[ENG20]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng(Hons) MECHANICAL ENGINEERING

SEMESTER 1 EXAM 2022-23

ADVANCED THERMOFLUIDS AND CONTROL MODULE NUMBER: AME6015

Date: Wednesday 11th January 2023 **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.

Formulae sheet is attached at the end of the paper for reference.

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

Question 1

A block diagram for a furnace temperature control system is shown in Figure Q1 below:

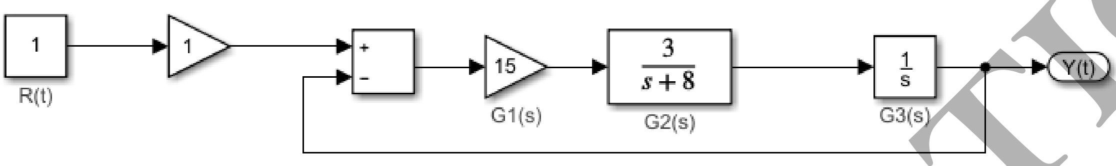

Figure Q1

Where,

$G_1(s) = 15$

$G_2(s) = \frac{3}{s+8}$

$G_3(s) = \frac{1}{s}$

a) Determine the system damping ratio, natural frequency, damped frequency, and steady state gain. **[7 marks]**

b) Determine the time domain response of the system, y(t), to a unit impulse input, r(t). **[6 marks]**

c) For a unit step input, determine the system rise time, peak time, maximum percentage overshoot, and settling time for a 2% tolerance. **[6 marks]**

d) If the input of $r(t) = 90, t \geq 0 \; and \; 0 , t \leq 0$ is applied, analyse the system steady state error. **[6 marks]**

Total: 25 marks

Question 2

A block diagram for a digital control system for a steam-turbine speed control is shown below in Figure Q2.

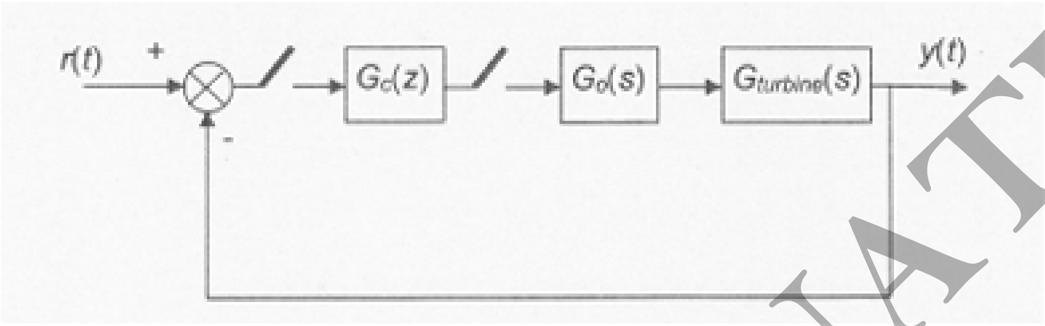

Figure Q2

Where,

The digital controller: G_C = **Kp**

The zero-order-hold: $G_O = \frac{1-e^{-sT}}{s}$

The dynamics of the steam-turbine: $G_{Turbine}(s) = \frac{0.5}{s+0.5}$

a) Determine the closed-loop z-transfer function for the system.

[12 marks]

b) if the gain of the digital controller Kp = 10, determine the range of the sampling time interval T that will make the closed-loop control system stable.

[6 marks]

c) If the sampling frequency f = 20kHz,determine the range of controller gain Kp that will make the closed-loop system stable.

[7 marks]

Total: 25 marks

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Question 3

A dynamic system is shown in the block diagram below, Figure Q3(a),

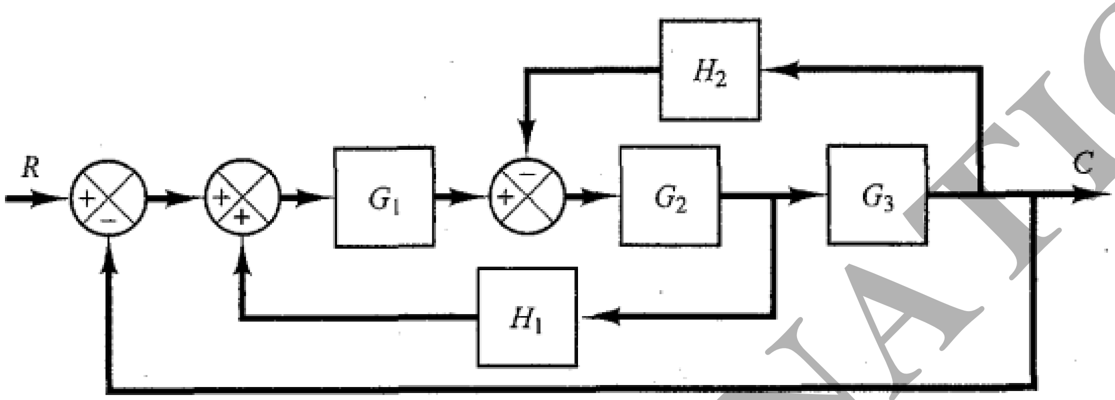

Figure Q3(a)

a) Show how the block diagram in figure Q3(a) could be reduced to describe the output over the input C/R. **[6 marks]**

b) From the Matlab graph shown in Q3(b) on the next page, estimate the gain and phase margins **[6 marks]**

c) Sketch the magnitude and phase for the following functions.

(i) \`$G1(s) = \frac{10}{0.2s+1}$ **[2 marks]**

(ii) $G2(s) = \frac{2500}{S^2 + 80S + 2500}$ **[2 marks]**

(iii) $G3(s) = \frac{8}{S}$ **[2 marks]**

d) Sketch the final result of G1(s)*G2(s)*G(s) and estimate the phase and gain margin. **[7 marks]**

Question 3 follows over the page…

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….Question 3 continued

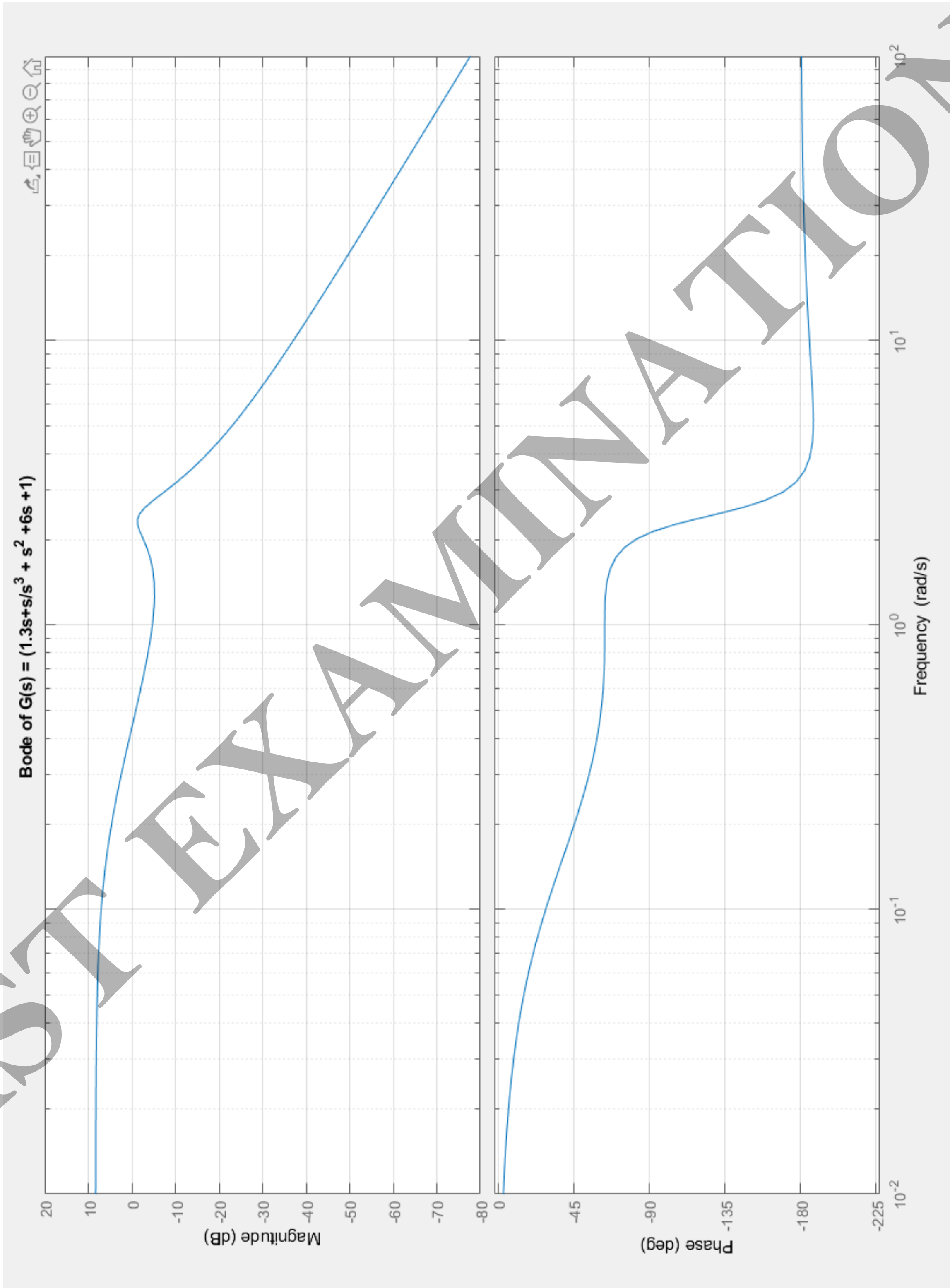

Figure 3(b)

Total: 25 marks
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Question 4

a) Steam at 7 bar, dryness fraction 0.9 expands reversibly at constant pressure until the temperature is 200 ˚c. Calculate the work input and heat supplied per unit mass of steam during the process.

[15 Marks]

b) Steam at 0.05 bar, 100 ˚c is to be condensed completely by a reversible constant pressure process. Calculate the heat rejected per kilogramme of steam and the change of specific entropy.

[10 Marks]

Total: 25 marks

Question 5

a) Derive the Darcy Weisbach Equation $h_f=\frac{f\,LV^2}{2gD}$ for the loss of Head due to friction in a pipeline using the energy equation

$$\frac{P_1}{\rho g}+Z_1+\frac{V1^2}{2g}=\frac{P_2}{\rho g}+Z_2+\frac{V_2^{\,2}}{2g}+HL$$

Where HL= the friction head loss h_f. **[17marks]**

b) Oil with specific gravity of 0.85 with kinematic viscosity of 6x10^{-4} m^2/s flows in a 15 cm pipe at a rate of 0.020 m^3/s. What is the head loss per 100 m length of pipe?

[8 marks]

Total marks: 25 marks

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Question 6

a)

A Prototype gate valve, which will control the flow I a pipe system conveying paraffin, is to be studied in a model. The pressure drop ΔP is expected to depend upon the gate opening h, the overall depth d, the velocity V, density ρ and viscosity μ. Perform dimensional analysis to obtain the relevant non-dimensional groups.

[15 marks]

b)

A Carnot engine is used in a nuclear power plant. It receives 1500 Mw of power as a heat transfer from a source at 327 o c and rejects thermal waste to a nearby river at 27 ˚c. The river temperature rises by 3 K because of this power rejection by the plant,

Calculate:

i) The mass flow rate of the river
ii) The efficiency of the power plant

Take the value of specific heat capacity C_p=4.177kJ/kg K**[** **[10 marks]**

Total marks: 25 marks

END OF QUESTIONS
Formula sheet follows over the page…

PLEASE TURN THE PAGE FOR FORMULA SHEETS AND PROPERTY TABLES...

Formula sheet

Blocks with feedback loop

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

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

Steady-State Errors

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

$$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+\frac{G_0(s)}{1+G_0(s)[H(s)-1]}}\theta_i(s)]$$ (if the feedback H(s) ≠ 1)

$$e_{ss} = \frac{1}{1+\lim_{z\to 1} G_0(z)}$$ (if a digital system subjects to a unit step input)

Laplace Transforms

A unit impulse function 1

A unit step function $\frac{1}{s}$

A unit ramp function $\frac{1}{s^2}$

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

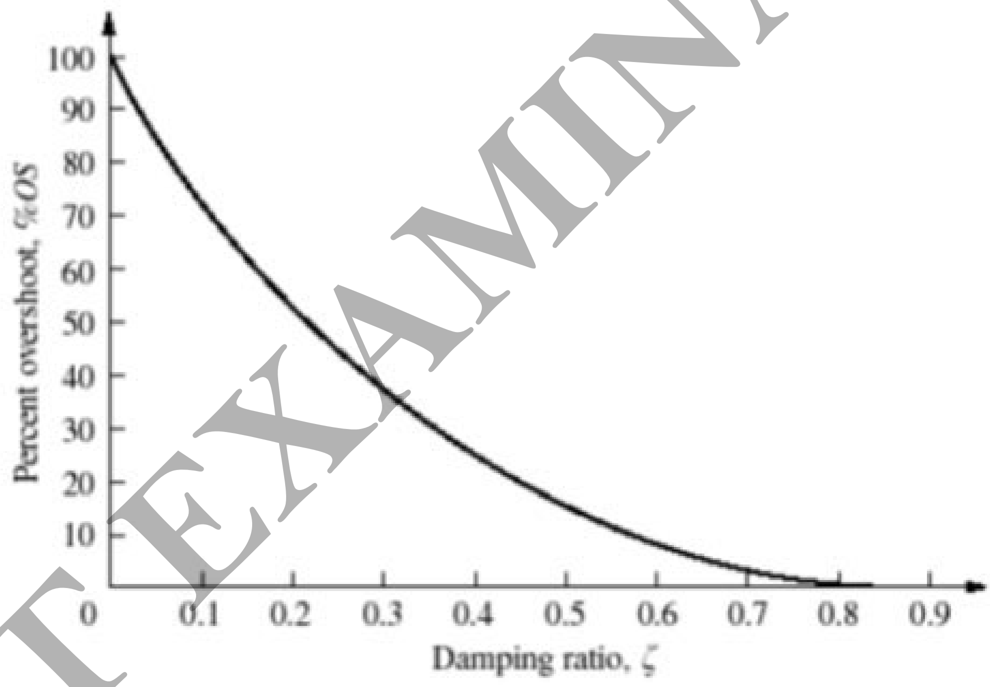
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

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

$\omega d t_r = 1/2\pi \quad \omega d t_p = \pi$

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

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



Controllability: $R = [B\ AB\ A^2B \ldots\ldots A^{(n-1)}\ B]$

Observability:

Laplace transform and Z transform table

Laplace Domain	Time Domain	Z Domain
1	$\delta(t)$ unit impulse	1
$\frac{1}{s}$	$u(t)$ *unit step*	$\frac{z}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$
$\frac{1}{s+a}$	e^{-at}	$\frac{z}{z-e^{-aT}}$
$\frac{1}{s(s+a)}$	$\frac{1}{a}\left(1-e^{-at}\right)$	$\frac{z\left(1-e^{-aT}\right)}{a(z-1)\left(z-e^{-aT}\right)}$
$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$\frac{z\left(e^{-aT}-e^{-bT}\right)}{a\left(z-e^{aT}\right)\left(z-e^{-bT}\right)}$
$\frac{b}{(s+a)^2+b^2}$	$e^{-at}\sin(bt)$	$\frac{ze^{-aT}\sin(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$
$\frac{s+a}{(s+a)^2+b^2}$	$e^{-at}\cos(bt)$	$\frac{z^2-ze^{-aT}\cos(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$

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Laplace Transforms of common functions

Functions		
Unit pulse (Dirac delta distribution)	$\delta(t)$	$F(s)=1$
Unit step function	$1(t)$	$F(s)=\frac{1}{s}$
Ramp function	$f(t)=at$	$F(s)=\frac{1}{s^2}$
Sine function	$f(t)=\sin at$	$F(s)=\frac{a}{s^2+a^2}$
Cosine function	$f(t)=\cos at$	$F(s)=\frac{s}{s^2+a^2}$
Exponential function	$f(t)=e^{at}$	$F(s)=\frac{1}{s-a}$
Operations		
Differentiation	$L(f'(t))$	$sF(s)-f(0)$
Integration	$L\left(\int f(t)dt\right)$	$\frac{1}{s}F(s)$
Time shift	$Lf(t-a)$	$e^{-as}F(s)$

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$W = \frac{P_1 V_1 - P_2 V_2}{n - 1}$ $\quad W = P(v_2 - v_1)$

$W = PV \ln\left(\frac{V_2}{V_1}\right)$

$Q = C_d A \sqrt{2gh}$

$V_1 = C\sqrt{2g\, h_2 \left(\frac{\rho g_m}{\rho g} - 1\right)}$

$\sum F = \frac{\Delta M}{\Delta t} = \Delta M^{\cdot}$

$F = \rho QV$

$Re = V L \rho/\mu$

$dQ = du + dw$

$du = cu\, dT$

$dw = pdv$

$pv = mRT$

$h = h_f + xh_{fg}$

$s = s_f + xs_{fg}$

$v = x V_g$

$Q - w = \sum mh$

$F = \frac{2\pi L \mu}{L_n\left(\frac{R_2}{R_1}\right)}$

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$$S_g = C_{pL}\ L_n\frac{T}{273} + \frac{h_{fg}}{T_f}$$

$$S = C_{pL}\ L_n\frac{T_f}{273} + \frac{hf_g}{T_f} + C_{pv}\ L_n\frac{T}{T_f}$$

$$S_2 - S_1 = MC_p\ L_n\frac{T_2}{T_1} - MRL_n\frac{P_2}{P_1}$$

$$F_D = \frac{1}{2}CD\ \rho u^2 s$$

$$F_L = \frac{1}{2}C_L\rho u^2 s$$

$$S_f = \frac{d}{ds}(P + \rho g Z)$$

$$Q = \frac{\pi D^4 \Delta p}{128\mu L}$$

$$h_f = \frac{64}{R}\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

$$h_f = \frac{4fLv^2}{d2g}$$

$$f = \frac{16}{Re}$$

$$h_m = \frac{Kv^2}{2g}$$

$$h_m = \frac{k(V_1 - V_2)^2}{2g}$$

$$\zeta = \left(1 - \frac{T_L}{T_H}\right)$$

$$S_{gen} = (S_2 - S_1)) + \frac{Q}{T}$$

$$W = (U_1 - U_2) - T_o(S_1 - S_2) - T_0 S_{gen}$$

$$W_u = W - P_0(V_2 - V_1)$$

$$W_{rev} = (U_1 - U_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2)$$

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$$\Phi = (U - U_0) - T(S - S_0) + Po(V - V_o)$$

$$I = ToS_{gen}$$

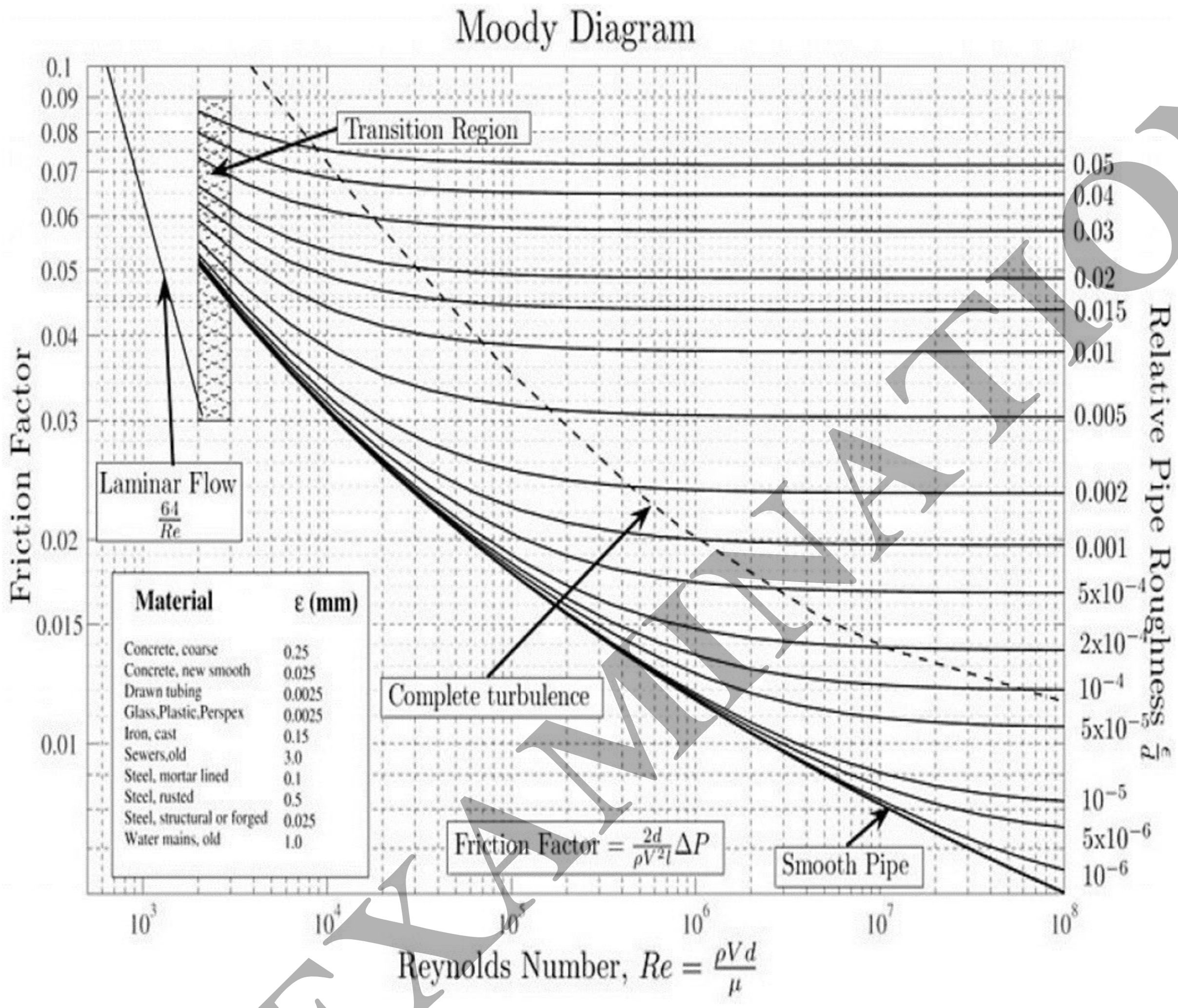
$$V = r\omega$$

$$\lambda = \mu \frac{V}{t}$$

$$F = \frac{2\pi L \mu u}{L_n\left(\frac{R_2}{R_1}\right)}$$

$$T = \frac{\pi^2 \mu N}{60t}\left(R_1^4 - R_2^4\right)$$

$$p = \frac{\rho g Q H}{1000}$$



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DIMENSIONS FOR CERTAIN PHYSICAL QUANTITIES

Quantity	Symbol	Dimensions	Quantity	Symbol	Dimensions
Mass	m	M	Mass /Unit Area	m/A ^{2}	ML^{-2}
Length	l	L	Mass moment	ml	ML
Time	t	T	Moment of Inertia	I	ML^2
Temperature	T	θ	-	-	-
Velocity	u	LT^{-1}	Pressure /Stress	p /σ	$ML^{-1}T^{-2}$
Acceleration	a	LT^{-2}	Strain	τ	$M^0L^0T^0$
Momentum/Impulse	mv	MLT^{-1}	Elastic Modulus	E	$ML^{-1}T^{-2}$
Force	F	MLT^{-2}	Flexural Rigidity	EI	ML^3T^{-2}
Energy - Work	W	ML^2T^{-2}	Shear Modulus	G	$ML^{-1}T^{-2}$
Power	P	ML^2T^{-3}	Torsional rigidity	GJ	ML^3T^{-2}
Moment of Force	M	ML^2T^{-2}	Stiffness	k	MT^{-2}
Angular momentum	-	ML^2T^{-1}	Angular stiffness	T/η	ML^2T^{-2}
Angle	η	$M^0L^0T^0$	Flexibiity	1/k	$M^{-1}T^2$
Angular Velocity	ω	T^{-1}	Vorticity	-	T^{-1}
Angular acceleration	α	T^{-2}	Circulation	-	L^2T^{-1}
Area	A	L^2	Viscosity	μ	$ML^{-1}T^{-1}$
Volume	V	L^3	Kinematic Viscosity	τ	L^2T^{-1}
First Moment of Area	Ar	L^3	Diffusivity	-	L^2T^{-1}
Second Moment of Area	I	L^4	Friction coefficient	f /μ	$M^0L^0T^0$
Density	ρ	ML^{-3}	Restitution coefficient		$M^0L^0T^0$
Specific heat- Constant Pressure	C_p	$L^2T^{-2}\theta^{-1}$	Specific heat- Constant volume	C_v	$L^2T^{-2}\theta^{-1}$

Note: a is identified as the local sonic velocity, with dimensions $L.T^{-1}$

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