OCD081

UNIVERSITY OF BOLTON

OFF CAMPUS DIVISION

B.ENG. (HONS) MECHANICAL ENGINEERING

MALAYSIA - KTG

SEMESTER 1 EXAMINATION 2018/2019

ADVANCED THERMOFLUIDS AND CONTROL SYSTEMS

MODULE NO: AME6005

Date: Thursday 10th January 2019 **Time: 3 Hours**

INSTRUCTIONS TO CANDIDATES:

This question paper consists of Two sections: Section A and Section B.

Answer Two questions from each Section.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.
For this examination you will be supplied with the following:
- **Steam tables**
- **Moody chart**
- **Formula sheet**

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.

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B.Eng (Hons) Mechanical Engineering
Semester 1 Examination 2018/2019
Advanced Thermofluids and Control Systems
Module No. AME6005

SECTION A
[50 marks]
Instruction: Answer **Two** questions.

QUESTION 1

The following diagram is for a combined gas – steam power plant system. Superheated steam is supplied from the steam generator to the steam turbine at 60 bar, 450^oC and leaves as wet steam at 0.08 bar. The steam turbine has thermal efficiency of 50% and output power of 10 MW, calculate:

(i) Assuming reversible adiabatic flows through the pump and turbine, determine the enthalpies at the inlets and out lets of pump and turbine. (8 marks)

(ii) The flow rate of steam to the turbine. (6 marks)

(iii) The heat transferred to the cooling water of the condenser. (3 marks)

(iv) The difference between the inlet and outlet temperatures of the condenser cooling water for water flow of 6 T/h. (Cp for water = 4.2 x10^3 kJ/Kg). (4 marks)

(v) The power supplied to from the flue gases to the steam generator. (4 marks)

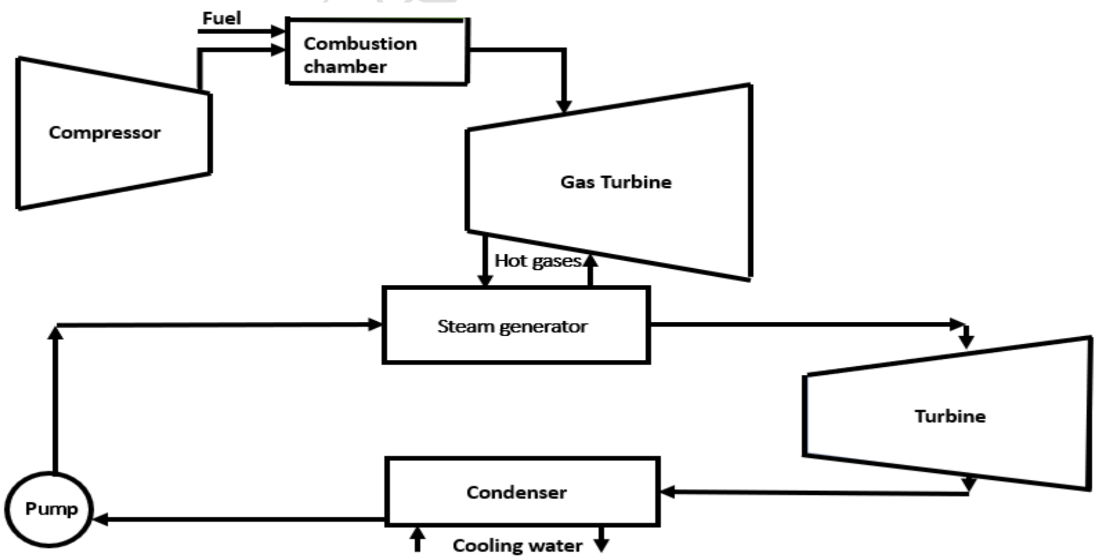

Figure. Q1

Total 25 marks

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QUESTION 2

a) State the assumptions made in solving problems in heat exchangers.

(3 marks)

b) A counter flow double pipe heat exchanger is to heat water from 20 ^oC to 80 ^oC at a rate of 1.2 kg/s. The heating is to be accompanied by geothermal water available at 160 ^oC at a mass flow rate of 2 kg/s. The inner tube is thin walled and has diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2.^oC, determine the length of the heat exchanger required to achieve the desired heating using the effectiveness - NTU method. C_{ph} = 4.3 kJ/kg.^oC ,C_{pc} = 4.18 kJ/kg. ^oC)

$$\text{NTU} = \frac{1}{C-1}\ In\ \left(\frac{\varepsilon-1}{\varepsilon C-1}\right)$$

(22 marks)

Total 25 marks

QUESTION 3

a) Define and explain the term Reynolds stress. What causes the friction factor to be higher in turbulent flow? (5 marks)

b) Water at 15 ^oC ($\rho = 999.1\ kg/m^3$) and μ=1.138 x 10^{-3} kg/m .s is flowing steadily in a 50 mm in diameter horizontal pipe made of stainless steel of roughness $\varepsilon = 0.002\ mm$, at a rate of 0.005 m^3/s. Determine the pressure drop, the head loss, and the required pumping power input for flow over a 60 m long of the pipe.

(20 marks)

Total 25 marks

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SECTION B
[50 marks]
Instruction: Answer **Two** questions.

QUESTION 4
For the control system is shown in **Figure Q4.**

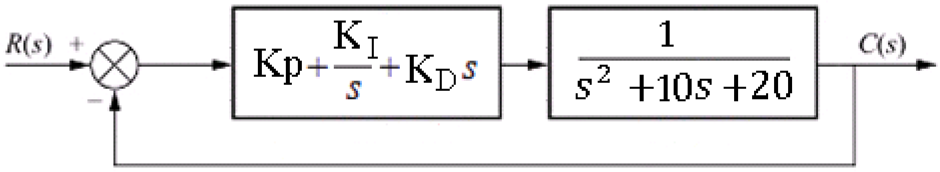

Figure Q4

The controller is used in order to improve step response of the system.

a) For KI and KD are set to zero (controller becomes proportional controller), determine the range of Kp to fulfill less than 5% overshoot requirement.

(10 marks)

b) Design PID controller to achieve maximum overshoot less than 5%, rise time tr less than 1 second and zero steady-state error for a unit step input.

(15 marks)

QUESTION 5

a) Analyse the stability of the sampled control system as shown in **Figure Q5**, when sampling time is
   (i) T=0.5 sec.
   (ii) T = 1 sec.

(19 marks)

Question 5 continued over the page

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Question 5 cont'd…

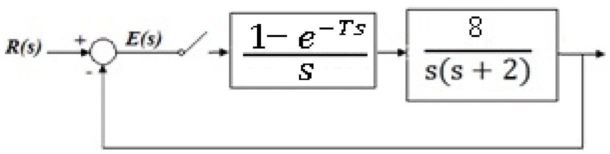

Figure Q5

b) If an 8 bits analogue to digital converter with the signal range between -5 V to +5 V.
Find
(i) the resolution of the AD converter, (2 marks)
(ii) integer number represented a value of 2.5 Volts, (2 marks)
(iii) the voltage does the integer 100 represent. (2 marks)

QUESTION 6

a) Briefly explain the following three approaches for the analysis and design of closed loop control systems
(i) Laplace transform. (2 marks)
(ii) The frequency responses technique. (2 marks)
(iii) The state space techniques. (2 marks)

b) Consider the mass-spring damper system depicted in **Figure Q6** .

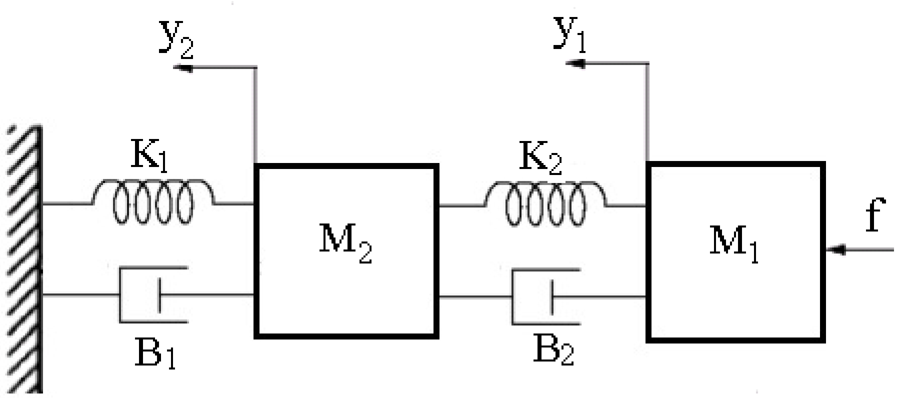

Figure Q6

Question 6 continued over the page

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Question 6 cont'd…

(i) Derive the differential equations describing the behaviour of the system. (8 marks)

(ii) Select the state variables and transfer the differential equations obtained from Figure Q6 above to the relevant first-order differential equations. (2 marks)

(iii) Determine the state space equations of the system. (9 marks)

Total 25 marks

END OF QUESTIONS

1- Steam Tables

- SATURATED STEAM: PRESSURE TABLE

		Volume, m³/kg		Energy, kJ/kg		Enthalpy, kJ/kg			Entropy, kJ/kg·K		
P, MPa	T, °C	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.000611	0.01	0.001000	206.1	0.0	2375.3	0.0	2501.3	2501.3	0.0000	9.1571	9.1571
0.0008	3.8	0.001000	159.7	15.8	2380.5	15.8	2492.5	2508.3	0.0575	9.0007	9.0582
0.001	7.0	0.001000	129.2	29.3	2385.0	29.3	2484.9	2514.2	0.1059	8.8706	8.9765
0.0012	9.7	0.001000	108.7	40.6	2388.7	40.6	2478.5	2519.1	0.1460	8.7639	8.9099
0.0014	12.0	0.001001	93.92	50.3	2391.9	50.3	2473.1	2523.4	0.1802	8.6736	8.8538
0.0016	14.0	0.001001	82.76	58.9	2394.7	58.9	2468.2	2527.1	0.2101	8.5952	8.8053
0.0018	15.8	0.001001	74.03	66.5	2397.2	66.5	2464.0	2530.5	0.2367	8.5259	8.7626
0.002	17.5	0.001001	67.00	73.5	2399.5	73.5	2460.0	2533.5	0.2606	8.4639	8.7245
0.003	24.1	0.001003	45.67	101.0	2408.5	101.0	2444.5	2545.5	0.3544	8.2240	8.5784
0.004	29.0	0.001004	34.80	121.4	2415.2	121.4	2433.0	2554.4	0.4225	8.0529	8.4754
0.006	36.2	0.001006	23.74	151.5	2424.9	151.5	2415.9	2567.4	0.5208	7.8104	8.3312
0.008	41.5	0.001008	18.10	173.9	2432.1	173.9	2403.1	2577.0	0.5924	7.6371	8.2295
0.01	45.8	0.001010	14.67	191.8	2437.9	191.8	2392.8	2584.6	0.6491	7.5019	8.1510
0.012	49.4	0.001012	12.36	206.9	2442.7	206.9	2384.1	2591.0	0.6961	7.3910	8.0871
0.014	52.6	0.001013	10.69	220.0	2446.9	220.0	2376.6	2596.6	0.7365	7.2968	8.0333
0.016	55.3	0.001015	9.433	231.5	2450.5	231.5	2369.9	2601.4	0.7719	7.2149	7.9868
0.018	57.8	0.001016	8.445	241.9	2453.8	241.9	2363.9	2605.8	0.8034	7.1425	7.9459
0.02	60.1	0.001017	7.649	251.4	2456.7	251.4	2358.3	2609.7	0.8319	7.0774	7.9093
0.03	69.1	0.001022	5.229	289.2	2468.4	289.2	2336.1	2625.3	0.9439	6.8256	7.7695
0.04	75.9	0.001026	3.993	317.5	2477.0	317.6	2319.1	2636.7	1.0260	6.6449	7.6709
0.06	85.9	0.001033	2.732	359.8	2489.6	359.8	2293.7	2653.5	1.1455	6.3873	7.5328
0.08	93.5	0.001039	2.087	391.6	2498.8	391.6	2274.1	2665.7	1.2331	6.2023	7.4354
0.1	99.6	0.001043	1.694	417.3	2506.1	417.4	2258.1	2675.5	1.3029	6.0573	7.3602
0.12	104.8	0.001047	1.428	439.2	2512.1	439.3	2244.2	2683.5	1.3611	5.9378	7.2980
0.14	109.3	0.001051	1.237	458.2	2517.3	458.4	2232.0	2690.4	1.4112	5.8360	7.2472
0.16	113.3	0.001054	1.091	475.2	2521.8	475.3	2221.2	2696.5	1.4553	5.7472	7.2025
0.18	116.9	0.001058	0.9775	490.5	2525.9	490.7	2211.1	2701.8	1.4948	5.6683	7.1631
0.2	120.2	0.001061	0.8857	504.5	2529.5	504.7	2201.9	2706.6	1.5305	5.5975	7.1280
0.3	133.5	0.001073	0.6058	561.1	2543.6	561.5	2163.8	2725.3	1.6722	5.3205	6.9927
0.4	143.6	0.001084	0.4625	604.3	2553.6	604.7	2133.8	2738.5	1.7770	5.1197	6.8967
0.6	158.9	0.001101	0.3157	669.9	2567.4	670.6	2086.2	2756.8	1.9316	4.8293	6.7609
0.8	170.4	0.001115	0.2404	720.2	2576.8	721.1	2048.0	2769.1	2.0466	4.6170	6.6636
1	179.9	0.001127	0.1944	761.7	2583.6	762.8	2015.3	2778.1	2.1391	4.4482	6.5873
1.2	188.0	0.001139	0.1633	797.3	2588.8	798.6	1986.2	2784.8	2.2170	4.3072	6.5242
1.4	195.1	0.001149	0.1408	828.7	2592.8	830.3	1959.7	2790.0	2.2847	4.1854	6.4701
1.6	201.4	0.001159	0.1238	856.9	2596.0	858.8	1935.2	2794.0	2.3446	4.0780	6.4226
1.8	207.2	0.001168	0.1104	882.7	2598.4	884.8	1912.3	2797.1	2.3986	3.9816	6.3802
2	212.4	0.001177	0.09963	906.4	2600.3	908.8	1890.7	2799.5	2.4478	3.8939	6.3417
3	233.9	0.001216	0.06668	1004.8	2604.1	1008.4	1795.7	2804.1	2.6462	3.5416	6.1878
4	250.4	0.001252	0.04978	1082.3	2602.3	1087.3	1714.1	2801.4	2.7970	3.2739	6.0709
6	275.6	0.001319	0.03244	1205.4	2589.7	1213.3	1571.0	2784.3	3.0273	2.8627	5.8900
8	295.1	0.001384	0.02352	1305.6	2569.8	1316.6	1441.4	2758.0	3.2075	2.5365	5.7440
10	311.1	0.001452	0.01803	1393.0	2544.4	1407.6	1317.1	2724.7	3.3603	2.2546	5.6149
12	324.8	0.001527	0.01426	1472.9	2513.7	1491.3	1193.6	2684.9	3.4970	1.9963	5.4933
14	336.8	0.001611	0.01149	1548.6	2476.8	1571.1	1066.5	2637.6	3.6240	1.7486	5.3726
16	347.4	0.001711	0.009307	1622.7	2431.8	1650.0	930.7	2580.7	3.7468	1.4996	5.2464
18	357.1	0.001840	0.007491	1698.9	2374.4	1732.0	777.2	2509.2	3.8722	1.2332	5.1054
20	365.8	0.002036	0.005836	1785.6	2293.2	1826.3	583.7	2410.0	4.0146	0.9135	4.9281
22.088	374.136	0.003155	0.003155	2029.6	2029.6	2099.3	0.0	2099.3	4.4305	0.0000	4.4305

SOURCES: Keenan, Keyes, Hill, and Moore, *Steam Tables*, Wiley, New York, 1969; G. J. Van Wylen and R. E. Sonntag, *Fundamentals of Classical Thermodynamics*, Wiley, New York, 1973.

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- **SUPERHEATED STEAM TABLE**

$P = 6$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg	$\hat{s}$ kJ/kg K
sat	0.03244	2589.7	2784.3	5.8891
300	0.03616	2667.2	2884.2	6.0673
350	0.04223	2789.6	3043.0	6.3334
400	0.04739	2892.8	3177.2	6.5407
450	0.05214	2988.9	3301.8	6.7192
500	0.05665	3082.2	3422.1	6.8802
550	0.06101	3174.6	3540.6	7.0287
600	0.06525	3266.9	3658.4	7.1676
700	0.07352	3453.2	3894.3	7.4234
800	0.08160	3643.1	4132.7	7.6566
900	0.08958	3837.8	4375.3	7.8727
1000	0.09749	4037.8	4622.7	8.0751
1100	0.10536	4243.3	4875.4	8.2661
1200	0.11321	4454.0	5133.3	8.4473
1300	0.12106	4669.6	5396.0	8.6190

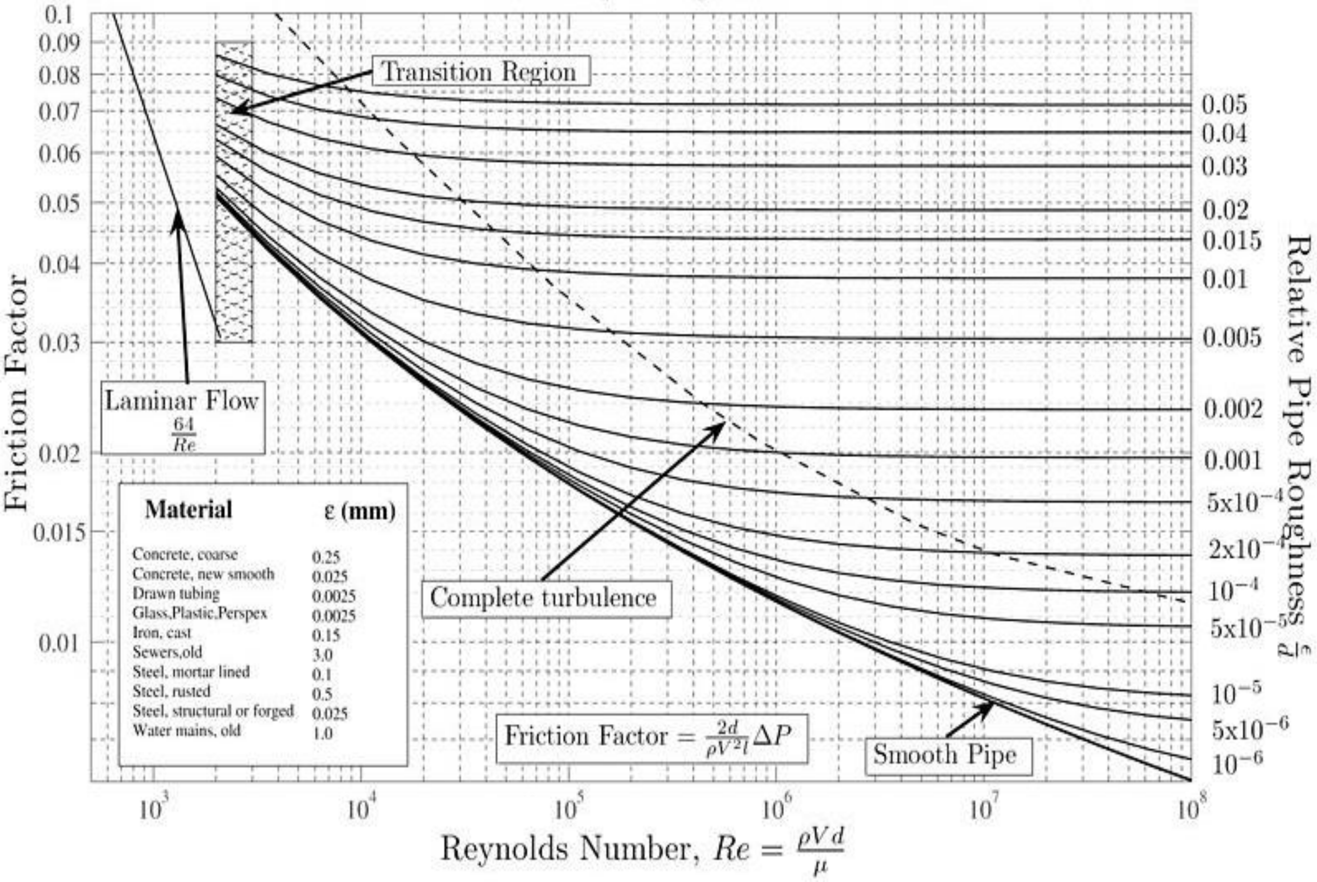
$P = 7$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg	$\hat{s}$ kJ/kg K
sat	0.02737	2580.5	2772.1	5.8132
300	0.02947	2632.1	2838.4	5.9304
350	0.03524	2769.3	3016.0	6.2282
400	0.03993	2878.6	3158.1	6.4477
450	0.04416	2077.9	3287.0	6.6326
500	0.04814	3073.3	3410.3	6.7974
550	0.05195	3167.2	3530.9	6.9486
600	0.05565	3260.7	3650.3	7.0894
700	0.06283	3448.6	3888.4	7.3476
800	0.06981	3639.6	4128.3	7.5822
900	0.07669	3835.0	4371.8	7.7991
1000	0.08350	4035.3	4619.8	8.0020
1100	0.09027	4240.9	4872.8	8.1933
1200	0.09703	4451.7	5130.9	8.3747
1300	0.10377	4667.3	5393.7	8.5472

$P = 8$ MPa

T °C	$\hat{v}$ m³/kg	$\hat{u}$ kJ/kg	$\hat{h}$ kJ/kg	$\hat{s}$ kJ/kg K
sat	0.02352	2569.8	2757.9	5.7431
300	0.02426	2590.9	2785.0	5.7905
350	0.02995	2747.7	2987.3	6.1300
400	0.03432	2863.8	3138.3	6.3633
450	0.03817	2966.7	3272.0	6.5550
500	0.04175	3064.3	3398.3	6.7239
550	0.04516	3159.8	3521.0	6.8778
600	0.04845	3254.4	3642.0	7.0205
700	0.05481	3444.0	3882.5	7.2812
800	0.06097	3636.1	4123.8	7.5173
900	0.06702	3832.1	4368.3	7.7350
1000	0.07301	4032.8	4616.9	7.9384
1100	0.07896	4238.6	4870.3	8.1299
1200	0.08489	4449.4	5128.5	8.3115
1300	0.09080	4665.0	5391.5	8.4842

2. The Moody chart



3- Laplace and Z transform table.

Laplace transform $f(s)$	Time function $f(t)$ $t > 0$	z-transform $f(z)$	Modified z-transform $f(z,m)$
$\frac{1}{s}$	$u_s(t)$	$\frac{z}{z-1}$	$\frac{1}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$	$\frac{mT}{(z-1)} + \frac{T}{(z-1)^2}$
$\frac{2}{s^3}$	t^2	$\frac{T^2 z(z+1)}{(z-1)^3}$	$T^2\left(\frac{m^2}{(z-1)} - \frac{2m+1}{(z-1)^2} + \frac{2}{(z-1)^3}\right)$
$\frac{1}{s+a}$	e^{-at}	$\frac{z}{z-e^{-aT}}$	$\frac{e^{-amT}}{z-e^{-aT}}$
$\frac{1}{(s+a)^2}$	te^{-at}	$\frac{Tze^{-aT}}{(z-e^{-aT})^2}$	$\frac{Te^{-amT}(e^{-aT}+m(z-e^{-aT}))}{(z-e^{-aT})^2}$
$\frac{a}{s(s+a)}$	$1-e^{-at}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$	$\frac{1}{(z-1)} - \frac{e^{-amT}}{z-e^{-aT}}$
$\frac{1}{(s+a)(s+b)}$	$\frac{1}{(b-a)}(e^{-at}-e^{-bt})$	$\frac{1}{(b-a)}\left(\frac{z}{z-e^{-aT}} - \frac{z}{z-e^{-bT}}\right)$	$\frac{1}{b-a}\left(\frac{e^{-amT}}{z-e^{-aT}} - \frac{e^{-bmT}}{z-e^{-bT}}\right)$
$\frac{a}{s^2(s+a)}$	$t - \frac{1}{a}(1-e^{-at})$	$\frac{Tz}{(z-1)^2} - \frac{(1-e^{-aT})z}{a(z-1)(z-e^{-aT})}$	$\frac{T}{(z-1)^2} + \frac{amT-1}{a(z-1)} + \frac{e^{-amT}}{a(z-e^{-aT})}$
$\frac{a}{s^2+a^2}$	$\sin(at)$	$\frac{z\sin(aT)}{z^2-2z\cos(aT)+1}$	$\frac{z\sin(amT)+\sin(1-m)aT}{z^2-2z\cos(aT)+1}$

Step response formula

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

$$PO = 100\, e^{-\varsigma\pi/\sqrt{(1-\varsigma^2)}}$$

$$T_r = \frac{2.16\varsigma + 0.60}{\omega_n}$$

$$T_s = \frac{4}{\varsigma\omega_n}$$