CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF INDUSTRIAL TECHNOLOGY

SPECIAL EXAMINATION
JANUARY 2016 SEMESTER

COURSE CODE	:	JCB 30703
COURSE TITLE	:	AUTOMATIC CONTROL SYSTEM
PROGRAMME LEVEL	:	BACHELOR
DATE	:	26 MAY 2016
TIME	:	9.00 AM – 12.00 PM
DURATION	:	3 HOURS

INSTRUCTIONS TO CANDIDATES

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1. Please read the instructions given in the question paper CAREFULLY.
2. This question paper is printed on both sides of the paper.
3. This question paper consists of TWO (2) sections. Section A and B.
4. Answer ALL questions in Section A. Choose ONE (1) questions in Section B.
5. Please write your answers on the answer booklet provided.
6. Appendices are enclosed as reference.
7. Please answer all questions in the English language only.

THERE ARE 14 PAGES OF QUESTIONS EXCLUDING THIS PAGE.

SECTION A (TOTAL: 50 marks)

INSTRUCTION: Answer ALL questions in Section A.
Please use the answer booklet provided.

Question 1

(a) An automatic Kinect servo bracket, used to track the human's palm. The output shaft, driven by the motor through a worm reduction gear, has a bracket attached on which are mounted two RGB cameras. Identify an appropriate block diagram of control system so that the system follows the palm movement.

(3 marks)

(b) The accurate control of a satellite position is important for monitoring illegal logging activities. Assuming the number of mechanical gears present is proportional to the turning angle, an odometric unit is used to measure the turn in degree. The current, $i(t)$, is proportional to the turn in degree. Complete the control system of the satellite and identify an appropriate block diagram describing the operation of the feedback control loop.

(3 marks)

(c) In a food and edible process control system, it is valuable to control the edible chemical compound of the food. To do so, a measurement of the compound can be obtained by using an mass spectrometer. The valve on the additive stream may be controlled. Identify an appropriate block diagram describing the operation of the control loop.

(2 marks)

(d) Increasing number of modern car have sensors that able regulate air-purifying systems for the health of the passengers. Identify an appropriate block diagram of an air-purifying system where the sensor automatically sets the interior air-quality and display on a dashboard panel. Identify the function of each element of the sensor fusion controlled air quality system.

(2 marks)

Question 2

An s-domain frequency response function transfer function is given as follows,

$$G(s) = \frac{K}{5000\left(\frac{s}{5}+1\right)\left(\frac{s}{20}+1\right)\left(\frac{s}{50}+1\right)}$$

(a) Using Bode plot methods, illustrate the asymptotic approximation for log-magnitude and phase plots.

(14 marks)

(b) Identify the range of K for stability.

(3 marks)

(c) Using asymptotic approximation technique, identify gain margin, phase margin, zero dB frequency, and $180°$ frequency from your Bode plot for $K = 10^3$.

(8 marks)

Question 3

A block diagram for a feedback control system is shown Figure 1.

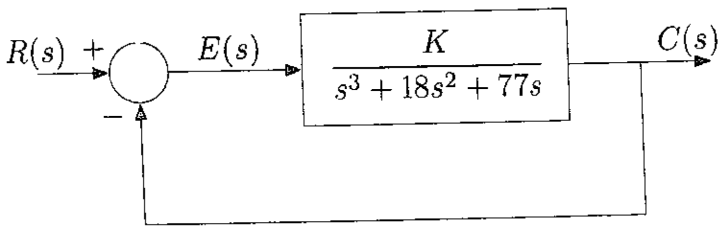


Figure 1: Feedback control system.

(a) Identify the closed-loop transfer function for Figure 1.

(3 marks)

(b) Construct the Routh table for closed-loop transfer function of Figure 1.

(3 marks)

(c) Solve the range of K for the closed-loop transfer function of Figure 1 that cause the system to be stable, unstable, and marginally stable. Assume $K > 0$.

(9 marks)

SECTION B (TOTAL: 25 marks)

INSTRUCTION: Answer ONE (1) question in Section B.
Please use the answer booklet provided.

Question 1

As a control system engineer at Hoover Dam, you have been assigned to develop a system that able to regulate the sluice gate opening based on reservoir level and downstream level measurement. Within this development, a fuzzy system has been chosen as the control tool to determine the desired status of the sluice gate control system which then reflect the desired turbine's speed that have been installed to generate electricity.

For this Fuzzy-based sluice gate control system, the inputs are:

$$X\,1 = \text{reservoir level} = \text{low, medium, high, ranging from 0 to 14 kilometer}$$
$$X\,2 = \text{downstream level measurement} = \text{low, medium, high, ranging from 0 to 30 meter}$$

Figure 2, Figure 3 and Figure 4 describe the membership function of reservoir level, downstream level and turbine's speed accordingly. The Fuzzy set rules are given by:

- If reservoir level is LOW and downstream level is LOW, then turbine's speed VERY LOW
- If reservoir level is LOW and downstream level is MEDIUM, then turbine's speed LOW
- If reservoir level is LOW and downstream level is HIGH, then turbine's speed MEDIUM
- If reservoir level is MEDIUM and downstream level is LOW, then turbine's speed VERY LOW
- If reservoir level is MEDIUM and downstream level is MEDIUM, then turbine's speed MEDIUM
- If reservoir level is MEDIUM and downstream level is HIGH, then turbine's speed HIGH

- If reservoir level is HIGH and downstream level is LOW, then turbine's speed MEDIUM
- If reservoir level is HIGH and downstream level is MEDIUM, then turbine's speed HIGH
- If reservoir level is HIGH and downstream level is HIGH, then turbine's speed VERY HIGH

(a) Construct the matrix representation of fuzzy rules.

(2 marks)

(b) On a Cartesian plot, generate a relevant membership area and the output for every rules, when

X1 (reservoir level) = 6 kilometer

X2 (downstream level) = 16 meter

(18 marks)

(c) Suggest the membership value which represent the water pressure for,

X1 (reservoir level) = 6 kilometer

X2 (downstream level) = 16 meter

(5 marks)

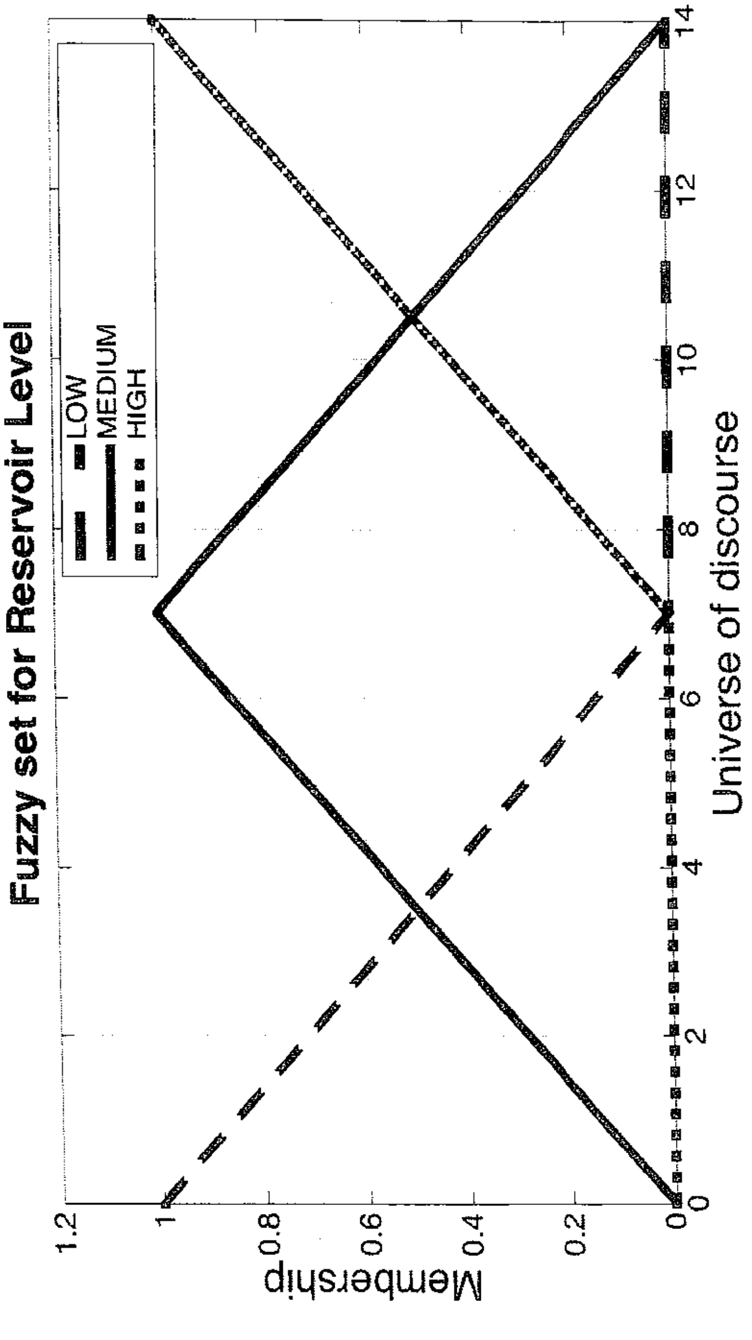


Figure 2: Reservoir level.

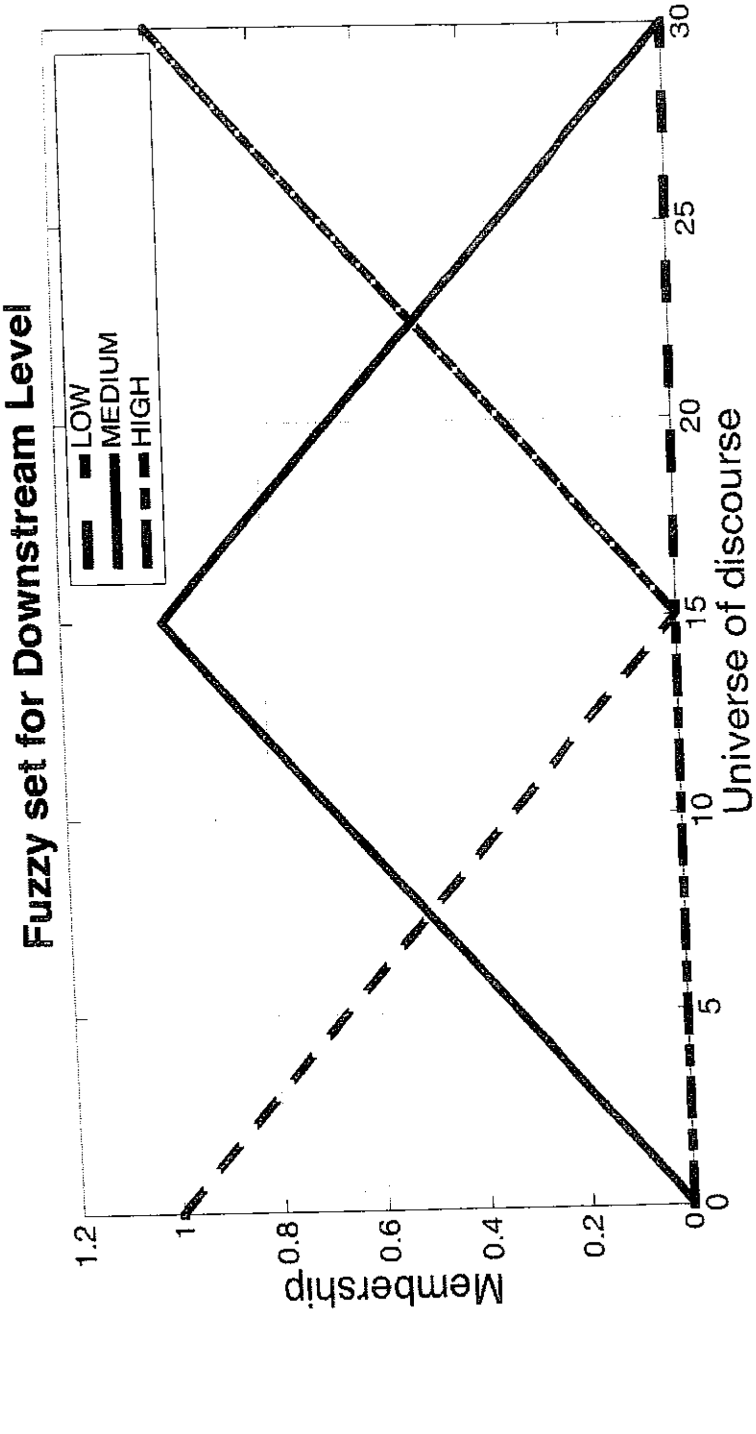


Figure 3: Downstream level.

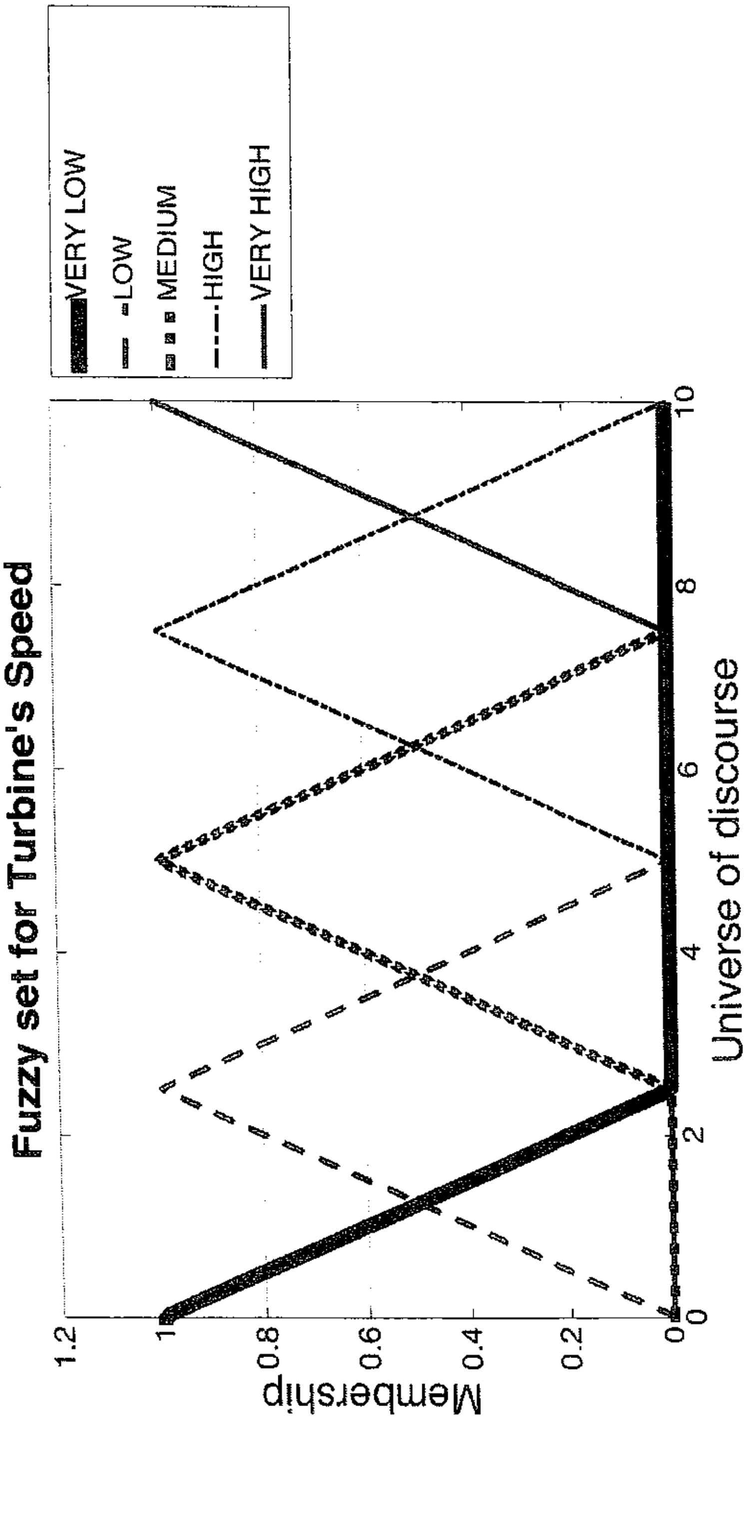
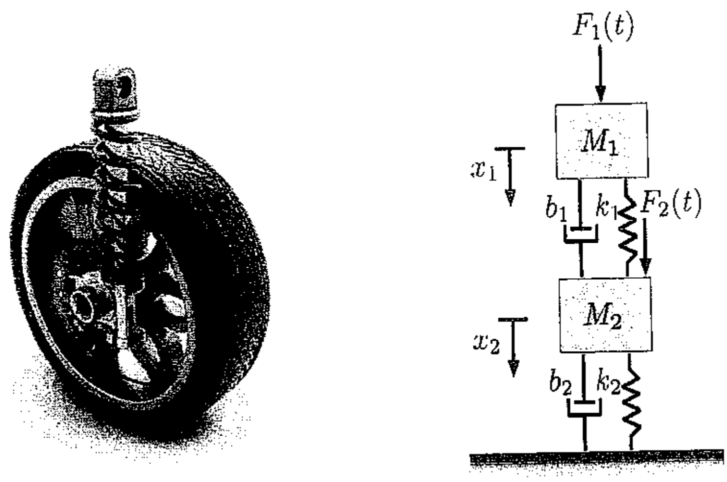


Figure 4: Turbine's speed.

Question 2



(a) Actual. (b) Modeling.

Figure 5: Automotive suspension system.

A simplified automotive suspension system in Figure 5a can be represented as a mass, spring and damper system as shown in Figure 5b. The motion of two masses M_1 (body weight) and M_2 (tyre weight) that are subjected to externally applied forces $F_1(t)$ and $F_2(t)$ is constrained by two springs and two dampers in the system. The spring and constants are k_1, k_2, b_1 and b_2 respectively. The symbols x_1 and x_2 are used to represent the displacement of M_1 and M_2.

(a) With aid of free-body-diagrams, determine the expressions for spring and damper forces acting on the masses M_1 and M_2.

(9 marks)

(b) Using mathematical derivation, determine the expressions of the equations of motion of the two masses M_1 and M_2.

(8 marks)

(c) By applying the Laplace transformation to the equation of motion, determine that the Laplace transforms of the system output $X_1(s)$ and $X_2(s)$ are given by equations (1) and (2):

(6 marks)

$$X_1(s) = \frac{F_1(s) + X_2(s)[sb_1 + k_1]}{M_1 s^2 + sb_1 + k_1} \quad (1)$$

$$X_2(s) = \frac{F_2(s) + X_1(s)[sb_1 + k_1]}{M_2 s^2 + s[b_1 + b_2] + k_1 + k_2} \quad (2)$$

(d) Discuss any necessary conditions that have to be satisfied for the above expression for $X_1(s)$ and $X_2(s)$ to be correct.

(2 marks)

END OF EXAMINATION PAPER

Time Response:

Underdamped Second Order Systems

Settling Time (within 2% of steady state value	$T_s = \frac{4}{\zeta w_n}$
Peak Time	$T_p = \frac{\pi}{w_d}$
Damped Frequency	$w_d = w_n\sqrt{1-\zeta^2}$
Damping Ratio	$\zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}}$
Closed-Loop Transfer Function	$G(s) = \frac{w_n^2}{s^2 + 2\zeta w_n s + w_n^2}$
Percent overshoot, %OS	$e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}} \times 100\%$

Frequency Response:

Closed-Loop Bandwidth	$w_{BW} = \frac{4}{T_s\zeta}\sqrt{(1-2\zeta^2)+\sqrt{4\zeta^4-4\zeta^2+2}}$ $= \frac{\pi}{T_p\sqrt{1-\zeta^2}}\sqrt{(1-2\zeta^2)+\sqrt{4\zeta^4-4\zeta^2+2}}$ $= w_n\sqrt{(1-2\zeta^2)+\sqrt{4\zeta^4-4\zeta^2+2}}$
Phase Margin	$\phi_m = \tan^{-1}\frac{2\zeta}{\sqrt{-2\zeta^2+\sqrt{1+4\zeta^4}}}$
Maximum Phase Shift of Compensator	$\phi_{max} = \sin^{-1}\left(\frac{1-\beta}{1+\beta}\right)$
Magnitude at w_{max}	$M_{max} = \frac{1}{\sqrt{\beta}}$

The State Model

For linear time-invariant system:
$$\dot{X} = AX(t) + BU(t)$$
$$Y(t) = CX(t) + DU(t)$$

where $A \in \Re^{n \times n}$, $B \in \Re^{n \times n_i}$, $C \in \Re^{n_o \times n}$, $D \in \Re^{n \times n_i}$.

The solution $X(t)$	$e^{At}X(0) + \int_0^t e^{A(t-\tau)}Bu(\tau)d\tau$
The matrix exponential e^{At}	$e^{At} = I + \frac{At}{1!} + \frac{A^2t^2}{2!} + \cdots$ $e^{At} = \mathcal{L}^{-1}((sI - A)^{-1})$
Eigenvalues	$\det(\lambda I - A) = 0$
Transfer function	$G(s) = \frac{Y(s)}{U(s)} = C(sI - A)^{-1}B + D$
Controllability matrix	$C = [B \quad AB \quad A^2B \quad \cdots \quad A^{n-1}B]$
Observability matrix	$O = [C \quad CA \quad CA^2 \quad \cdots \quad CA^{n-1}]^T$
Ackermann's formula	Controller: $K = [0 \quad 0 \quad \cdots \quad 0 \quad 1][B \quad AB \quad \cdots \quad A^{n-2}B \quad A^{n-1}B]^{-1}\alpha_c(A)$ Estimator: $G = \alpha_e(A)([C \quad CA \quad \cdots \quad CA^{n-1}]^T)^{-1}[0 \quad 0 \quad \cdots \quad 0 \quad 1]^T$

Table 13.1 Partial table of z- and s-transforms

	$f(t)$	$F(s)$	$F(z)$	$f(kT)$
1.	$u(t)$	$\frac{1}{s}$	$\frac{z}{z-1}$	$u(kT)$
2.	t	$\frac{1}{s^2}$	$\frac{Tz}{(z-1)^2}$	kT
3.	t^n	$\frac{n!}{s^{n+1}}$	$\lim_{a\to 0}(-1)^n \frac{d^n}{da^n}\left[\frac{z}{z-e^{-aT}}\right]$	$(kT)^n$
4.	e^{-at}	$\frac{1}{s+a}$	$\frac{z}{z-e^{-aT}}$	e^{-akT}
5.	$t^n e^{-at}$	$\frac{n!}{(s+a)^{n+1}}$	$(-1)^n \frac{d^n}{da^n}\left[\frac{z}{z-e^{-aT}}\right]$	$(kT)^n e^{-akT}$
6.	$\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$	$\frac{z \sin \omega T}{z^2 - 2z\cos \omega T + 1}$	$\sin \omega kT$
7.	$\cos \omega t$	$\frac{s}{s^2+\omega^2}$	$\frac{z(z-\cos \omega T)}{z^2 - 2z\cos \omega T + 1}$	$\cos \omega kT$
8.	$e^{-at}\sin \omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$	$\frac{ze^{-aT}\sin \omega T}{z^2 - 2ze^{-aT}\cos \omega T + e^{-2aT}}$	$e^{-akT}\sin \omega kT$
9.	$e^{-at}\cos \omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$	$\frac{z^2 - ze^{-aT}\cos \omega T}{z^2 - 2ze^{-aT}\cos \omega T + e^{-2aT}}$	$e^{-akT}\cos \omega kT$

Laplace Transform $F(s)$	Time Function $f(t)$
1	Unit-impulse function $\delta(t)$
$\frac{1}{s}$	Unit-step function $u_s(t)$
$\frac{1}{s^2}$	Unit-ramp function t
$\frac{n!}{s^{n+1}}$	$t^n (n = \text{positive integer})$
$\frac{1}{s+\alpha}$	$e^{-\alpha t}$
$\frac{1}{(s+\alpha)^2}$	$te^{-\alpha t}$
$\frac{n!}{(s+\alpha)^{n+1}}$	$t^n e^{-\alpha t} (n = \text{positive integer})$
$\frac{1}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(e^{-\alpha t} - e^{-\beta t})(\alpha \neq \beta)$
$\frac{s}{(s+\alpha)(s+\beta)}$	$\frac{1}{\beta-\alpha}(\beta e^{-\beta t} - \alpha e^{-\alpha t})(\alpha \neq \beta)$
$\frac{1}{s(s+\alpha)}$	$\frac{1}{\alpha}(1 - e^{-\alpha t})$
$\frac{1}{s(s+\alpha)^2}$	$\frac{1}{\alpha^2}(1 - e^{-\alpha t} - \alpha t e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)}$	$\frac{1}{\alpha^2}(\alpha t - 1 + e^{-\alpha t})$
$\frac{1}{s^2(s+\alpha)^2}$	$\frac{1}{\alpha^2}\left[t - \frac{2}{\alpha} + \left(t + \frac{2}{\alpha}\right)e^{-\alpha t}\right]$
$\frac{s}{(s+\alpha)^2}$	$(1 - \alpha t)e^{-\alpha t}$

Laplace Transform $F(s)$	Time Function $f(t)$
$\frac{\omega_n}{s^2+\omega_n^2}$	$\sin \omega_n t$
$\frac{s}{s^2+\omega_n^2}$	$\cos \omega_n t$
$\frac{\omega_n^2}{s(s^2+\omega_n^2)}$	$1-\cos \omega_n t$
$\frac{\omega_n^2(s+\alpha)}{s^2+\omega_n^2}$	$\omega_n\sqrt{\alpha^2+\omega_n^2}\,\sin(\omega_n t-\theta)$ where $\theta=\tan^{-1}(\omega_n/\alpha)$
$\frac{\omega_n}{(s+\alpha)(s^2+\omega_n^2)}$	$\frac{\omega_n}{\alpha^2+\omega_n^2}e^{-\alpha t}+\frac{1}{\sqrt{\alpha^2+\omega_n^2}}\sin(\omega_n t-\theta)$ where $\theta=\tan^{-1}(\omega_n/\alpha)$
$\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\frac{\omega_n}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin \omega_n\sqrt{1-\zeta^2}\,t\ (\zeta<1)$
$\frac{\omega_n^2}{s(s^2+2\zeta\omega_n s+\omega_n^2)}$	$1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t+\theta\right)$ where $\theta=\cos^{-1}\zeta\quad(\zeta<1)$
$\frac{s\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\frac{-\omega_n^2}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t-\theta\right)$ where $\theta=\cos^{-1}\zeta\quad(\zeta<1)$
$\frac{\omega_n^2(s+\alpha)}{s^2+2\zeta\omega_n s+\omega_n^2}$	$\omega_n\sqrt{\frac{\alpha^2-2\alpha\zeta\omega_n+\omega_n^2}{1-\zeta^2}}\,e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t+\theta\right)$ where $\theta=\tan^{-1}\frac{\omega_n\sqrt{1-\zeta^2}}{\alpha-\zeta\omega_n}\quad(\zeta<1)$
$\frac{\omega_n^2}{s^2(s^2+2\zeta\omega_n s+\omega_n^2)}$	$t-\frac{2\zeta}{\omega_n}+\frac{1}{\omega_n\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin\left(\omega_n\sqrt{1-\zeta^2}\,t-\theta\right)$ where $\theta=\cos^{-1}(2\zeta^2-1)\quad(\zeta<1)$