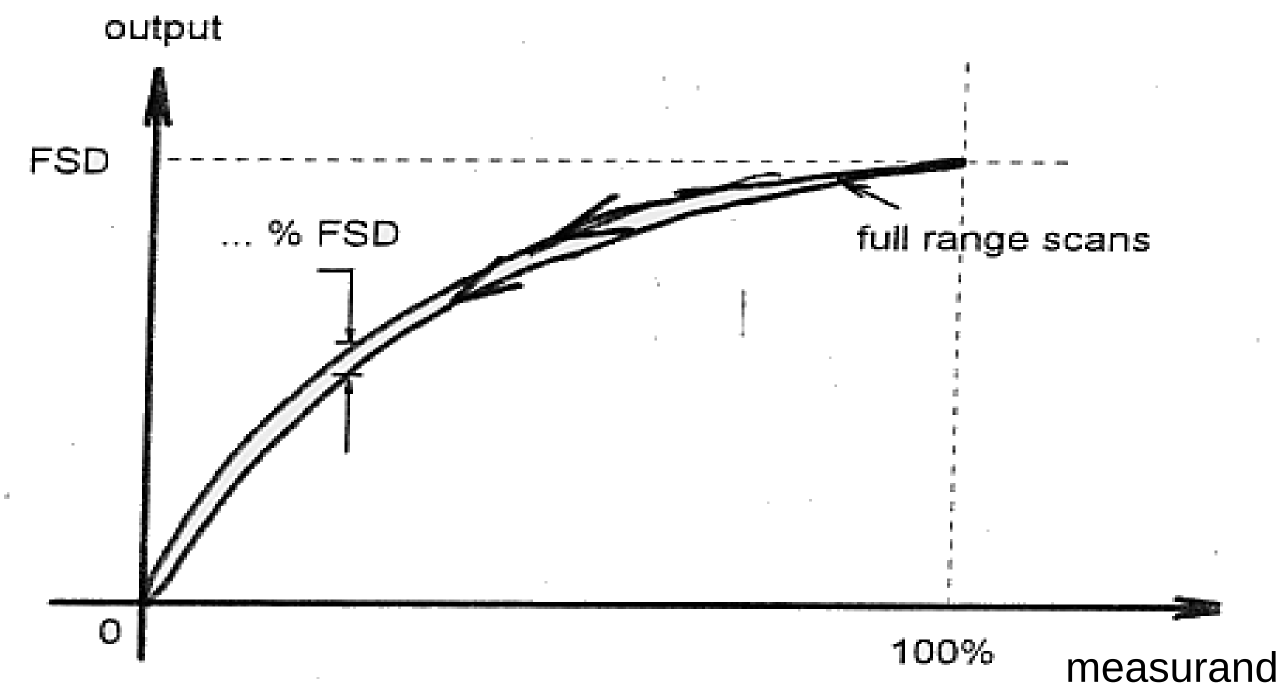
- is the slope of the output vs input (measurand) in the graph;
- note the difference between sensitivity and resolution.



Repeatability

Repeatability:

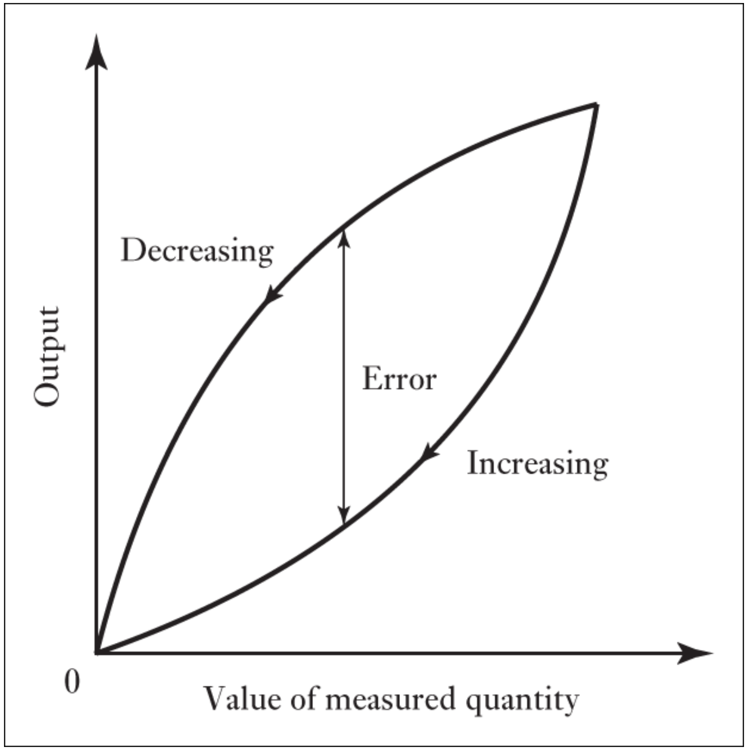
- relates to the maximum difference between any two output values at the same value of measurand taken during full range traverses of the measurand and approached from the same direction.



Hysteresis Error

Hysteresis error:

- the difference in transducer output obtained when any measurement point is approached from different directions during a full range scan of the transducer.



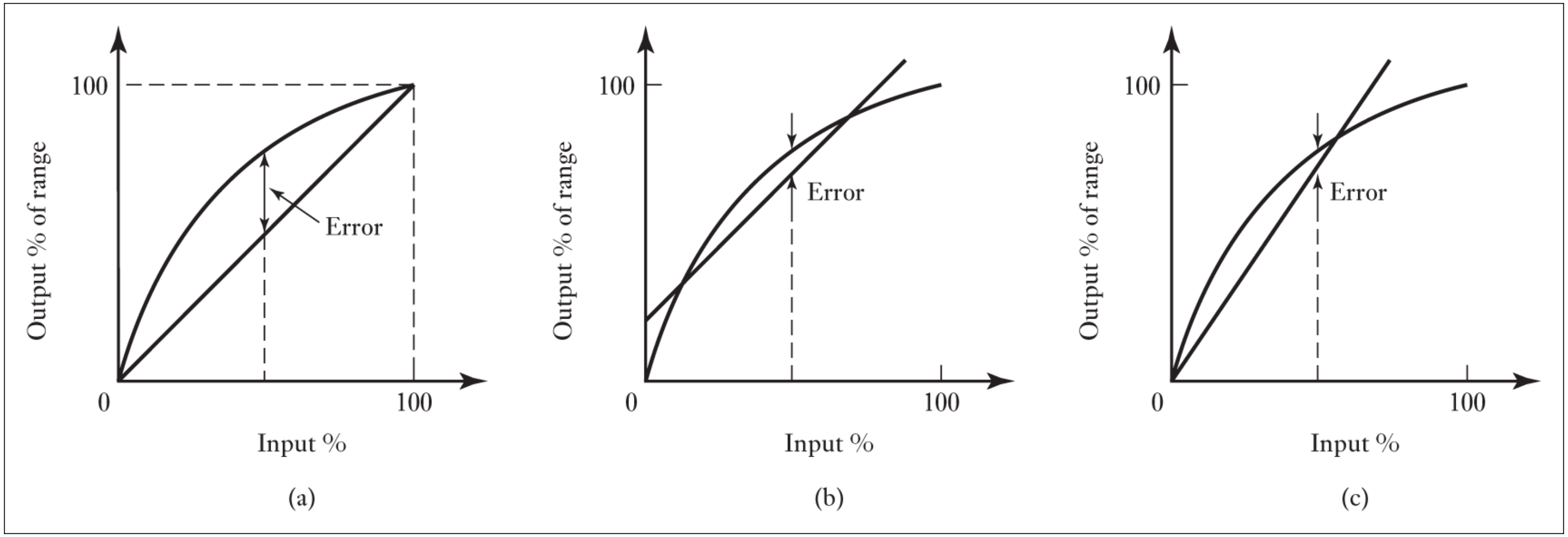
Non-linearity Error

Non-linearity error:

- For many transducers a linear relationship between the input and output is assumed over the working range, i.e., a graph of output plotted against input is assumed to give a straight line. Errors occur as a result of the assumption of linearity.
- Non-linearity is not necessarily a source of error at all. It only becomes one if the transducer is assumed to have a linear output (most are).

The error is defined as the **maximum difference** of the actual input-output curve from a straight line. Various methods are used for numerical expression of the nonlinearity error, depending on how to define the reference straight line.

Non-linearity Error (cont'd)



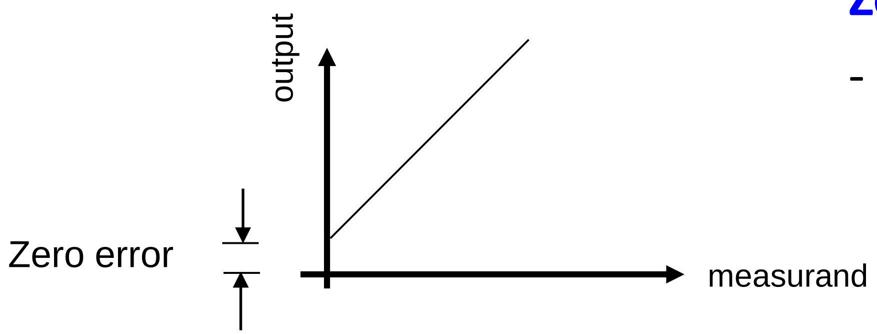
To calculate non-linearity error, the straight line is defined as, respectively

(a) end- range values: the straight line joins the output values at the end points of the range.

(b) best straight line for all values: the straight line is the best fit line by using the method of least squares when all data values are considered.

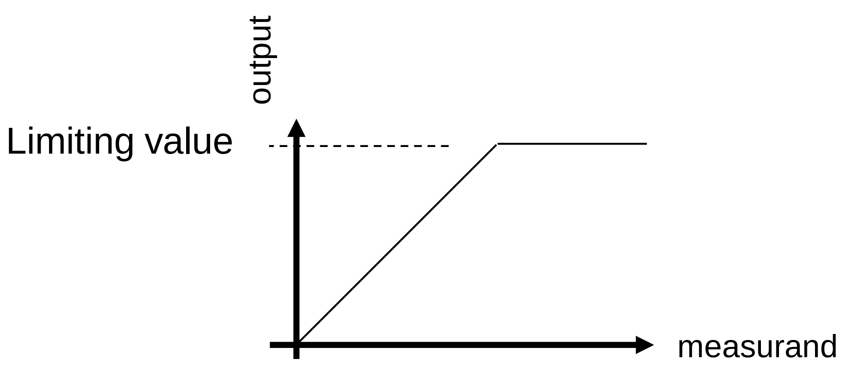
(c) best straight line through the zero point: the straight line is the best fit line which passes through the zero point by using the method of least squares when all data values are considered.

In addition, analytical linear line: the straight line is the response that the transducer should have as given by theory.



Zero error:

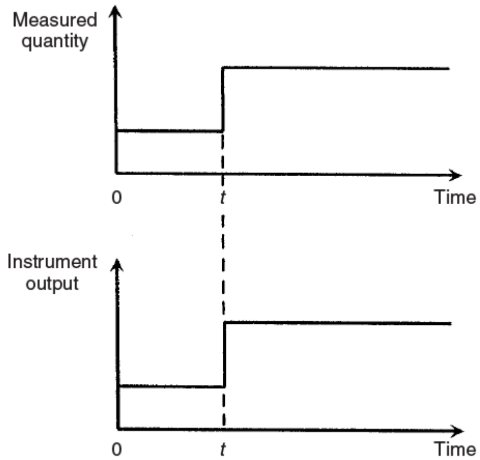
- self explanatory – may be specified as …% FSD or as a specified output value.



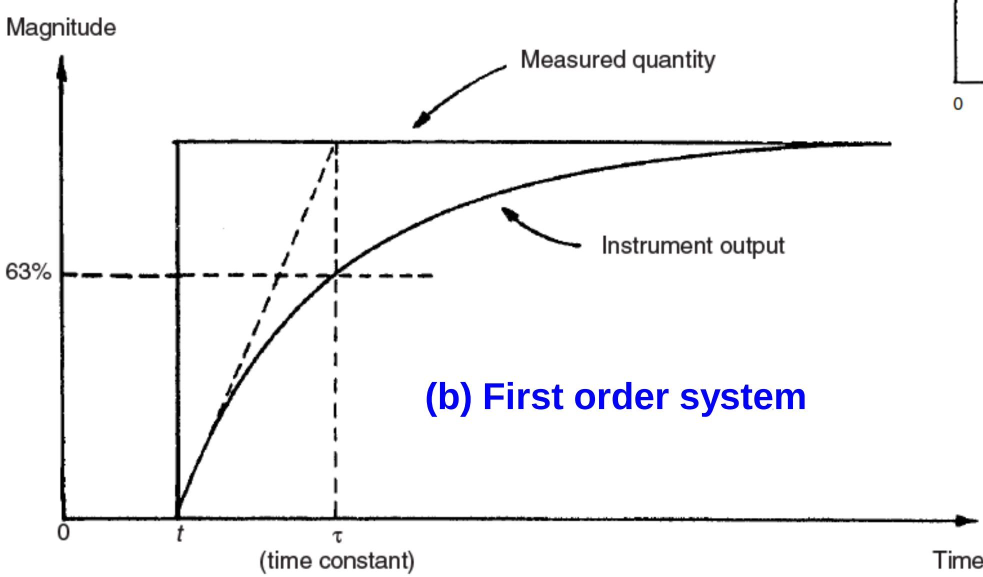
Limiting value:

- occurs due to the transducer being taken outside its calibrated operating range;
- often results in abrupt levelling off or saturation of the output.

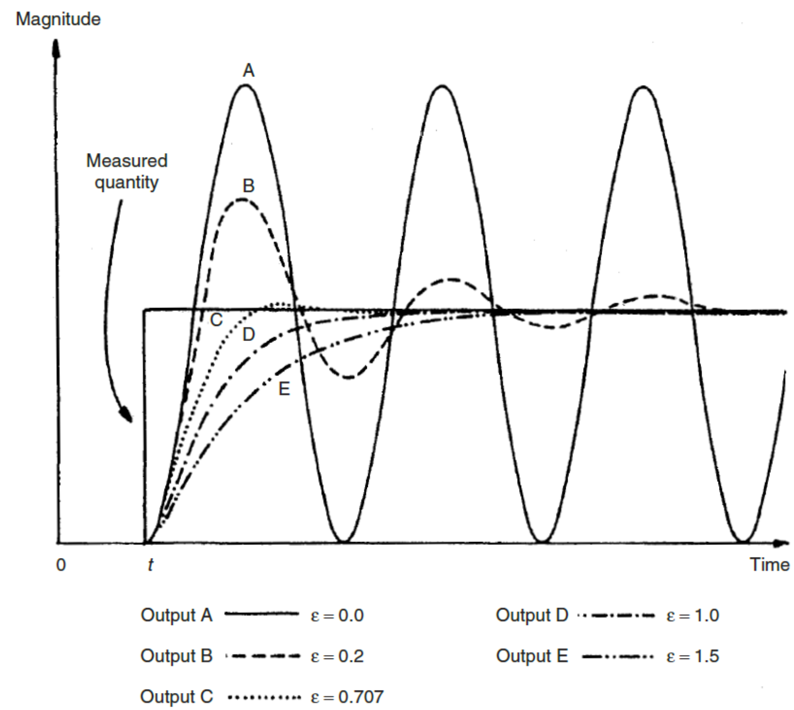
Dynamic Characteristics of Sensor Performance



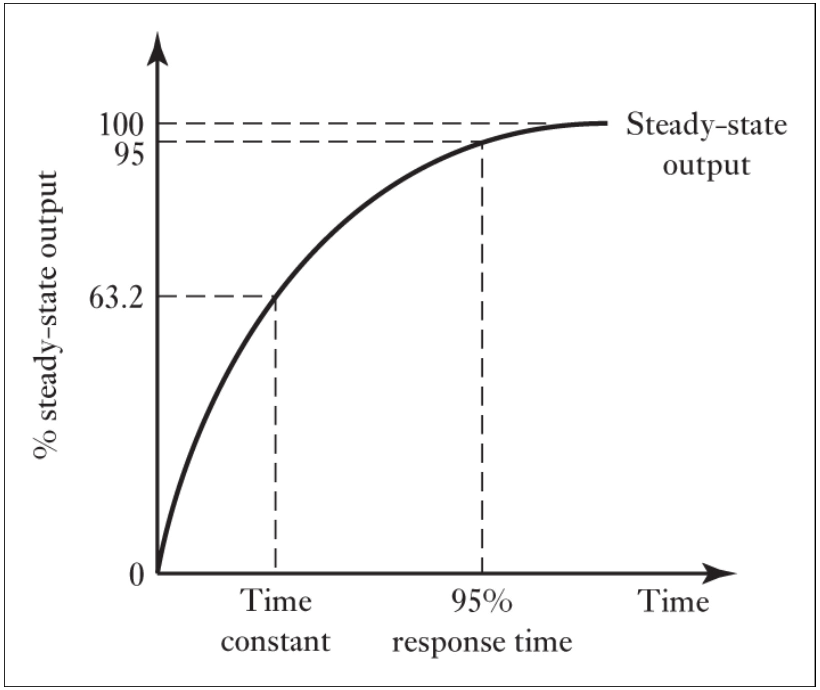
(a) Zero order system



(b) First order system



(c) Second order system



Response time:

- is the time which elapses after the input to a system element is abruptly increased from zero to a constant value up to the point at which the system or element gives an output corresponding to some specified percentage, e.g. 95% of the value of the input.

Settling time:

- is the time taken for the output to settle to within some percentage, 2% of the steady-state value.

Rise time:

- is the time take for the output to rise to some specified percentage of the steady-state output.

System Design

When designing an instrumentation system it is necessary to:

1. **Choose the most appropriate measurement technique**
    - Should it be contact-less?
    - What signal processing is available?
    - What power sources are available?
2. **Choose the transducer**, e.g.
    - Is reliability important?
    - How accurate does it need to be?
    - Is weight important?
    - Is it to operate in a harsh environment?
3. **Design the signal conditioning as required**
4. **Whilst balancing overall cost against performance**

Thank You！