[ENG31]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BSC (HONS) MECHATRONICS TOP-UP

SEMESTER ONE EXAMINATION 2018/2019

ADVANCED MECHATRONIC SYSTEMS

MODULE NO: MEC6002

Date: Wednesday 16th January 2019 **Time: 10:00 – 12:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

Q1.

(a) Explain the Open loop and close loop control systems with the aids of block diagrams.

(6 marks)

(b) An Automobile brake control system can be represented by the block diagram shown in Figure Q1(b). Using block diagram reduction techniques, find the following transfer functions for this control system.

(i) Y(s)/R(s)

(4 marks)

(ii) Y(s)/D(s)

(10 marks)

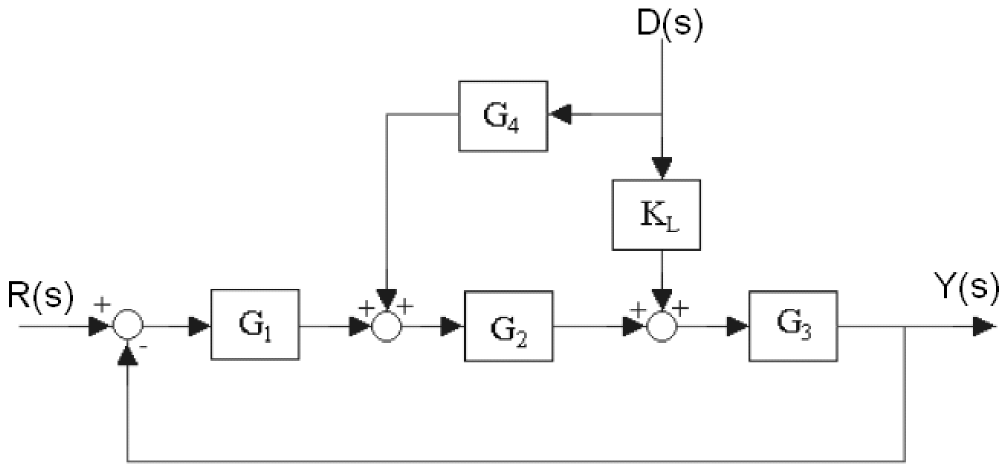

Figure Q1 (b) Automobile brake control system. Where R(s) is the input, D(s) is the disturbance and Y(s) is the output.

(c) A mercury-in-glass thermometer has the following transfer function. Please sketch the output temperature over the time when an impulse input is applied to the system.

$$G(s) = \frac{\theta_o}{\theta_i} = \frac{2}{3s+4}$$

(5 marks)

(Total 25 marks)

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Q2.

(a) The differential equation for a car suspension system is :

$$4\frac{d^2\theta_o}{dt^2} + 10\frac{d\theta_o}{dt} + 9\theta_o = 2\theta_i$$

Where θ_o is the output and θ_i is the input.

(i)	Find the transfer function of this system.	**(4 marks)**
(ii)	Find the damping factor.	**(2 marks)**
(iii)	Find the damped frequency.	**(2 marks)**
(iv)	Find the subsidence ratio.	**(2 marks)**
(v)	Find the 5% settling time t_s.	**(2 marks)**

(b) The block diagram of a servo control system can be shown in Figure Q2(b).

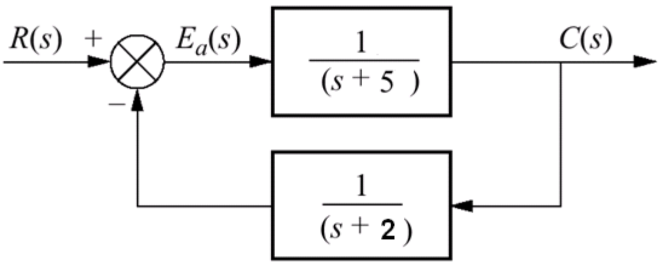

Figure Q2 (b) a servo motor control system

Determine the steady state error (e_{SS}) for a ramp function response of the above system.

(7 marks)

(c) Apply Routh-Hurwitz stability criterion to determine the range of values of K for a robot control system with the transfer function of T(s) which will result in a stable response.

$$T(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{s+7}{s^3 + 4s^2 + 8s + K}$$

(6 marks)

Total 25 marks

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Q3.

(a) A RLC circuit is shown in Figure 3(a) below.

where C is the Capacitance, L is the Inductance, R is Resistance, $I_1(t)$ is the total current and V(t) is the source voltage.

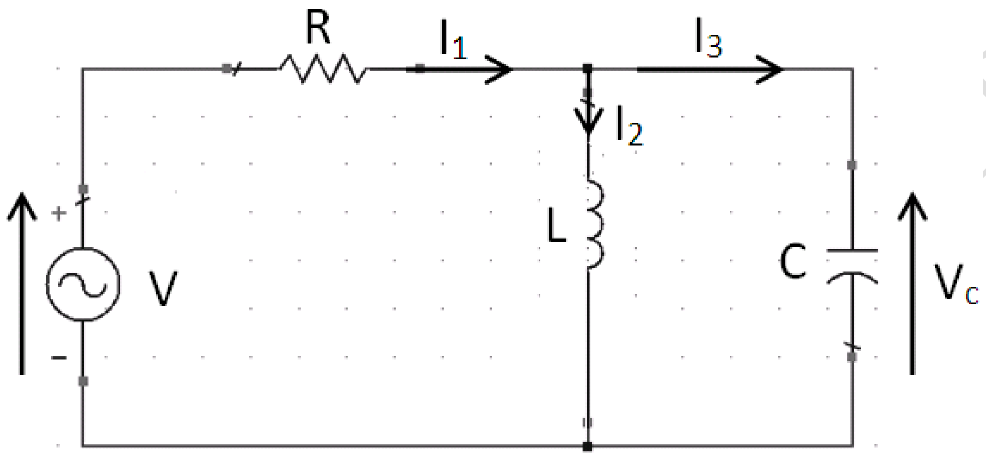

Figure 3(a): RLC electrical circuit

(i) Develop a differential equation for the RLC electrical circuit shown in Figure 3(a) above.

(8 marks)

Determine the Laplace transforms of the differential equations obtained from (i) above. Assume that the system is subjected to a unit step input ,the initial conditions of the system are zeros (i.e. at time = 0, *x*, *x'*, *x''* are all zeros) and the capacitor is initially discharged as the following expression.

$$\int v_c(t)dt = \int_0^t v_c(t)dt$$

(2 marks)

(ii) Determine the transfer function G(s) = V_c(s)/V(s) **(2 marks)**

Question 3 continues over the page….

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Question 3 continued….

(b) A suspension system for a scooter is shown in Figure 3(b).
where
f(t) is the input force, y1(t) and y2(t) represents the output displacements, k1, k2 and k3 are the spring stiffness constants, C is the viscous damping coefficient.

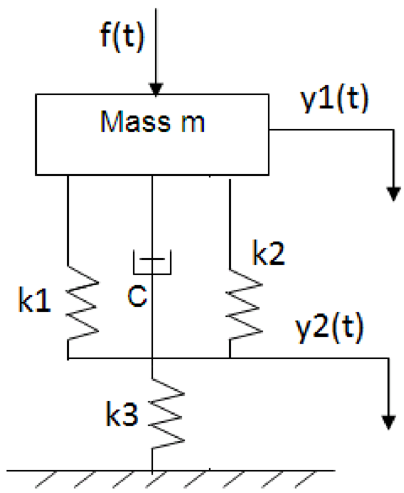

Figure 3(b) A suspension System

(i) Develop the differential equations for the suspension system

(3 marks)

(ii) Determine the Laplace transforms of the differential equations obtained from (i) above. Assume that the system is subjected to a unit step input, y(0) =0 and y'(0)=0. **(6 marks)**

(iii) Determine the transfer function G(s)=Y1(s)/F(s) **(4 marks)**

Total 25 marks

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Q4 Figure Q4 shows a mechatronic control system, in which the

$$G_P(s) = \frac{2}{10s^2 + 3s}$$

and a controller Gc(s) is applied into the system.

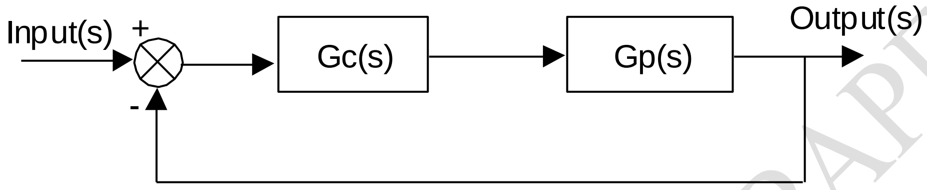

Figure Q4 A Mechatronic Control System

The design criteria for this system are:

Rise time < 3 sec
Overshoot < 15%
Steady state error <= 0.02 (for a unit parabolic input = $1/s^3$)

(a) Design a PID controller to determine the parameters K_p, K_i, and K_d and clearly identify the design procedure. **(18 marks)**

(b) If a velocity feedback is introduced into the system of the Figure Q4, draw a block diagram with the velocity feedback and determine the transfer function for the whole system. **(7 marks)**

Total 25 marks

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Q5. Figure Q5 shows a manufacturing system which includes a CNC machining centre, a sensor system, and an industrial robot with its control system.

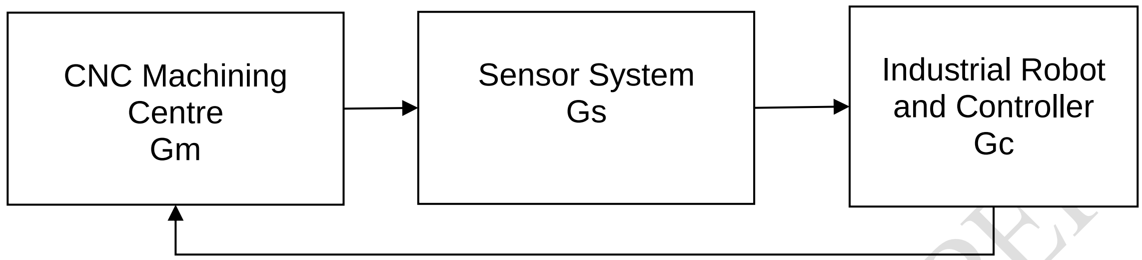

Figure Q5 A Manufacturing System

The CNC machining centre is controlled by its digital controller. The sensor system detects the types of component on CNC machine table and sends the detected analogue information to the robot controller. The robot picks and places the components from the CNC machine table and sends digital control signals to the CNC machining centre.

(a) Draw a closed-loop control system, with the help of a block diagram, for the manufacturing system shown in Figure Q5. Clearly identify all the elements and explain how the whole closed-loop control system works. **(7 marks)**

(b) If the robot controller has a 10 bit Analogue to Digital Converter with the signal range between -15 Volt to +15 Volt:

(i) What is the resolution of the AD converter? **(2 marks)**

(ii) What integer number represents a value of -8 Volts? **(2 marks)**

(iii) What voltage does the integer 1000 represent? **(3 marks)**

(iv) What voltage does 0100110101 represent? **(3 marks)**

Question Q5 continued over the page….

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Question Q5 continued….

(c) If the CNC machining centre consists of a Digital to Analogue Converter with zero order element in series with the sensor system, as shown in Figure Q5 (c), which has a transfer function

$$G_p(s) = \frac{6}{s(s+2)}$$

find the sampled-data transfer function, G(z) for the digital control system. The sampling time, T, is 0.02 seconds. **(8 marks)**

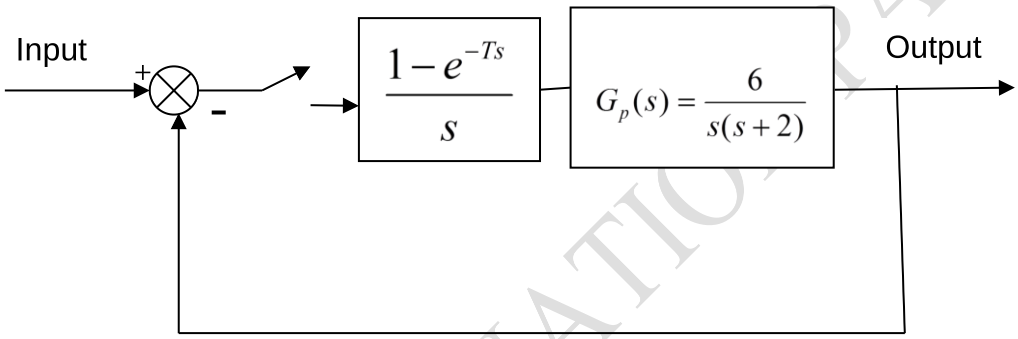

Figure Q5 (c)

Total 25 marks

Q6.

(a) An automated assembly line is assembling a car model. The line involves the processes of: plastic mould arriving, spray painting, and metal logo fixing.

You are asked to select sensors to detect the following:

- the arrival of a plastic moulding
- the presence on the model of paint of the correct colour
- the correct presence, orientation and position of the metal logo

Use your answer to part a) above to justify your recommendation for each sensor selected. **(9 marks)**

Question Q6 continued over the page….

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Question Q6 continued….

(b) Figure Q6(b) shows the driven system with a compound gear train for this automated assembly line. A DC motor with a maximum speed of 1500 rpm, a maximum torque of 50 Nm and a maximum power of 800 W has been selected. The system has used a gear train, where the first driver Gear A has 20 teeth, Gear B 40 teeth, Gear C 12 teeth and Gear D 48 teeth.

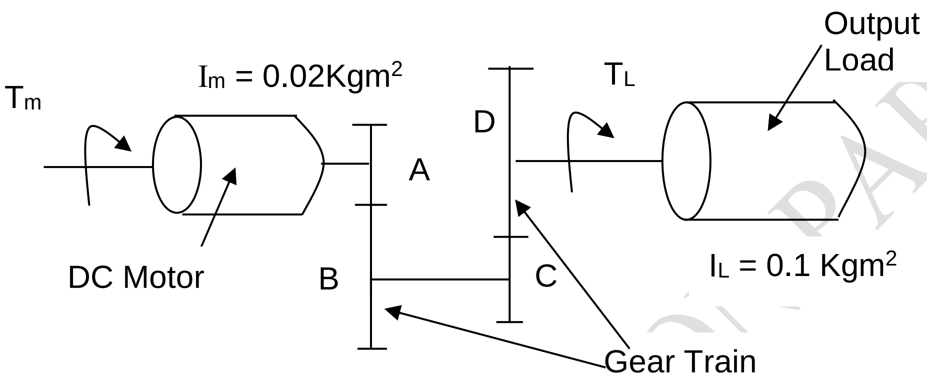

Figure Q6(b) The driven system

(i) If the load torque is 200 Nm and it is operating at a constant angular velocity of 20 rpm, can the selected motor meet the load's torque and speed requirements? **(6 marks)**

(ii) If the load needs to be accelerated from rest to the speed of 20 rpm within 0.2 second, can the selected motor meet the load's torque requirement? **(6 marks)**

(iii) Check the power for above two cases (i) and (ii). **(4 marks)**

Total 25 marks

END OF QUESTIONS

Formula sheets over the page….

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Formula sheet

G(s) = $\dfrac{Go(s)}{1+Go(s)H(s)}$ (for a negative feedback)

G(s) = $\dfrac{Go(s)}{1-Go(s)H(s)}$ (for a positive feedback)

Steady-State Errors

$e_{ss} = \lim_{s\to 0}[s(1-G_O(s))\theta_i(s)]$ (for an open-loop system)

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+G_o(s)}\theta_i(s)]$ (for the closed-loop system with a unity feedback)

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_1(s)}{1+G_1(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

$e_{ss} = \lim_{s\to 0}[-s\cdot\dfrac{G_2(s)}{1+G_2(G_1(s)+1)}\cdot\theta_d]$ (if the system subjects to a disturbance input)

Laplace Transforms

A unit impulsefunction	1
A unit step function	$\dfrac{1}{s}$
A unit ramp function	$\dfrac{1}{s^2}$

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First order Systems

$$G(s) = \frac{\theta_o}{\theta_i} = \frac{G_{ss}(s)}{\tau s + 1}$$

$$\tau\left(\frac{d\theta_o}{dt}\right) + \theta_o = G_{ss}\theta_i$$

$\theta_O = G_{ss}(1 - e^{-t/\tau})$ (for a unit step input)

$\theta_O = AG_{ss}(1 - e^{-t/\tau})$ (for a step input with size A)

$\theta_o(t) = G_{ss}(\frac{1}{\tau})e^{-(t/\tau)}$ (for an impulse input)

Second-order systems

$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n \frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\omega_d t_r = 1/2\pi$ $\omega_d t_p = \pi$

P.O. = $\exp^{(\frac{-\zeta\pi}{\sqrt{(1-\zeta^2)}})} \times 100\%$

$t_s = \frac{4}{\zeta\omega_n}$ $\omega_d = \omega_n\sqrt{(1-\zeta^2)}$

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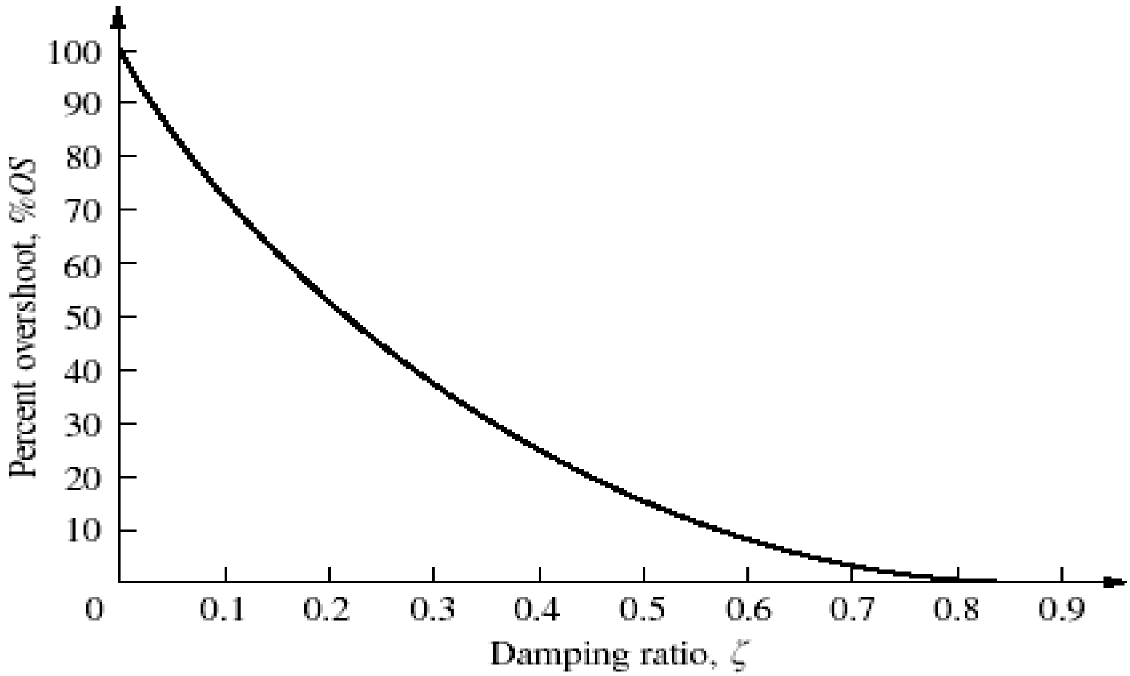

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Table 4.1 Laplace transforms

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-sT}}{s}$		A delayed unit step function
$\frac{1-e^{-sT}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	te^{-at}	
$\frac{2}{(s+a)^3}$	t^2e^{-at}	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos\omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin\omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos\omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos\omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta<1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta=\cos\phi$	

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Table 15.1 *z*-transforms

Sampled f(t), sampling period T	$F(z)$
Unit impulse, $\delta(t)$	1
Unit impulse delayed by kT	z^{-k}
Unit step, $u(t)$	$\dfrac{z}{z-1}$
Unit step delayed by kT	$\dfrac{z}{z^k(z-1)}$
Unit ramp, t	$\dfrac{Tz}{(z-1)^2}$
t^2	$\dfrac{T^2 z(z+1)}{(z-1)^3}$
e^{-at}	$\dfrac{z}{z-e^{-aT}}$
$1-e^{-at}$	$\dfrac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
$t\,e^{-at}$	$\dfrac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
$e^{-at}-e^{-bt}$	$\dfrac{(e^{-aT}-e^{-bT})z}{(z-e^{-aT})(z-e^{-bT})}$
$\sin \omega t$	$\dfrac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
$\cos \omega t$	$\dfrac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
$e^{-at}\sin\omega t$	$\dfrac{z\,e^{-aT}\sin\omega T}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$
$e^{-at}\cos\omega t$	$\dfrac{z(z-e^{-aT}\cos\omega T)}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$

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