ELEC207 - Instrumentation & Control

Part-A: Instrumentation

Problem Class 4

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Lecture schedule:
Monday 1700-1800 (CHAD-CHAD)
Thursday 1400-1500 (CTH-LTA)

Office Location: Room 513, Electrical Engineering

Lecture covers

- Exam questions:
  - Transient analysis
  - Accelerometer
  - Interference and Noise

Transient Analysis

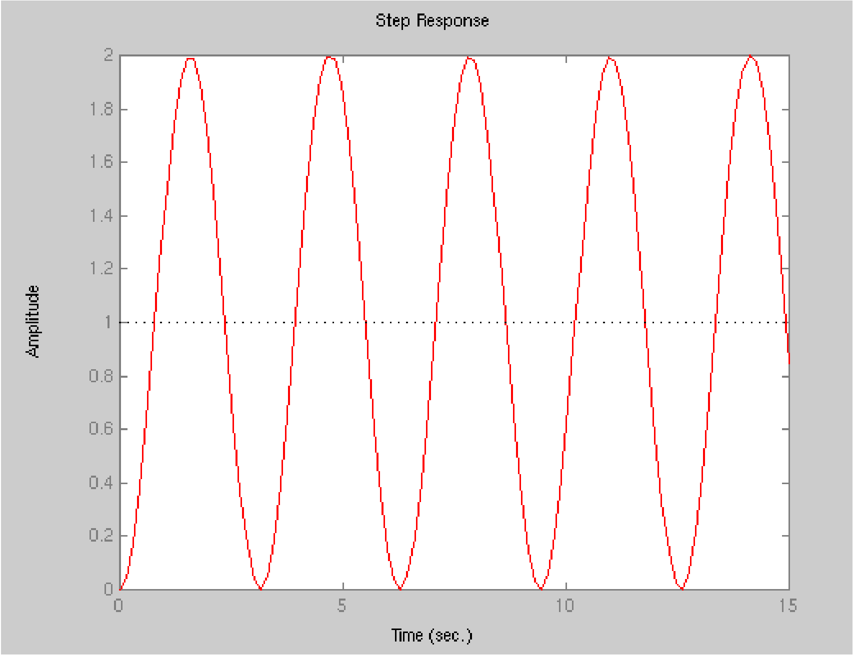
Sketch and briefly describe the step response of a second order system when:

1. $\xi = 0$
2. $\xi < 0$,

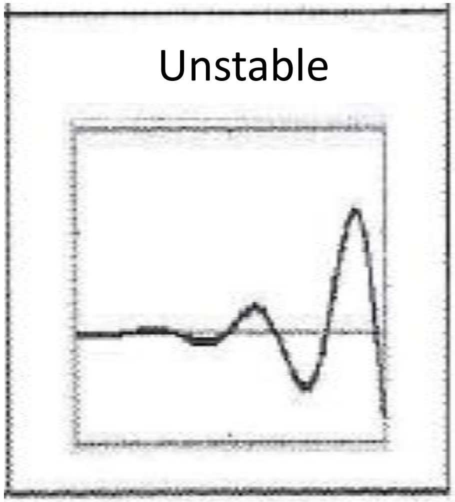
where ξ is the damping ratio of the second order system.

(4 marks)

$\xi = 0$



$\xi < 0$



Accelerometer

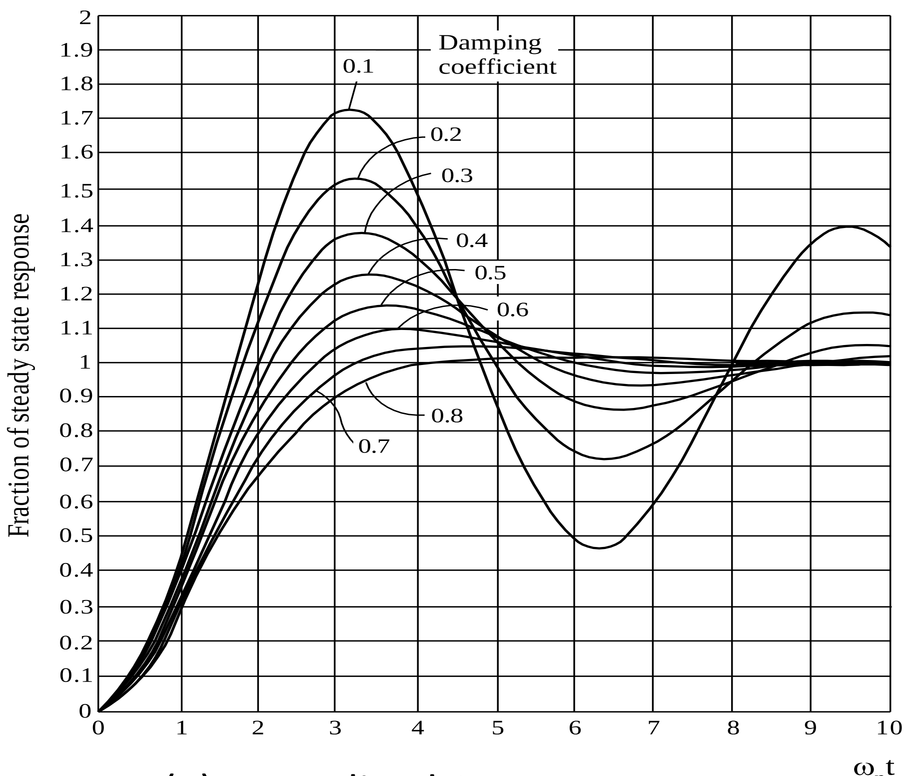
a) Sketch a diagram to show the main internal components of a servo accelerometer. With reference to this diagram, explain how the servo accelerometer is able to produce an electrical output in response to an applied acceleration. **(10 marks)**

b) What are the advantages of the servo accelerometer. **(5 marks)**

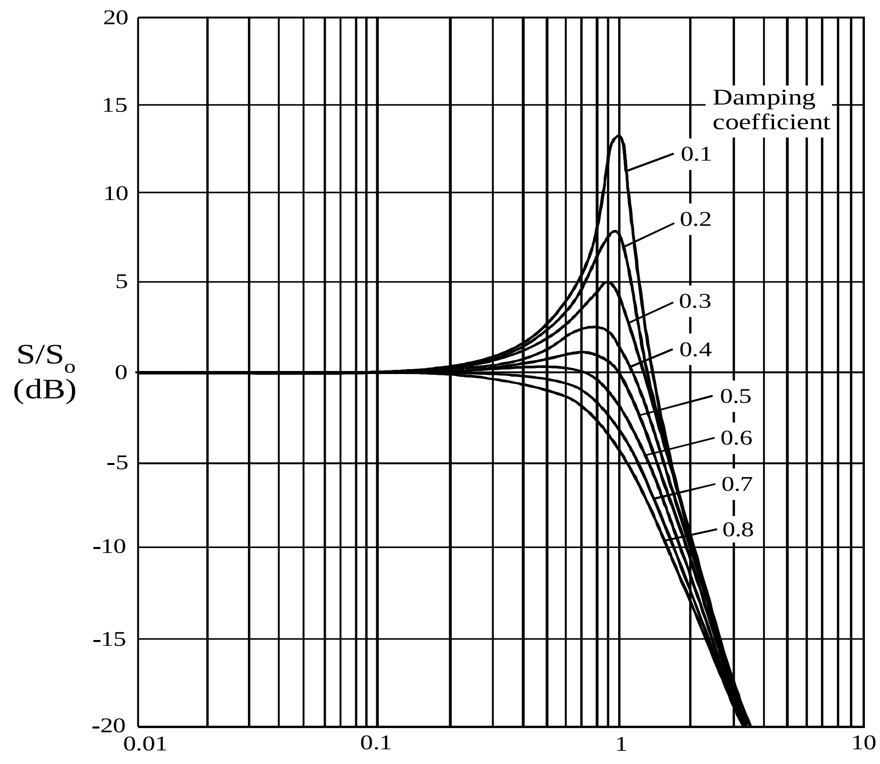
See slides 17-19, Lecture 11

Transient Analysis

Q) A servo accelerometer with natural resonant angular frequency ω_n = 100rad/s, damping coefficient ξ = 0.4 and low frequency sensitivity 3V/g is subject to both sinusoidal and step accelerations. With reference to the normalised dynamic response curves shown in figures (a) and (b), determine:



(a)Normalised Step Response



(b)Normalised Sine Response

Transient Analysis

(i) the *peak-to-peak* output voltage corresponding to an applied sinusoidal acceleration of amplitude 2g and angular frequency 80 rad/s. **(5 marks)**

(ii) the magnitude of the peak output voltage produced during the transient for an applied step acceleration of 5g. **(4 marks)**

(iii) the time taken for the output voltage to reach its first maximum for an applied step acceleration. **(4 marks)**

(iv) the time for the output to settle within 5% of its final value for an applied step acceleration. **(4 marks)**

Transient Analysis

(i) the *peak-to-peak* output voltage corresponding to an **applied sinusoidal acceleration** of amplitude 2g and angular frequency 80 rad/s. **(5 marks)**

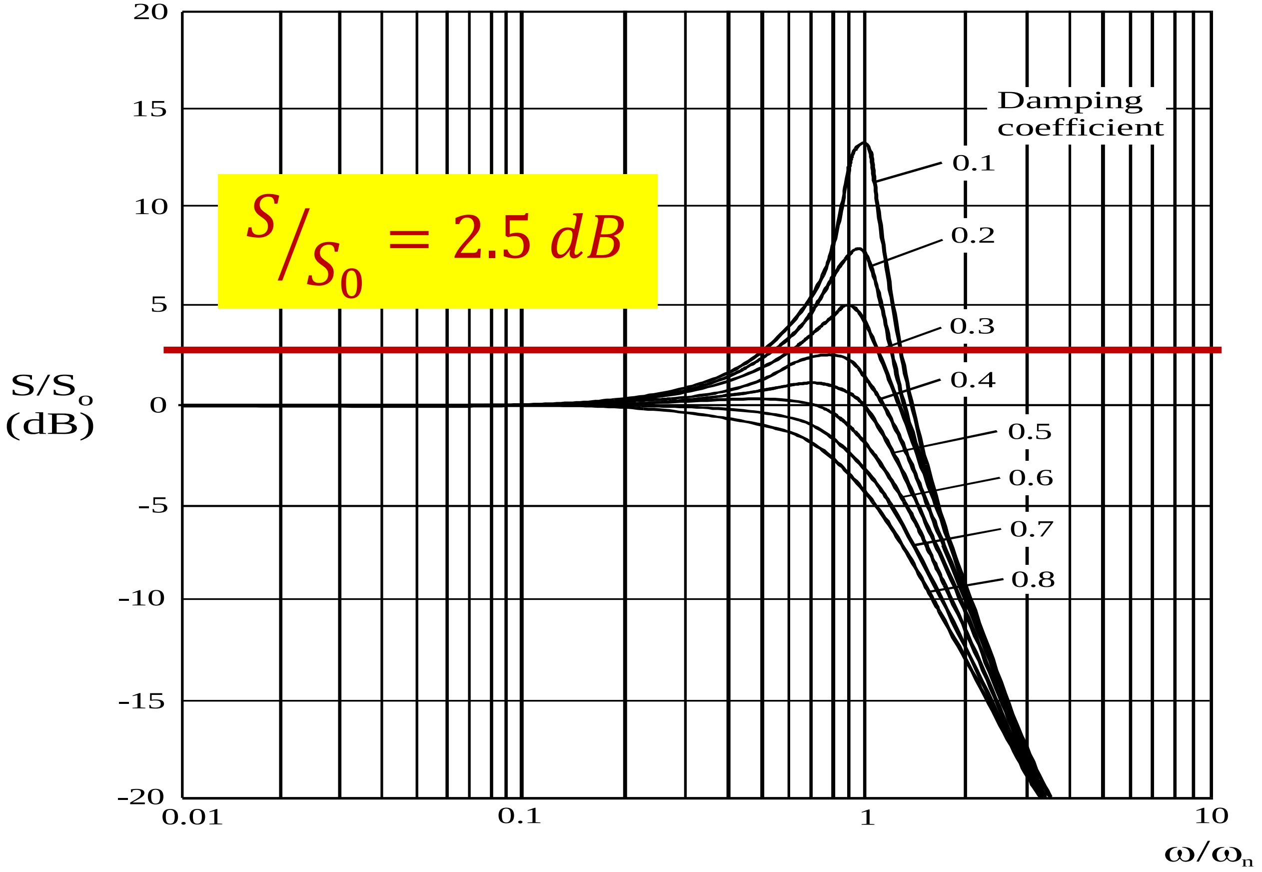
Given: ω_n = 100 rad/s, ξ = 0.4 and S_0 = 3 V/g
ω = 80 rad/s,

Required: $V_{p\text{-}p}$ = ?

<u>(Three step solution)</u>

Solution

I. Find the value of S/S_0 (dB) from the curve corresponding to $\xi=0.4$.



$20 \times \log_{10}(S/S_0) = 2.5$ dB (reading from the graph)

Solution

II. Find the value of S (Do not forget to convert the decibels!)

$20 \times \log_{10}(S/S_0) = 2.5$ dB (reading from the graph)

$$S/S_0 = 10^{2.5/20} = 1.33$$

$$S_0 = 3 \text{ V/g (given)}$$

$$S = 3 * 1.33$$

$$\boxed{S = 3.99\ V/g}$$

Solution

III. Find V_{p-p}

$$\boxed{S = 3.99\, V/g}$$

$$\text{Output voltage} = \text{S} \, * \text{input accelration}$$

$$\text{input accelration} = \text{2g (given)}$$

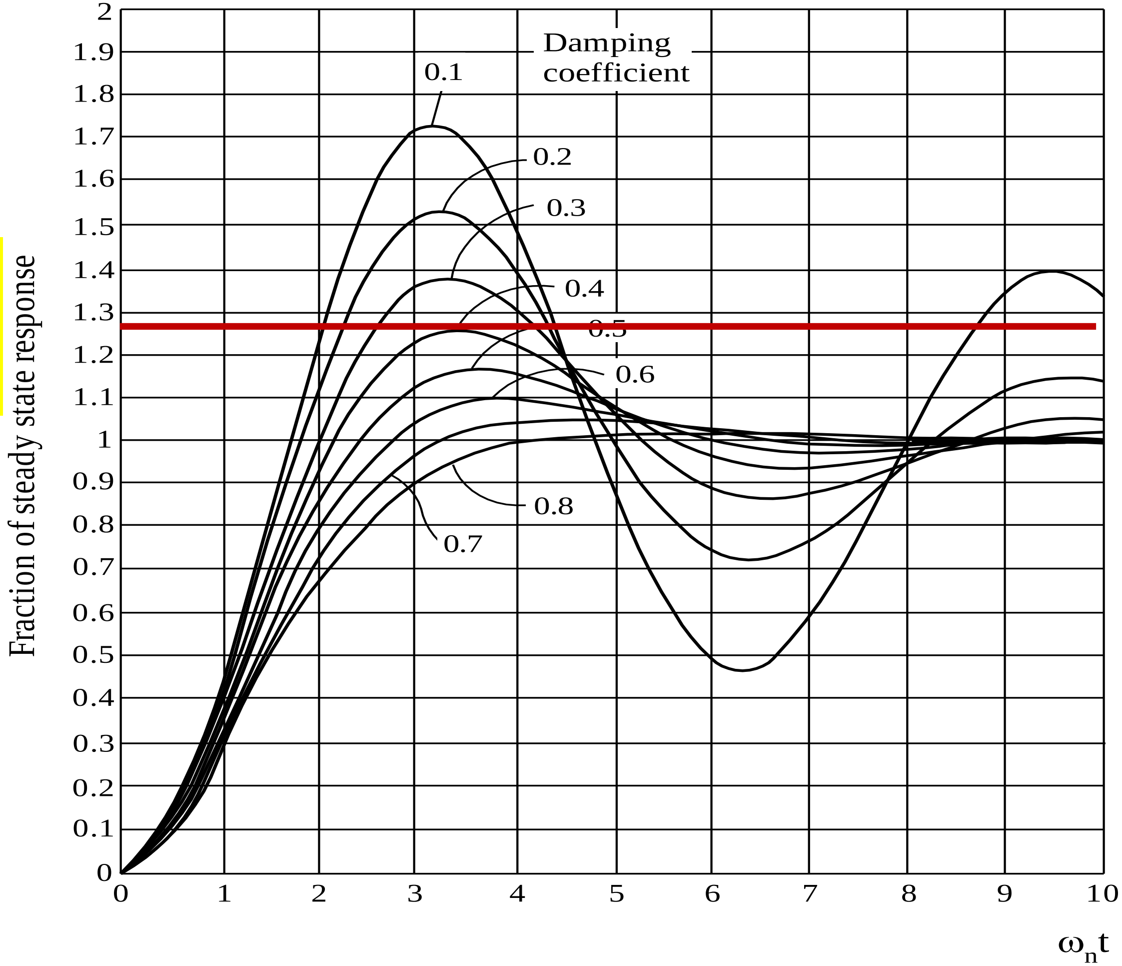
$$\text{Output voltage} = 3.99 \, * 2 = 7.98 \text{ V}$$

$$\boxed{V_{p-p} = 7.98 \, * 2 = 15.96 \text{ V}}$$

Transient Analysis

(ii) the magnitude of the peak output voltage produced during the transient for an applied step acceleration of 5g. **(4 marks)**

$$\frac{S}{S_0} = 1.25$$



Transient Analysis

(ii) the magnitude of the peak output voltage produced during the transient for an applied step acceleration of 5g. **(4 marks)**

$$\frac{\mathrm{S}}{\mathrm{S}_0} = 1.25 \text{ (from graph)}$$

$$S_0 = 3 \text{ V/g (given)}$$

$$\mathrm{S} = 3 \, * \, 1.25$$

$$\boxed{\mathrm{S} = 3.75 \text{ V/g}}$$

$$\text{Output voltage} = \mathrm{S} \, * \text{input acceleration}$$

$$\boxed{\text{Output voltage} = 3.75 \, * 5 = 18.75 \text{ V}}$$

Transient Analysis

(iii) the time taken for the output voltage to reach its first maximum for an applied step acceleration. **(4 marks)**

Slides 17-19, Lecture 10

$$T_p = \frac{\pi}{\omega_n \sqrt{\left(1-\zeta^2\right)}}$$

T_p is the time at which the first oscillation peak occurs.

$$T_p = \frac{\pi}{100\sqrt{\left(1-(0.4)^2\right)}}$$

ω_n = 100 rad/s

$$\boxed{T_p = 34.3\ \text{ms}}$$

Transient Analysis

(iv) the time for the output to settle within 5% of its final value for an applied step acceleration. **(4 marks)**

$$e^{-\zeta.\omega_n t} = 0.05$$

Slides 17-19, Lecture 10

$$e^{-(0.4)(100)t} = 0.05$$

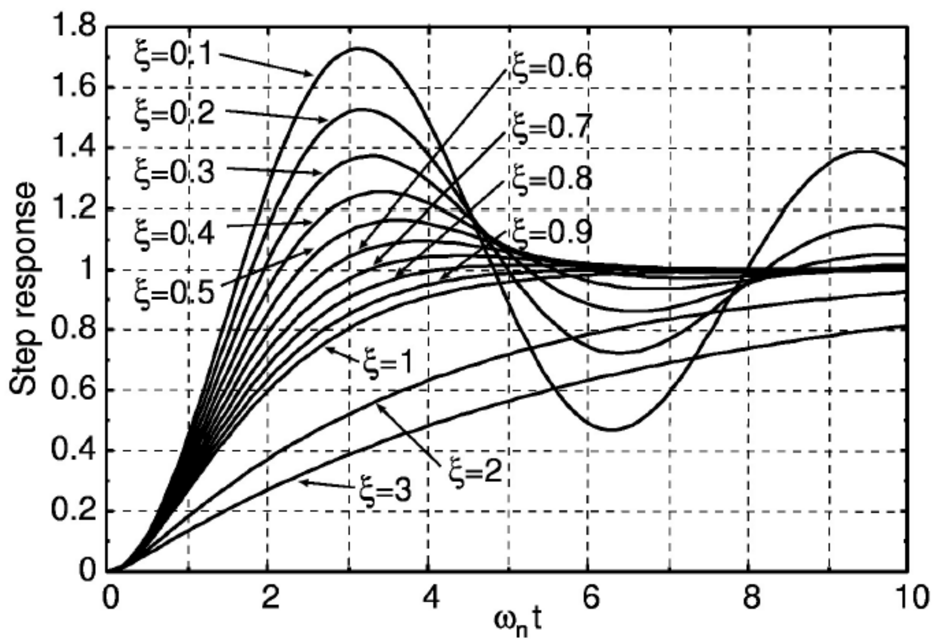
$$-(0.4)(100)t = -2.9957$$

$$t = \frac{2.9957}{40}$$

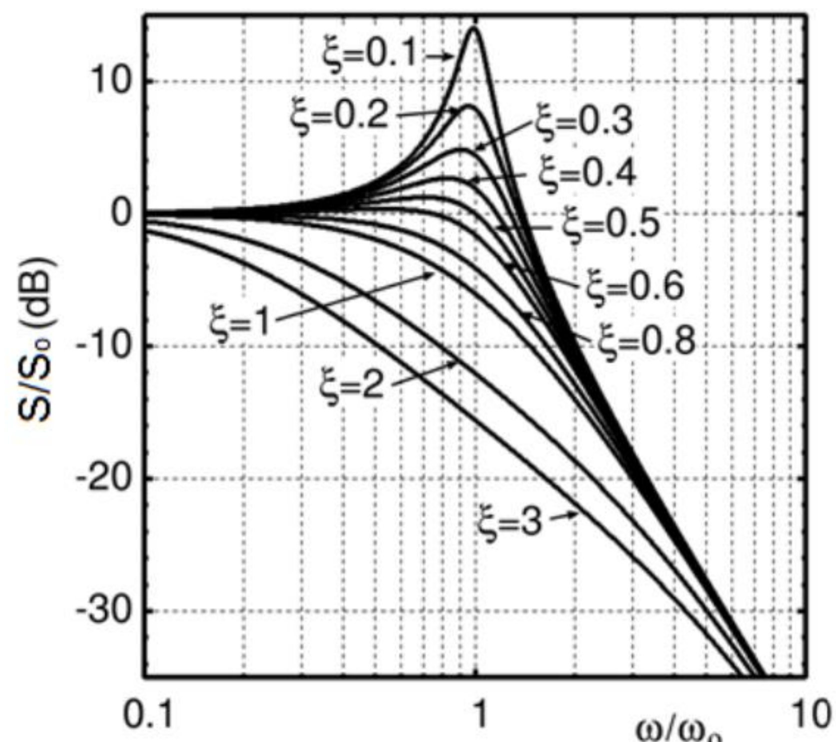
$$\boxed{t = 74.9\,\text{ms}}$$

Transient Analysis

Q) A servo accelerometer with natural resonant angular frequency ω_n = 120 rad/s, damping coefficient ξ = 0.2 and low frequency sensitivity 3 V/g is subject to both sinusoidal and step accelerations. With reference to the normalised dynamic response curves shown in figures (a) and (b), determine:



(a) Normalised Step Response



(b) Normalised sinusoidal response

Transient Analysis

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(i) the *peak-to-peak* output voltage corresponding to an applied **sinusoidal acceleration** of amplitude 2 g and angular frequency 108 rad/s. **(3 marks)**

(ii) the magnitude of the peak output voltage produced during the transient for an applied **step acceleration** of 7g. **(3 marks)**

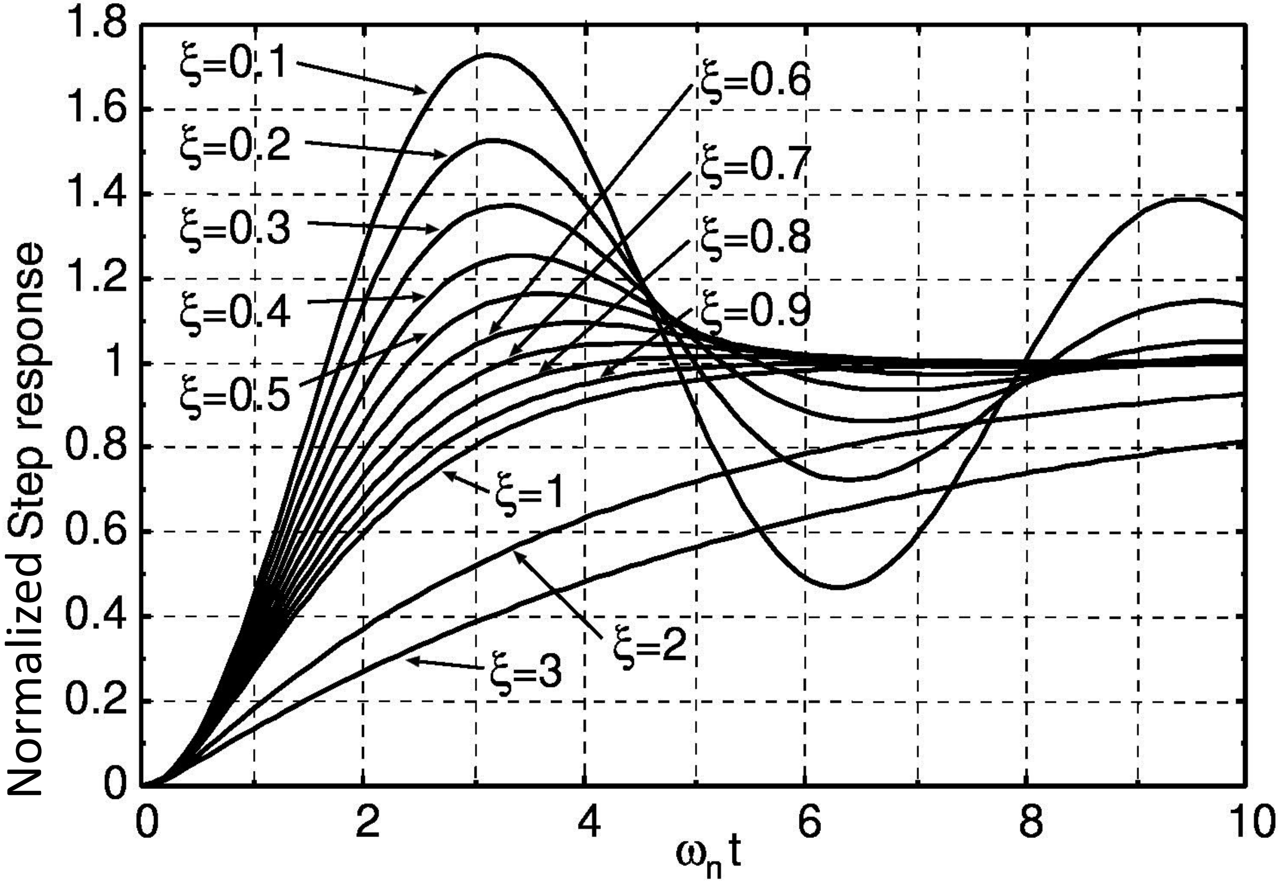
(iii) the time taken for the output voltage to reach its first maximum for an applied **step acceleration**. **(3 marks)**

Accelerometer

Q. During a test measurement, a **step acceleration** of 10 g was applied to a servo accelerometer. A damped oscillatory output was observed during which the output voltage of the accelerometer reached a peak voltage of 19 V at the first overshoot, occurring 8 ms after the application of the step. The output voltage eventually settled to 15 V.

With reference to the normalised step response curves shown in Figure (next slide), <u>determine the low frequency sensitivity</u> (in V/g), <u>the natural resonance frequency (in Hz) and the damping coefficient of the accelerometer.</u>

Accelerometer



Accelerometer

- Given:
  - Step acceleration = 10 g
  - Steady state voltage (V_S) = 15 V
  - Peak output voltage (V_P) = 19 V
  - Time of first oscillation peak (T_P) = 8 ms
- Find:
  - Steady state sensitivity (S_0) (Low frequency sensitivity)
  - Natural resonance frequency (f_n)
  - Damping coefficient (ξ)

Accelerometer

- Steady state sensitivity (S_0) (Low frequency sensitivity)

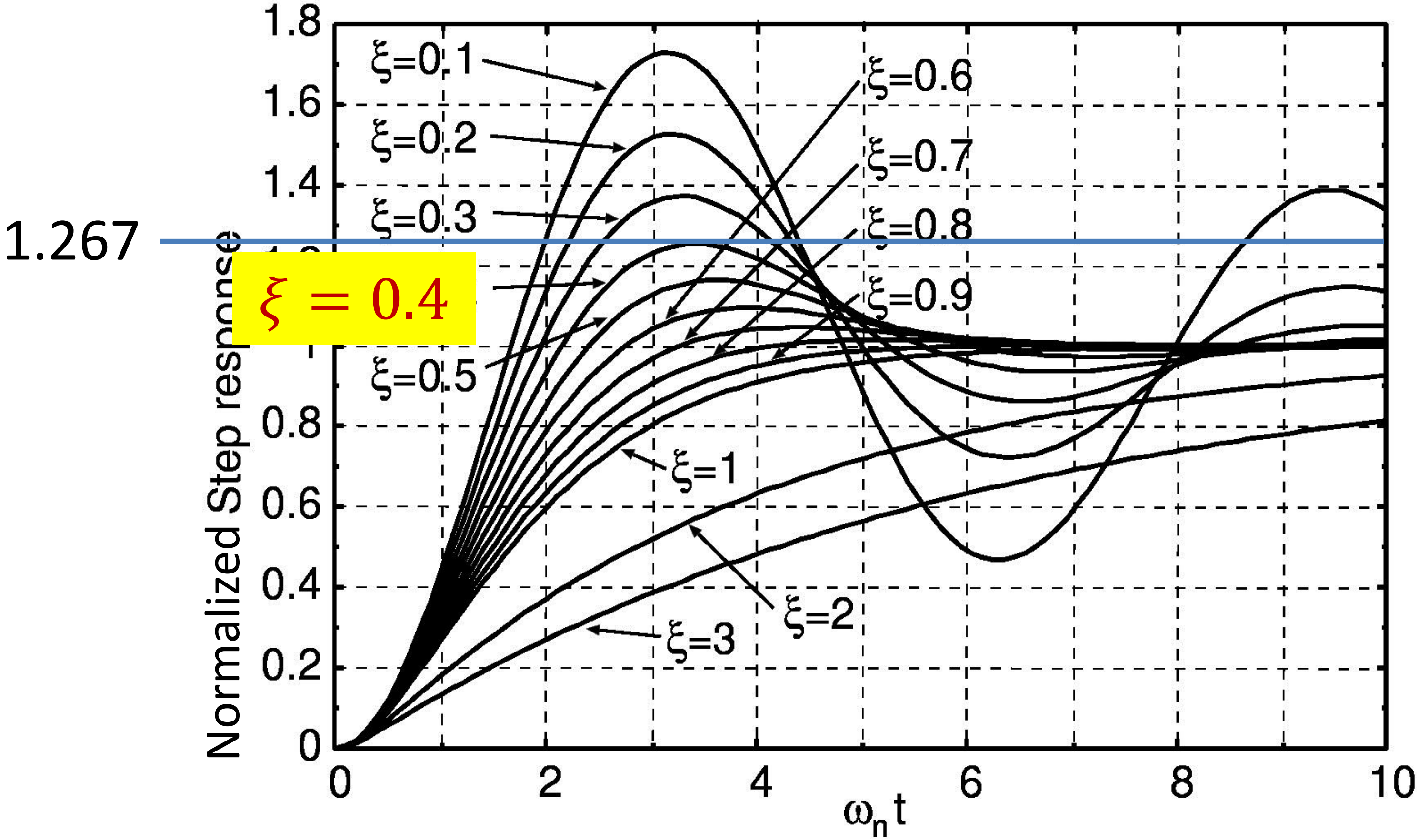
$$S_0 = \frac{steady\ state\ voltage\ (V_s)}{acceleration}$$

$$S_0 = \frac{15}{10} = 1.5\frac{V}{g}$$

- Damping ratio (ξ)
  - $\frac{S}{S_0} = \frac{V_P}{V_S} = \frac{19}{15} = 1.267$
  - From graph, find a curve with first peak at "1.267"

Accelerometer

From graph, find a curve with first peak at “1.267”



Accelerometer

- Natural resonance frequency (f_n) = ?

Slides 17-19, Lecture 10

$$T_p = \frac{\pi}{\omega_n \sqrt{(1-\zeta^2)}}$$

T_p is the time at which the first oscillation peak occurs.

$$T_p = \frac{\pi}{2\pi f_n \sqrt{(1-\zeta^2)}}$$

$$f_n = \frac{\cancel{\pi}}{2\cancel{\pi} T_p \sqrt{(1-\zeta^2)}}$$

$$f_n = \frac{1}{2(0.008)\sqrt{(1-0.4^2)}}$$

$$\boxed{f_n = 68.19 Hz}$$

Interference and Noise

a) Briefly describe the following two sources of noise in instrumentation systems: electrostatic and electromagnetic coupling. Use diagrams for illustration.

b) Describe noise prevention methods to minimize the influence of noise due to electromagnetic (electrostatic) coupling. Use diagrams for illustration.

Electrostatic coupling: Slides 5-8 of Lecture 12

Electromagnetic coupling: Slides 11-13 of Lecture 12

Summary

Topics covered:

- ✓ Exam questions:
  - ✓ Transient analysis
  - ✓ Accelerometer
  - ✓ Interference and Noise

Next Lecture:

- Revision class in semester 2 (TBA by Prof S. Maskell)