Schedule Sem 2 2006

Part 1 – Instrumentation
- Week 1 – Module 1 (lectures, activity & tute)
- Week 2 – Module 2
- Week 3 – Module 3
- Week 4 – Module 4
- Week 5 – Module 5
- Week 6 – Module 6
- Week 7 – Revision of Part 1
- Week 8: Class Test (1 hour) covers Part 1

Schedule Sem 2 2006

Part 1 – Basic control engineering
- Week 8 – Module 7 (cont) & Lab exercises
- Week 9 – Module 8 & Lab exercises
- Week 10 – Module 9 & Lab exercises (*)
- Week 11 – Module 10 % Lab exercises (*)
- Week 12 – Module 11 (*)
- Week 13 – Revision of Part 2, submission of Assignment
- Final exam (TBA)
Week 1 – Module 1

- **Wednesday:**
  - Lecture 1: Unit specification - assessment info
  - Lecture 2: Module 1 Overview of instrumentation and process control, concepts and basic theory of measurement
- **Friday:**
  - Lecture 3: Module 1 (continued)
  - Activity 1: do exercises of Module 1
  - Tutorial: Practice MATLAB/Simulink in computer lab (CAD Lab)

Today's topics (Wed 12.7)

- Lecture 1:
  - Unit specification (aim, objectives etc.)
  - Assessment information
- Lecture 2:
  - Part I: Fundamentals of Instrumentation
  - Module 1: Introduction to instrumentation and control engineering, definitions and basic concepts

What will the subject involve in?

- Measuring systems, automatic control systems, especially marine and offshore control systems
- For examples: Marine Control Systems for Oil Rigs, Floating Structures, Sea-Going Vessels, Production systems, etc.
Why do we need con. sys?

• Because of disturbance / noise
• What are the purposes of the control systems?
  • To explore our world and space
  • To release operator’s duties
  • To enhance accuracy and reliability
  • To increase productivity, effectiveness

Week 1 – Lecture 1

Outline of Subject
Assessment Information
Aims
- Fundamentals of instrumentation, methods of common measurements, AS standard symbols
- Basic control theory, knowledge and understanding of marine and offshore control systems and components and performance
- Control applications in marine and offshore systems: PID control, level control system, pneumatic control, autopilot, dynamic positioning systems etc.

Prerequisites
- E03-206 Engineering Mathematics II
- E03-181 Electrical Fundamentals
We need some basic mathematical & physical foundations such as complex numbers, matrix manipulation, ordinary differential equations, Laplace transform, Newton’s laws, Kirchoff’s laws, etc.

Learning Outcomes
- List variables which are measured and/or controlled in a typical measuring or control system.
- Describe methods of measuring temperature, pressure, level, flow, speed, ship position, etc.
- Explain AS standard symbols for instrumentation and control engineering.
Learning Outcomes

- Describe methods used to represent a dynamic system (ODEs, Block Diagrams)
- Describe methods used in automatic control systems to reduce steady state error and deviation during a disturbance
- Describe linear first and second order measuring/control systems and PID controllers

Learning Outcomes

- Explain stability of control systems
- Describe automatic control systems
- Use MATLAB/Simulink to perform technical computation

Generic graduate attributes

- Ability to apply knowledge of basic science and engineering fundamentals
- Ability to understand problem iden, formulation and solution
- Ability to utilise a system approach to design and operational performance
- Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams
- Expectation of the need to undertake lifelong learning and the capacity to do so
**Contents of Subject**

- Part I - Fundamentals of Instrumentation – Modules 1 ~ 6
- Part II - Basic Control Engineering – Modules 7~11
- Tutorials in Computer lab – G18
- Investigative Study (experiments in CE LAB – G51)

See Schedule for detail.

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**Learning Resources**

- **Textbooks:**
  - Lecture Notes and Handouts (electronic copies: http://academic.amc.edu.au/~hnguyen
  - Recommended Readings:
    - Richards, R.J, *Solving Problems in Control*
    - Kou, B.C, *Automatic Control Systems*
    - Ogata, K., *Modern Control Engineering*

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**Recommended Software:**

- Matlab/Simulink (Computer Labs)
- LABVIEW (Computer Labs)
- Optional: Other programming languages (Fortran, C++, VB)

Note that in a series of tutorials: practise using MATLAB/Simulink – simple programs to compute, draw graphics, solve ODEs, simulation and analysis of control systems, etc.
Assessment Info

- Class Test 10% Week 8
- Lab 10% From Week 8
- Tutorial participation 10% Every Week
- Assignment 25% Week 13
- Final Exam 45% TBA

Students are expected to have a minimum 80% of attendance for lecture, tutorial and lab.
Class Test: 1 Hour, Final Exam: 3 Hours

Summary of Lecture 1

- Unit specification:
  - Subject information
  - Aims, learning objectives
  - Learning resources
  - Assessment Information

Lecture 1 has been completed

Any questions?
Week 1 – Lecture 2
Module 1
Part I – Fundamentals of Instrumentation
Introduction to Instrumentation and Control Systems
Definitions and Concepts

Learning Outcomes
- Brief history of development of instrumentation and control systems
- Brief history of control applications in marine and offshore systems
- Define system, processes, signals, Open-loop control, Closes-loop control
- Needs for instrumentation and purposes
- Examples of control systems

Introduction to Inst & PC
- In pre-Christian times: first automatic control system to open the doors of an ancient Greek temple – open-loop control system
- 1774, James Watt’s flyball governor to control the speed of steam engine – closed-loop control system – the first significant CLCS
- 1940s: pneumatic transmission systems
(See Table 1 & Figure 1 – pp. 2)
Water clock of Ktesibios
http://automata.cps.unizar.es/animhistoria/11.html

Example:
Heat exchanger

Introduction to Inst & PC

Control Applications in M&O Systems:
- Manoeuvring, control and ship positioning systems
- Robust and reliable control systems
- Fault monitoring, detection system
- Engine and machinery control systems, etc.

Ship’s Automatic Control Systems:
- 1810: Gyroscope by C.A. Bohnerberger
- 1911: Ship’s first automatic steering mechanism by Elmer Sperry
Introduction to Inst & PC

- Ship’s Automatic Control Systems:
  - Later in 1922, position feedback control system by Nicholas Minorsky – PID control system
  - 1960s: linear quadratic optimal and Kalman filter – Ship LQG controllers: dynamic positioning system, roll stabilisation system
  - Nonlinear control systems
  - Computer-based control systems
- Modern Control Theories: optimal control, self-tuning control, neural network control, etc.

Overview of History

Source: T.I. Fossen 2002

Example: AWRS
Research Activities
International Research Activities
IFAC (International Federation of Automatic Control) Meetings,
Conferences, Workshops: CAMS and MCMC (every three years).
http://www.ifac-control.org

Organization of Lecture Notes
- Part I Fundamentals of Instrumentation
  - Module 1 Introduction, Basic Theory of Measurement
  - Module 2 Transducers, AS Drawing Symbols, Temperature
  - Module 3 Pressure and Flow
  - Module 4 Level, Density and Viscosity
  - Module 5 Displacement and Position Measurement, GNSS
  - Module 6 Velocity and Acceleration Measurements
- Part II Basic Control Engineering
  - Module 7 Modeling of Dynamic Systems, Laplace transform
  - Module 8 Transfer functions, Block Diagrams
  - Module 9 Concepts of Stability and PID Control
  - Module 10 Control Components
  - Module 11 Control Applications

Definitions and Concepts
- System (SISO, MIMO), Input/s, Output/s
- Process, Signals (continuous, discrete)
- A/D, D/A Interfaces
- Open-loop Control System
- Closed-loop Control System
- Examples of M&O Control Systems
System

Input(s) ➔ SYSTEM ➔ Output(s)

Single Input Single Output: SISO
Multi-Input Multi-Output: MIMO

Process: Variables

- Electrical system (C, V, A)
- Hydraulic system (m³, kPa, ft³, psi)
- Pneumatic system (kPa, psi, m², ft²)
- Thermal system (°C, deg/w)
- Other physical types
  (Example 3 at pp. 10)

Review of Basic Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>British</th>
<th>SI</th>
<th>SI Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Foot</td>
<td>K</td>
<td>1.0 = 0.025 m</td>
</tr>
<tr>
<td>Mass</td>
<td>Pound</td>
<td>kg</td>
<td>1.0 = 453.6 kg</td>
</tr>
<tr>
<td>Temperature</td>
<td>Degree</td>
<td>°C</td>
<td>1.0 = 33 K</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

Table 1.3.1 Basic Units

<table>
<thead>
<tr>
<th>Operator</th>
<th>British</th>
<th>SI</th>
<th>SI Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Hertz</td>
<td>Hz</td>
<td>Hz</td>
</tr>
<tr>
<td>Power</td>
<td>Kilowatt</td>
<td>kW</td>
<td>kW</td>
</tr>
<tr>
<td>Voltage</td>
<td>Volt</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Resistance</td>
<td>Ohm</td>
<td>Ω</td>
<td>Ω</td>
</tr>
<tr>
<td>Current</td>
<td>Ampere</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>Energy</td>
<td>Joule</td>
<td>J</td>
<td>J</td>
</tr>
<tr>
<td>Force</td>
<td>Newton</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pascals</td>
<td>Pa</td>
<td>Pa</td>
</tr>
<tr>
<td>Temperature</td>
<td>Degree</td>
<td>°C</td>
<td>°C</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

Example:

1. 1 lb = 0.5 kg
2. 1 in = 2.54 cm
Signals: Continuous- Discrete

\[
\begin{array}{c}
\text{Input} \\
\downarrow \quad \downarrow \\
\text{SYSTEM} \\
\downarrow \quad \downarrow \\
\text{Output} \\
\end{array}
\]

- Continuous time, \( t \)
- Index, \( k \)

\[
\begin{array}{c}
u_c(t) \\
\downarrow \\
\text{u(k)} \\
\downarrow \\
y(t) \\
\downarrow \\
y(k) \\
\end{array}
\]

A/D and D/A Interfaces

- Continuous time system
- System actuation signal, \( u_c(t) \)
- Digital to analogue (D/A) interface
- Controller output sequence, \( u(k) \)
- Digital computer
- Continuous time system output, \( y(t) \)
- Analogue to digital (A/D) interface
- Sample system output, \( y(k) \)

Open-Loop System

- DC field supply voltage
- Set desired speed
- DC armature supply voltage
- Speed
- Field rheostat
- MOTOR
- LOAD

*(Chesmond, C.J. et al., 1990)*
Closed-Loop System

Set desired speed

DC armature supply voltage

velocity transducer

Load

Motor

(Chesmond, C.J. et al., 1990)

Difference between O.L.S & C.L.S

Open-loop (feed-forward) system

Motor

Controller

Speed

Desired speed

y(t)

r(t)

e(t)

Closed-loop (feedback) system

Controller

Motor

b(t)

Speed log

y(t)

Desired speed

Eg: Autopilot System

Gyrocompass (Course)

Wind, waves, and currents

Steering Machine

Autopilot (Control Sys)

Indicators (Course, Rudder)

Rudder
Flow control system

Possible projects: control algorithms for flow control, hydraulic control

Control laws: PID, self-tuning, optimal, neural network, etc.

Chemical system (blending)
Possible methods:

1. Measure \( x \) and adjust \( w_2 \) (feedback control)
2. Measure \( x_1 \) and adjust \( w_2 \) (feed-forward control)
3. Measure \( x_1 \) and \( x \), adjust \( w_2 \) (feed-forward and feedback control)
4. Use a larger tank (design change).

Control method 1: feedback

Control method 2: feed-forward
Feedback

1. Please write down your ideas and images about the subject.
2. What do you want to get from study of this subject?
3. Take examples of measuring and/or control systems you know.

Summary of Lecture 2

- History of inst and control systems
- History of marine and offshore control systems, research activities
- Systems with inputs & outputs, process and signals
- Open-loop control systems
- Closed-loop control systems
- Examples of M&O control systems
Any questions?

Week 1 – Lecture 3

Module 1
Part I – Fundamentals of Instrumentation
Theory of Measurements: Static performance of measuring system

Learning Outcomes
Explain needs for instrumentation
Describe general structure of a measuring system and ideal measuring system
Explain static performance of a measuring system: sensitivity, linearity, range and span, scale factor, accuracy and precision, possible and probable errors, reproducibility, repeatability, stability, etc.
Explain the importance of calibration
Classify measuring systems
Dynamic performance
Needs for instrumentation?

- **Instrumentation:**
  - Metrology: “the science of measurement”
  - (Concise Oxford Dictionary): the design, provision, or use of instruments in industry, science, etc.
  - In general, the application of instruments for monitoring, sensing, and measurements (J.A. Haslam et al. 1981).
- **Purposes:**
  - Product testing and quality control
  - Fault monitoring and detection
  - Part of a control system
  - Maintenance and repair; or
  - Research and development

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**Instrumentation**

Successful instrumentation: accurate measurement – needs and limitations of instruments are understood.

Measurement: comparison with a standard, calibration and periodic routine maintenance of the instruments are prerequisites of accurate measurement.

Instrumentation: multidiscipline subject – physics, thermodynamics, mechanics, fluids, electrical principles... “little bit about everything” (J.A. Haslam et al. 1981)

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**General Structure of Measuring System**

<table>
<thead>
<tr>
<th>Primary quantity</th>
<th>Transducer</th>
<th>Signal Conditioner</th>
<th>Recorder or Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical variable</td>
<td>Sensor</td>
<td>Converter</td>
<td>Display</td>
</tr>
<tr>
<td></td>
<td>Converter</td>
<td>Amplifier</td>
<td>Pen recorder</td>
</tr>
<tr>
<td></td>
<td>Transmitter</td>
<td></td>
<td>Printer, etc.</td>
</tr>
</tbody>
</table>
System Performance

- **Ideal measuring system**: where the output signal has a linear relationship with the *measurand* (quantity to be measured), where no errors are introduced by effects such as static friction, and where the output is a faithful reproduction of the input no matter how the input varies.
- **Static Performance**: when steady or constant input signals are applied, comparison of the steady output with the ideal case gives the static performance of the system.
- **Dynamic Performance**: when changing input signals are applied, comparison with the ideal case gives the dynamic performance of the measuring system.

Static Performance

- Sensitivity
- Range, Span
- Accuracy and Precision
- Linearity
- Possible and Probable Errors
- Other Static Performance Terms: Reproducibility, Repeatability, Stability, Constancy, Tolerance, Resolution, Dead-band, Hysteresis.
Static Sensitivity

- Static sensitivity is the ratio of the change in output to the corresponding change in input under static or steady state conditions.

\[
K = \frac{\Delta y}{\Delta u}
\]

- \(\Delta y\) is the change in output
- \(\Delta u\) is the change in input

Unit depends on the instrument or measuring system being considered.

Sensitivity: Example

A measuring system: a transducer, an amplifier, and a recorder:

- Transducer (°C-mV): \(K_1 = 0.2\text{mV/°C}\)
- Amplifier (mV-V): \(K_2 = 2.0\text{V/mV}\)
- Recorder (V-mm): \(K_3 = 5.0\text{mm/V}\)

\[
K = K_1 \times K_2 \times K_3
\]

\[
K = 0.2(\text{mV/°C}) \times 2.0(\text{V/mV}) \times 5.0(\text{mm/V})
\]

\[
K = 2.0\text{mm/°C}
\]

Example

A temperature-measuring system incorporates a platinum resistance thermometer, a Wheatstone bridge, a voltage amplifier, and a pen recorder. The individual sensitivities are transducer: 0.35ohm/°C, Wheatstone bridge: 0.01V/ohm, amplifier gain: 100V/V, and pen recorder: 0.1cm/V.

Determine:
1. the overall system sensitivity
2. temperature change corresponding to a recorder pen movement of 4cm
Range, Span

Range of a variable is a numerical statement of the minimum and maximum values that the variable can assume. A DC voltmeter: 0V-30V, mA-meter: 4mA-20mA

Span is the numerical difference between two range values. DC voltmeter: 30V-0V = 30V, mA-meter: 20mA-4mA = 16mA

Scale Factor is derived by taking the span of variable being measured and dividing it by the span of converted value.

Accuracy and Precision

- Accuracy is normally stated in terms of errors introduced, where

$$\text{error (\%)} = \frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\%$$

The error as a percentage of the measuring range of the equipment:

$$\text{error (\%)} = \frac{\text{indicated value} - \text{true value}}{\text{max scale value}} \times 100\%$$

Examples of Error

A 0-10bar pressure gauge: error of +/- 0.15bars when calibrated by manufacturer.

(a) Percentage error of the gauge:

$$\text{Error (\%)} = \frac{0.15\text{bars}}{10\text{bars}} \times 100\% = \pm 1.5\%$$

(b) Possible error when reading of 2.0bars:

$$\text{Error (\%)} \text{ at 2.0bars} = \frac{0.15\text{bars}}{2.0\text{bars}} \times 100\% = 7.5\%$$
Example

A 0-100°C thermometer is found to have a constant error of +0.2°C. Calculate the percentage error at readings of
(a) 10°C,
(b) 50°C and
(c) 100°C

Sources of Error

Incorrect observation, incorrect position or graduation of scale… significant sources of error which combine to affect adversely the accuracy of measurements:
- Friction, backlash, & inertia (mechanic)
- Hydraulic friction, leakage, & inertia (hydraulic)
- Heat loss through imperfect insulation and imperfect thermal conductivity
- Distributed pneumatic capacitance & resistance
- Offset, drift, effects of distributed resistance, conductance, & capacitance, etc.

Illustration of difference between accuracy and precision

[Diagram showing accuracy and precision with different symbols for high accuracy (H.A.), handprinted (H.P.), low accuracy (L.A.), and low printed (L.P.).]
Possible and Probable Errors

Maximum possible error:
Maximum possible error = \( \pm (a + b + c)\% \)

Probable error:
Root-sum-square error = \( \pm \sqrt{a^2 + b^2 + c^2}\% \)

Example: \( \pm 2\% \pm 3\% \pm 5\% \)

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Linearity

The ratio of the maximum deviation from a linear relationship (ideal) between the input and output to the maximum scale – expressed as percentage of full scale.

\[
\text{Linearity} = \frac{\text{Actual (V)} - \text{Indicated (V)}}{V_{\text{max}}} \times 100\%
\]

Example: Linearity

An ohmmeter used to measure resistance in range of 0 to 200 Ohms gave the maximum deviation of 2.0 Ohms. The linearity is as follows

\[
\text{Linearity(\%)} = \frac{2.0\Omega}{(200 - 0)\Omega} \times 100\% = 1.0(\%)
\]
Other static-performance terms

- **Reproducibility**: A general term applied to the ability of a measuring system or instrument to display the same reading for a given input applied on a number of occasion.
- **Repeatability**: The reproducibility when a constant input is applied repeatedly at short intervals of time under fixed conditions of use.
- **Stability**: The reproducibility when a constant input is applied over long periods of time compared with the time of taking a reading, under fixed conditions of use.

- **Tolerance**: The maximum error.
- **Resolution**: The smallest change of input to an instrument which can be detected with certainty, expressed as a percentage of full scale.
- **Dead-band**: The largest change of input to which the system does not respond due to friction or backlash effects, expressed as a percentage of full scale.
- **Hysteresis**: The maximum difference between readings for the same input when approached from opposite directions, i.e. when increasing and decreasing the input, expressed as a percentage of full scale.
- **Constancy**: The reproducibility when a constant input is presented continuously and the conditions of test are allowed to vary within specified limits, due to some external effect such as a temperature variation.

Standards and Calibration

**Standards**:
- Requirement for more accurate measurements has evolved as human beings have developed more complex and sophisticated technologies.
- Standards help to make devices manufactured in different places compatible to each other.
- It is important to understand the need for calibration and adjustment of test and production equipment.
- Australian Standards Organization in Sydney, NSW.

**Calibration**:  
- Calibration is the process of adjusting test and production equipment to conform to standards, and verifying (certifying) their compliance to those standards.
- Calibration methods and period are often instructed by manufacturer of the equipment.
Classification of MSs

Types of signal: analogue, digital and hybrid (combination of analogue and digital)

Types of physical processes: mechanical, hydraulic, pneumatic, electrical and electronic (microprocessor/computer based)

Trend shows an increase of electronic and computer-based measuring equipment because of rapid speed of response, ease with electrical signals, digital and graphical visualization, and reliability and programmability

Dynamic Performance

The dynamic performance of both measuring and control systems is extremely important and is specified by responses to certain standard test inputs.

- **Step input**: which takes the form of an abrupt change from one steady value to another. This indicates how well the system can cope with the change and results in the transient response.
- **Ramp input**: which varies linearly with time and gives the ramp response, indicating the steady-state error in following the input.
- **Sine-wave input**: which gives the frequency response or harmonic response of the system. This shows how the system can respond to inputs of a cyclic nature as the frequency $f$ (Hz) or $\omega$ (rad/s, $\omega=2\pi f$) varies.

All systems will to some extent fail to follow exactly a changing input; and a measure of how well a system will respond is indicated by its dynamic specifications (step or transient parameters or frequency-response parameters)

Many systems, although different in nature, produce identical forms of response – the system dynamics are similar
Test Input Signals

It is necessary for the designer to test the performance of a measuring or control system using test input signals.

**Test Inputs:** Typical test inputs: step, ramp and sine wave

Zero-Order System

- Zero-order measuring system
  
  \[ y = Ku \]

- Step input – *step response*
- Ramp input – *ramp response*
- Sine wave input – *frequency response*

Examples of zero-order measuring systems

- Potentiometer (output voltage proportional to the displacement of the wiper)
- The zero-order measuring system has an important property: that the output is proportional to the input no matter how the input varies – *ideal measuring system.*
First-order Systems

- First-order measuring system (standard form)
  \[ \frac{\tau}{dt} + y = Ku \]
  \[ H = \frac{K}{\tau s + 1} \]

  \( \tau \): time constant
  \( K \): static sensitivity

- Step input, ramp input and sine wave input

Examples of first-order measuring systems

- Mercury-in-glass thermometer, build-up of air pressure in a resistor/bellows system, a series resistance-capacitance network, etc.

Example

- Mercury-in-glass thermometer, where the heat conduction through the glass bulb to the mercury is described by a first-order differential equation:
  \[ 4 \frac{dy}{dt} + 2y = 2 \times 10^{-3} u \]
  \[ 2 \frac{dy}{dt} + y = 10^{-3} u \]
  \( T = 2 \text{sec} \)
  \( K = 10^{-3} \text{m/°C} \)
Example
Determine the time constant and the static sensitivity of the systems
a) \[
\frac{dy}{dt} + 3y = 1.5 \times 10^{-5} u
\]
for a thermocouple in a protective sheath, where \( y \) = output voltage in V and \( u \) = input temperature in °C.
b) \[
1.4 \frac{dy}{dt} + 4.2y = 9.6u
\]
for a resistor/bellows system, \( y \) = bellows displacement in mm, and \( u \) = input pressure in bars

Second-order System
- Second order measuring system
\[
\frac{d^2y}{dt^2} + 2\xi \omega_n \frac{dy}{dt} + \omega_n^2 y = ku
\]
\[
y(s) = \frac{K}{u(s) (1/\omega_n^2)s^2 + (2\xi/\omega_n)s + 1}
\]
\( \xi \) is a measure of the damping present in a system and is equal to the ratio of actual damping to critical damping
\( \omega_n \) is a measure of the speed of response of the second-order system – higher values of \( \omega_n \) would mean that the system would respond more rapidly to sudden changes

Example of 2nd-order system
- The dynamic performance of a piezo-electric accelerometer can be described by the following differential equation:
\[
\frac{d^2y}{dt^2} + 3.0 \times 10^5 \frac{dy}{dt} + 2.25 \times 10^{10} y = 11.0 \times 10^{10} u
\]
where \( y \) = output charge in pC, and \( u \) = input acceleration m/s².
By comparison with the standard equation, determine the values of \( \omega_n \), \( \xi \) and the static sensitivity \( K \).
(ans: 1.5 \times 10^5, 0.01, 4.89pC/(m/s²))
Second-order System

\( \xi < 1 \): The system is said to be underdamped and results in oscillations occurring in the step response and (for values of \( \xi < 0.707 \)) resonance effects in the frequency response.

\( \xi = 1 \): This is the critically damped condition: ie no oscillations or overshoots appear in the step response and there is no resonance in the frequency response. This is the point of change-over from an underdamped condition to an overdamped condition.

\( \xi > 1 \): The system is overdamped in the step response and no resonance in the frequency response.

Examples of second-order measuring/control system

- Mass-spring system with damping, yaw angle vs rudder system (Nomoto). A large number of devices and mechanisms.
- Simulation in MATLAB/Simulink (illustrates responses with different values of \( \xi \) and \( \omega_n \)).

Example: Step-response Specs
Summary of Lecture 3

- Definition and concepts of instrumentation, needs for instrumentation, ideal measuring system, structure of a measuring system
- Static performance of a measuring system: sensitivity, range, span, scale factor, accuracy and precision, linearity, possible and probable errors, reproducibility, repeatability, stability, constancy, tolerance, resolution, dead-band, hysteresis.
- Standards & calibration
- Classification of measuring systems
- Dynamic Performance: test input signals
- Examples of control systems

Any questions?

Activity 1

1. Define system, process and signal
2. Describe open-loop system.
3. Describe closed-loop system.
4. What is the main difference between OL sys and CL sys?
5. Discuss about advantages and disadvantages.
Activity 1 (continued)
Do exercises at the end of Module 1.

Week 1 (continued)
Tutorial: MATLAB/Simulink
Review of MATLAB