2012 Engineering Tripos 1A , Paper 1, Section A   Dr. L Xu

Q1. a) Apply Bernoulli's Equation along the centre line of the probe:

$$p_o - p_s = \Delta p = \frac{1}{2}\rho_A \cdot V^2$$

Inside the U-tube hydrostatics gives:

$$\Delta p = p_0 - p_s = (\rho_L - \rho_A)gh$$

Solving for velocity:

$$V = \sqrt{\frac{2(\rho_L - \rho_A)gh}{\rho_A}} = \sqrt{2 \cdot \frac{850 - 1.2}{1.2} 9.81 \cdot 0.01} = 11.8\text{ms}^{-1}\text{; } V = \underline{\underline{11.8\text{ ms}^{-1}}}$$ [4]

b) $V = \sqrt{2Kh}$; ($K = \frac{\rho_L - \rho_A}{\rho_A} g$). Differentiate both sides:

$$\frac{dV}{V} = \frac{1}{2}\frac{dh}{h} \quad => \quad \frac{dV}{V} = \frac{1}{2}\frac{\pm 0.5}{10.0} = \pm 0.025 = \pm \underline{\underline{2.5\%}}$$

Or substitute the upper/lower bounds of the readings:

$V_{\text{Upper}} = 12.07\text{ms}^{-1}$; $V_{\text{Lower}} = 11.48\text{ms}^{-1}$

$$\frac{\Delta V}{V} = +0.023/-0.027 \approx \pm 0.025 \underline{\underline{\approx \pm 2.5\%}}$$ [4]

c) Nneglecting air column weight in the U-Tube:

$\Delta p = \rho_L gh \quad => \quad V = \sqrt{2\frac{\rho_L}{\rho_A} gh} = 11.79\text{ms}^{-1}$; $\left|\frac{\Delta V}{V}\right| \cong 0.0007 \le 0.1\%$, This is much smaller than the reading error of $\pm 2.5\%$ therefore can be neglected. [2]

Q2. At each measurement station y_i, streamtube height $\Delta Y_i = 0.1$m.

Volume flow rate through the stream tube: $q_i = \vec{\mathbf{A}}_i \cdot \vec{V}_i = A_i \cdot V_{n,i}$, where

$A_i = \Delta Y_i \cdot unit\,width$ and $V_{n,i} = V_i \cos\alpha_i$; $unit\,width = 1.0$m

$$q_{TOTAL} = \sum_i \Delta Y_i \cdot V_i \cos\alpha_i \cdot unitwidth$$

$$= 1.0 \cdot 0.1 \cdot (3.0\cos 30°) + (5\cos 25°) + (7\cos 21°) + (7.5\cos 17°) = 1.0 \cdot 0.1 \cdot (2.6 + 4.53 + 6.54 + 7.17)$$

$$= \underline{\underline{2.084\text{m}^3\text{s}^{-1}}}$$

Q3. a). At the nozzle exit, $p_e = p_a = 10^5$ Nm^{-2}

Apply Bernoulli's Equation from the nozzle exit to the top of the water column:

$p_e + \frac{1}{2}\rho V_e^2 = p_a + \rho g h = p_o = p_{o,1}$, as there is no loss of heat in the nozzle.

$p_{o,1} = p_o = p_a + \rho g h = 10^5 + 10^3 \cdot 9.81 \cdot 20.0 = \underline{\underline{2.962 \cdot 10^5}}$ Nm^{-2} (1.962bar gauge)

Conservation of mechanical energy between the nozzle exit and the top of the water height: $\frac{1}{2}\rho V_e^2 = \rho g h$ as static pressure being constant => $V = \sqrt{2gh} = \underline{\underline{19.81\text{ms}^{-1}}}$

[8]

b). All kinetic energy is lost to the potential at the top, the total power required is:

$$P = \dot{m}\frac{1}{2}\rho V_e^2 = \rho A_e \frac{1}{2}\rho V_e^3 = 10^3 \cdot 0.16 \cdot \frac{1}{2}(2gh)^{3/2} = \underline{\underline{6.22*10^5\text{W}=622\text{kW}}}$$

(or $P = \Delta p_o \cdot \dot{Q} = (p_o - p_a) \cdot V_e A_e$) [7]

c) neglect the nozzle height, apply continuity to find V_1:

$$V_1 \cdot A_1 = V_e A_e; \quad V_1 \cdot A_1 = V_1 \cdot 10 \cdot A_e = V_e A_e; \quad V_1 = \frac{1}{10}V_e = \underline{\underline{1.981\text{ms}^{-1}}}$$

$$p_1 = p_{o,1} - \frac{1}{2}\rho V_1^2 = 296200 - 1962 = \underline{\underline{294000\text{Nm}^{-2}}} \quad (= 2.94\text{bar, } 1.94\text{bar gauge})$$

[5]

The forces to hold nozzle is those to balance the forces the fluid acting on the nozzle, they have the same magnitudes and same directions as the forces acting on the fluid by the nozzle in both *x* and *y* direction respectively. So the force coefficients of forces acting on the fluid are the same both in magnitude and in direction to those required to hold the nozzle. Solving the force coefficients of the nozzle acting the fluid instead:

SFME in *x*-direction:

$$F_x + (p_1 - p_a) \cdot A_1 = -\dot{m}V_1; \quad F_x = -\dot{m}V - (p_1 - p_a) \cdot A_1$$

$$C_{f,x} = \frac{-\rho A_e V_e V_1 - 0.5 \cdot \rho (V_e^2 - V_1^2) \cdot 10 A_e}{\rho V_e^2 A_e} = \frac{-1}{10} - \frac{1}{2}(1 - \frac{1}{100}) \cdot 10 = \frac{-20}{200} - \frac{990}{200} = -\frac{970}{200} = \underline{\underline{-5.05}}$$

SFME in *y*-direction:

$$F_y = \dot{m}V_e = \rho A_e V_e^2; \quad C_{f,y} = \frac{\rho A_e V_e^2}{\rho A_e V_e^2} = \underline{\underline{1.0}}$$

[10]

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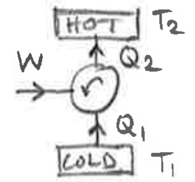
4.



$T_2 = 27°C = 273+27 = 300K$

$Q_1 = 1.25\,kW$

a) $T_1 = -23°C = 273-23 = 250K$

The minimum power is supplied when the cyclic process is reversible, so the entropy change of the cold reservoir equals that of the hot reservoir. $\Rightarrow \dfrac{Q_1}{T_1} = \dfrac{Q_2}{T_2} \Rightarrow Q_2 = \dfrac{T_2}{T_1} Q_1$

By the 1st law, $W = Q_2 - Q_1$ $\Rightarrow W = \left(\dfrac{T_2}{T_1} - 1\right) Q_1 = \left(\dfrac{300}{250} - 1\right) 1.25\,kW$

$= 0.25\,kW$

$COP_R = \dfrac{Q_1}{W}$ by definition $\Rightarrow COP_R = \dfrac{1.25\,kW}{0.25\,kW} = 5$

b) The actual power is $W = 0.50\,kW$

By the 1st law, $Q_2 = Q_1 + W = 1.25\,kW + 0.5\,kW = 1.75\,kW$

The total entropy generation due to irreversibility is the entropy increase of the hot reservoir minus the entropy decrease of the cold reservoir $= \dfrac{Q_2}{T_2} - \dfrac{Q_1}{T_1} = \left(\dfrac{1.75}{300} - \dfrac{1.25}{250}\right) \times 10^3 \ \dfrac{\text{Watts}}{K}$

$= 0.8333 \text{ Watts } K^{-1}$

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5. a) Isentropic compression $\Rightarrow \dfrac{T}{p^{(\gamma-1/\gamma)}} = \text{const} \Rightarrow T_2 = T_1\left(\dfrac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = 270(10)^{\frac{0.4}{1.4}} = 521.3\,K$

b) 1st law applied to a system: $Q - W = E_2 - E_1 = U_2 - U_1$ ← because kinetic energy and gravitational P.E. can be neglected.

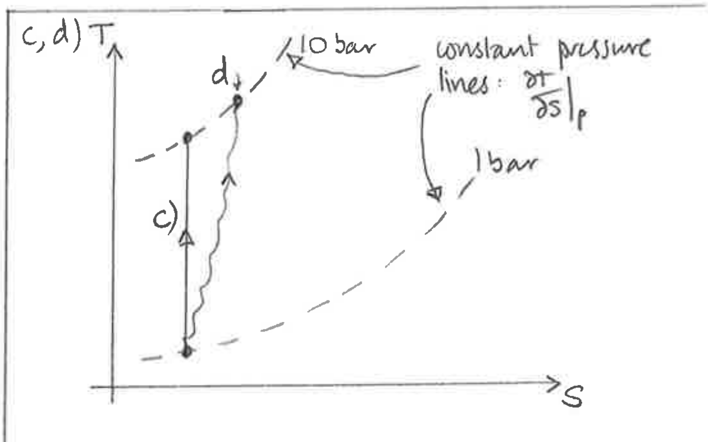
no heat input $\Rightarrow -W = mC_v(T_2 - T_1)$

To work out C_v from R and γ: $R = C_p - C_v = C_v(\gamma - 1) \Rightarrow C_v = R/(\gamma-1)$

W above is the work done by the system. The work done on the system per unit mass of gas is:

$\dfrac{W}{m} = C_v(T_2 - T_1) = \dfrac{R}{(\gamma-1)}(T_2 - T_1)$

$= \dfrac{287}{0.4}\left(10^{2/7} - 1\right)270 = 180.3\,kJ\,kg^{-1}$



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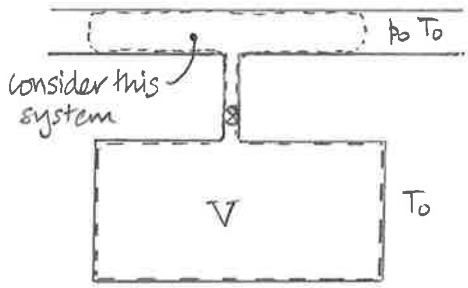
6.



Examiner's note: This question can also be solved using the 1st law applied to a control volume, including the Steady Flow Energy Equation (which is sometimes called the 'non-steady flow energy equation)

a) Consider a system containing the air that will end up inside the vessel. The gas in the main does work on this system as it pushes the air into the vessel. Neglecting kinetic energy and gravitational potential energy, the first law gives $Q - W = U_1 - U_0$. The process takes place quickly so we can safely assume no heat transfer ($Q=0$). W above is the work done by the system so, for work done on the system:

$$W = U_1 - U_0 = m_1 c_v (T_1 - T_0)$$

but the work done on the gas $= \int p \, d\mathcal{V} = p_0 m_1 v_0$ ← specific volume that this mass of air had when it was in the main; m_1 ↑ mass of air that enters vessel

$\Rightarrow W = p_0 m_1 v_0 = R T_0 m_1$ because air is treated as a perfect gas: $p_0 v_0 = R T_0$

$$\Rightarrow R T_0 m_1 = m_1 c_v (T_1 - T_0)$$
$$\Rightarrow (R + c_v) T_0 = c_v T_1$$
$$\Rightarrow c_p T_0 = c_v T_1$$
$$\Rightarrow T_1 = \gamma T_0 \quad \text{as required}$$

$$m_1 = \frac{p_1 V}{R T_1} = \frac{p_0 V}{\gamma R T_0} \quad \text{because } p_1 = p_0 \text{ and } T_1 = \gamma T_0$$

b) After the gas has entered the vessel, it is hotter than its surroundings, which are at T_0. Heat conducts through the vessel walls into the surroundings. The mass in the vessel stays constant so the pressure drops as the temperature drops.

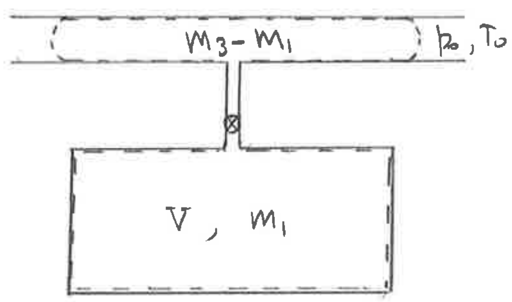
The mass does not change, so

$$m_2 = m_1$$

$$\Rightarrow \frac{p_2 V}{R T_2} = \frac{p_1 V}{R T_1} = \frac{p_0 V}{\gamma R T_0}$$

$$\Rightarrow \frac{T_2}{T_0} = \gamma \frac{p_2}{p_0} = 0.8\gamma$$

c)



The mass of air that ends up inside the vessel after the next fill is m_3. Therefore the mass that started outside the vessel is $m_3 - m_1$. Consider a system containing the mass of air that ends up inside the vessel, m_3. This is a system. Assume an adiabatic process.

The work done on the system is the work required to compress the mass $m_3 - m_1$:

$$W = p_0 v_0 (m_3 - m_1) = RT_0 (m_3 - m_1) \quad \text{via the same analysis as in a).}$$

The 1st law applied to this system gives:

$$W = \underbrace{m_1}_{\text{mass already in the vessel}} c_v (T_3 - \underbrace{T_2}_{\text{temperature of air already in the vessel}}) + \underbrace{(m_3 - m_1)}_{\text{mass that enters the vessel}} c_v (T_3 - \underbrace{T_0}_{\text{temperature of air that enters the vessel}})$$

$$\Rightarrow RT_0 (m_3 - m_1) = m_1 c_v (T_3 - T_2) + (m_3 - m_1) c_v (T_3 - T_0)$$

$$\Rightarrow \frac{R}{c_v}(m_3 - m_1) = m_1 \left(\frac{T_3}{T_0} - \frac{T_2}{T_0} - \frac{T_3}{T_0} + \frac{T_0}{T_0} \right) + m_3 \left(\frac{T_3}{T_0} - \frac{T_0}{T_0} \right)$$

$$\Rightarrow \frac{R}{c_v}(m_3 - m_1) = m_1 \left(1 - \frac{4}{5}\gamma \right) + m_3 \left(\frac{T_3}{T_0} - 1 \right)$$

$$\Rightarrow \frac{R}{c_v}(m_3 - m_1) = -(m_3 - m_1) + m_3 \frac{T_3}{T_0} - m_1 \frac{4}{5}\gamma$$

$$\Rightarrow \left(\frac{R}{c_v} + 1 \right)(m_3 - m_1) = m_3 \frac{T_3}{T_0} - m_1 \frac{4}{5}\gamma \quad ; \text{ but } \frac{R}{c_v} + 1 = \frac{c_p - c_v}{c_v} + 1 = \gamma$$

$$\Rightarrow \gamma (m_3 - m_1) = m_3 T_3/T_0 - m_1 4/5\,\gamma$$

$$\Rightarrow m_3 \left(\gamma - \frac{T_3}{T_0} \right) = m_1 \left(\gamma - \frac{4\gamma}{5} \right) = m_1 \frac{\gamma}{5}$$

; but $m_1 = \dfrac{p_1 V}{RT_1}$ and $m_3 = \dfrac{p_3 V}{RT_3}$

where $p_1 = p_3 = p_0$

$$\Rightarrow \frac{m_3}{m_1} = \frac{T_1}{T_3} = \frac{\gamma T_0}{T_3}$$

$$\Rightarrow \frac{\gamma T_0}{T_3} \left(\gamma - \frac{T_3}{T_0} \right) = \frac{\gamma}{5}$$

$$\Rightarrow \frac{\gamma T_0}{T_3} - 1 = \frac{1}{5}$$

$$\Rightarrow \frac{T_3}{T_0} = \frac{5\gamma}{6}$$

$$\Rightarrow \frac{m_3}{m_1} = \frac{6}{5}$$

2012 - PART IA - Paper 1: Mechanical Engineering - Section B
Aylmer Johnson and Nathan Crilly

7a) NO MOMENTS ACT ABOUT AXIS

b) CONSERVATION OF MOMENT OF MOMENTUM

$$m\,l\omega_1 l + m\,2l\omega_1 2l = 2m\,2l\omega_2\,2l$$

$$\therefore \quad \omega_1 + 4\omega_1 = 8\omega_2$$

$$\therefore \quad \omega_2 = \frac{5}{8}\omega_1$$

c) CONSERVATION OF ENERGY

WHEN OP $= l$: "$\frac{1}{2}mv^2$"

$$KE_1 = \frac{1}{2}m(l\omega_1)^2 + \frac{1}{2}m(2l\omega_1)^2$$

$$= \frac{1}{2}ml^2(5\omega_1^2)$$

WHEN OP $= 2l$:

$$KE_2 = \underbrace{\frac{1}{2}(2m)(2l\omega_2)^2}_{\text{TANGENTIAL}} + \underbrace{\frac{1}{2}mv^2}_{\text{RADIAL}}$$

$$= \frac{1}{2}ml^2(8\omega_2^2) + \frac{1}{2}mv^2$$

$$\therefore \quad 5\omega_1^2 = 8\cancel{\omega_2^2} + \frac{v^2}{l^2} = \frac{25}{8}\omega_1^2 + \frac{2v^2}{l^2}$$

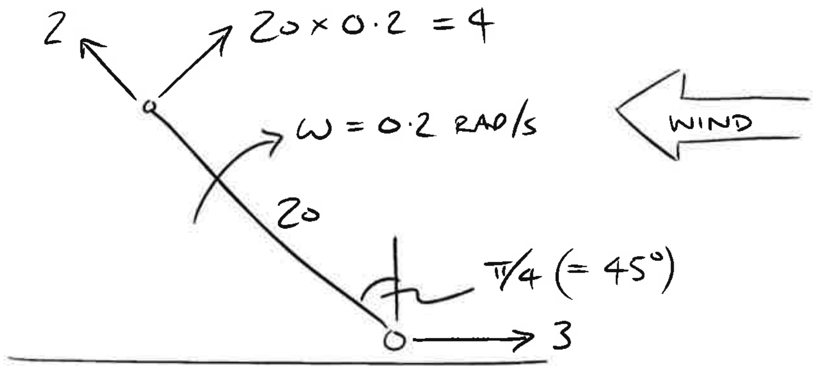
$$\left(\frac{5}{8}\omega_1\right)^2$$

$$\therefore \quad 5\omega_1^2 = \frac{25}{8}\omega_1^2 + \frac{v^2}{l^2} \qquad \therefore \quad \frac{15}{8}\omega_1^2 = \frac{v^2}{l^2}$$

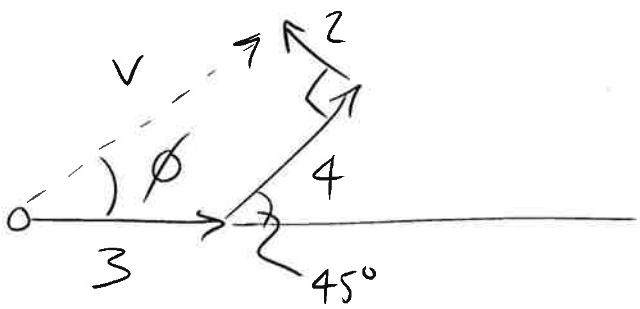
$$\therefore \quad v^2 = \frac{15}{8}\omega_1^2 l^2$$

$$\therefore \quad v = \sqrt{\frac{15}{8}}\,\omega_1 l$$

8)



a)

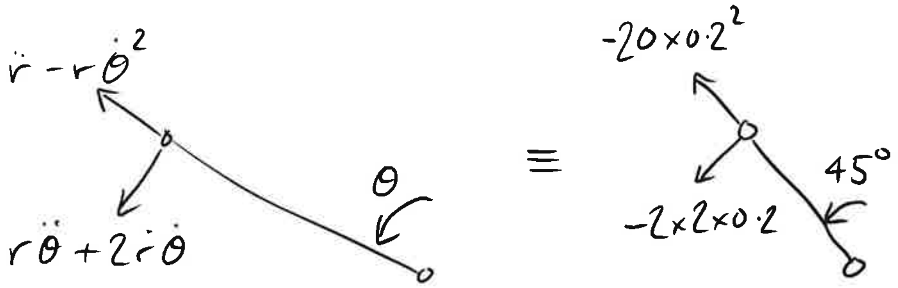


$$V_H = 3 + 2\frac{1}{\sqrt{2}} = 4.41 \qquad V_V = \frac{1}{\sqrt{2}}(4+2) = 4.24$$

$$\therefore V = \underline{\underline{6.12 \text{ m/s}}} \qquad \phi = \tan^{-1}\left(\frac{4.24}{4.41}\right) = \underline{\underline{43.87^\circ}}$$

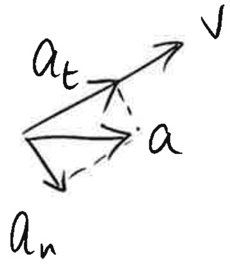
$$= \underline{\underline{0.766 \text{ RAD}}}$$

b) FROM p1 OF D.B.:



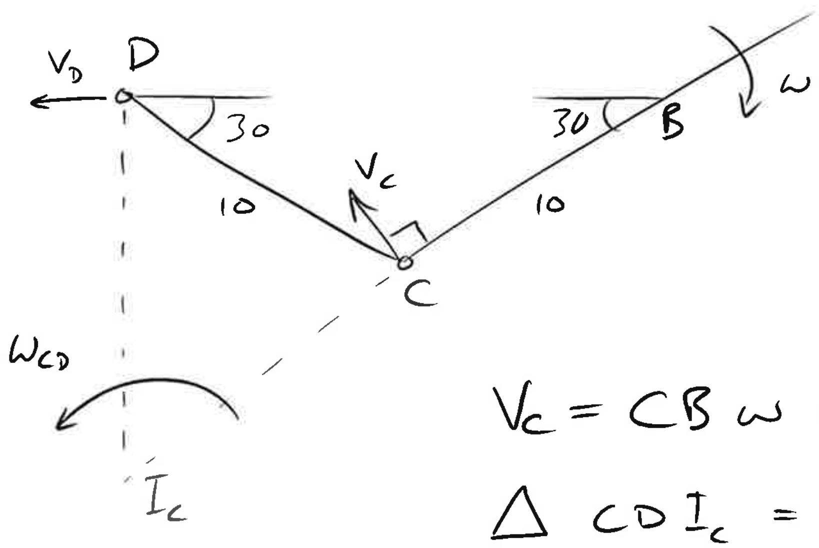
$$\therefore a_V = \frac{1}{\sqrt{2}}(0.8 - 0.8) = \underline{\underline{0}}$$

c) $a = 2(0.8)(1/\sqrt{2}) \rightarrow$



a_n IS DOWN $\therefore$ $\underline{\underline{\text{DOWNWARDS}}}$

9a)



$V_C = CB\,\omega = CI_C\,\omega_{CD}$

$\triangle\ CDI_C$ = EQUILATERAL

$\therefore\ CB = CI_C = DI_C = 10\,\text{mm}$

$\therefore\ \omega_{CD} = \omega = \underline{\underline{10\ \text{RAD/s}}}$ (↶)

b) POWER EQUATION

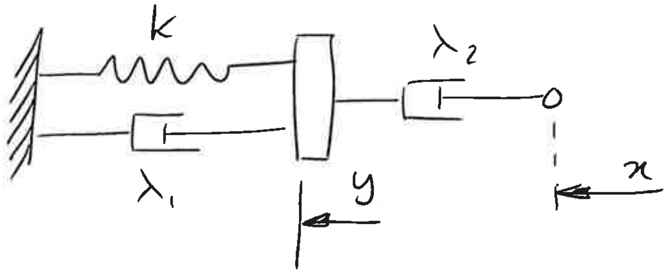
$V_D = \omega_{CD}(10) = \underline{\underline{100}}\ \text{mm/s}\ (\leftarrow)$

c) $F V_{A(V)} = (20)\,V_{D(H)}$

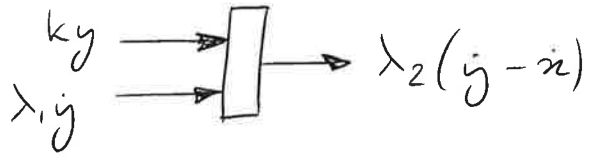
$V_{A(V)} = 20\omega\cos 30 = 20\omega\frac{\sqrt{3}}{2} = 10\omega\sqrt{3}\ \ \text{mm/s}$

$\therefore\ F = \frac{(20)(100)}{10\omega\sqrt{3}} = \underline{\underline{\frac{20}{\sqrt{3}}\ N}}$

10)



a)



"$\sum F = 0$" $\quad -ky - \lambda_1 \dot{y} - \lambda_2 \dot{y} + \lambda_2 \dot{x} = 0$

$$\therefore \left(\frac{\lambda_1 + \lambda_2}{k}\right)\dot{y} + y = \frac{\lambda_2}{k}\dot{x}$$

$$\therefore \underline{\underline{T = \frac{\lambda_1 + \lambda_2}{k}}} \text{ — (1)} \qquad \underline{\underline{b = \frac{\lambda_2}{k}}} \text{ — (2)}$$

b) $\quad T\dot{y} + y = b\dot{x} \quad ; \quad x = \alpha t \Rightarrow \dot{x} = \alpha$

$\therefore T\dot{y} + y = b\alpha \qquad \therefore y = Ae^{-t/T} + b\alpha$

I.C. $\quad y = 0 \;@\; t = 0 \qquad \therefore 0 = A + b\alpha \quad \therefore A = -b\alpha$

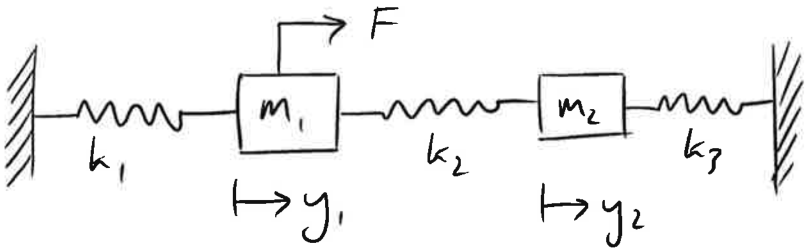
$$\therefore \underline{\underline{y = b\alpha\left(1 - e^{-t/T}\right)}}$$

c) $\quad$ IF $t = T$, $\; y = \frac{\alpha T}{2} \qquad \therefore \frac{\alpha T}{2} = b\alpha\left(1 - e^{-1}\right)$

SUBSTITUTING (1) AND (2): $\quad \frac{\alpha(\lambda_1 + \lambda_2)}{2k} = \frac{\lambda_2 \alpha}{k}\left(1 - e^{-1}\right)$

α AND k CANCEL, GIVING: $\quad \underline{\underline{\lambda_2 = 3.78\lambda_1}}$

1 a)



"$\sum F = ma$"

$$F - k_1 y_1 + k_2(y_2 - y_1) = m_1 \ddot{y}_1 \quad \text{—— ①}$$

$$k_2(y_1 - y_2) - k_3 y_2 = m_2 \ddot{y}_2 \quad \text{—— ②}$$

$$\therefore \begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 + k_3 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} F \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 300 & -200 \\ -200 & 400 \end{bmatrix}$$

$\therefore$ $\underline{\underline{m_1 = m_2 = 1\text{kg}}}$; $\underline{\underline{k_2 = k_3 = 200 \text{ N/m}}}$; $\underline{\underline{k_1 = 100 \text{ N/m}}}$

b) FOR ω_n,

$$\left| [k] - \omega^2 [m] \right| = 0 = \begin{vmatrix} 300 - \omega^2 & -200 \\ -200 & 400 - \omega^2 \end{vmatrix}$$

$$= (300 - \omega^2)(400 - \omega^2) - 200^2 = \omega^4 - 700\omega^2 + 80000 = 0$$

$$\therefore \omega^2 = \frac{700 \pm \sqrt{700^2 - 320000}}{2} = 350 \pm 206.2 = 556, 144$$

$$\therefore \omega = \underline{\underline{23.6, 12}} \text{ RAD/S}$$

c) NEITHER MASS MOVES AT $\omega = 0$

$$\begin{bmatrix} 300 - \omega^2 & -200 \\ -200 & 400 - \omega^2 \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} F \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \frac{1}{DET} \begin{bmatrix} 400 - \omega^2 & 200 \\ 200 & 300 - \omega^2 \end{bmatrix} \begin{bmatrix} F \\ 0 \end{bmatrix} = \frac{F}{DET} \begin{bmatrix} 400 - \omega^2 \\ 200 \end{bmatrix}$$

So, ONLY $Y_1 = 0$, WHEN $\omega^2 = 400$ $\therefore$ $\omega = 20$ RAD/S

d) $\underline{Y} = \left\{ [K] - \omega^2 [m] \right\}^{-1} [F]$

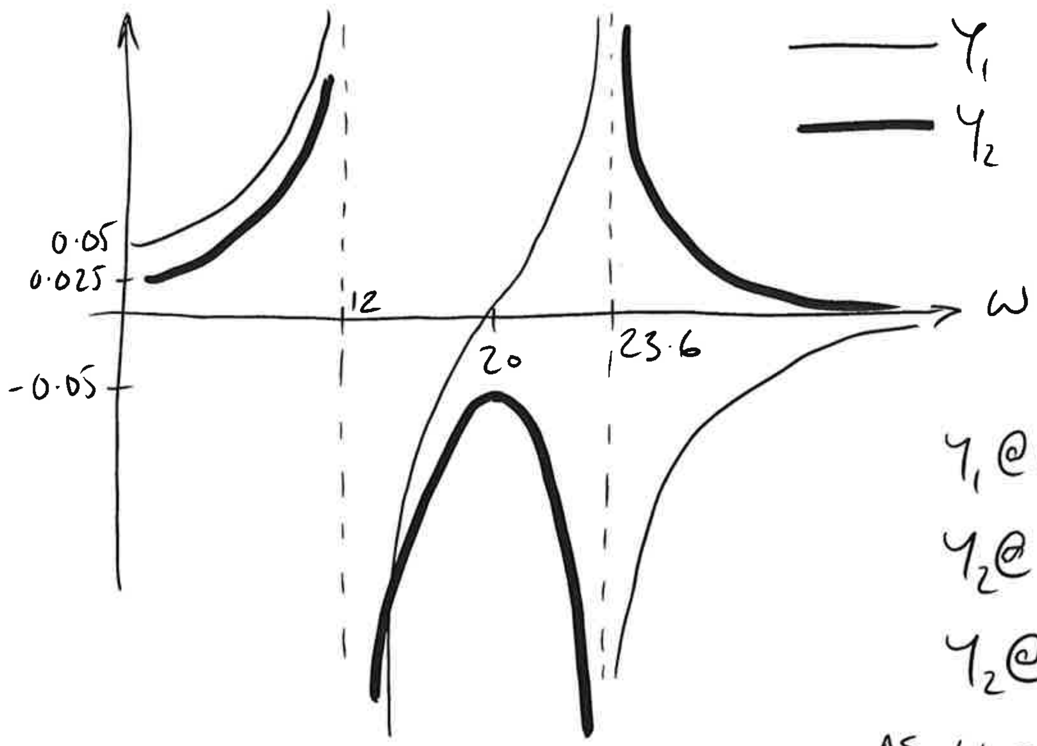
$$= \left\{ \begin{bmatrix} 300 & -200 \\ -200 & 400 \end{bmatrix} - \omega^2 \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \right\}^{-1} [F]$$

$$= \begin{bmatrix} 300 - \omega^2 & -200 \\ -200 & 400 - \omega^2 \end{bmatrix}^{-1} [F]$$

$$= \frac{1}{(300 - \omega^2)(400 - \omega^2) - 400} \begin{bmatrix} 400 - \omega^2 & 200 \\ 200 & 300 - \omega^2 \end{bmatrix} \begin{bmatrix} 10 \\ 0 \end{bmatrix}$$

$$Y_1 = \frac{(400 - \omega^2)(10)}{\omega^4 - 700\omega^2 + 80000} = \frac{4000 - 10\omega^2}{\omega^4 - 700\omega^2 + 80000}$$

$$Y_2 = \frac{200(10)}{\omega^4 - 700\omega^2 + 80000} = \frac{2000}{\omega^4 - 7000\omega^2 + 80000}$$



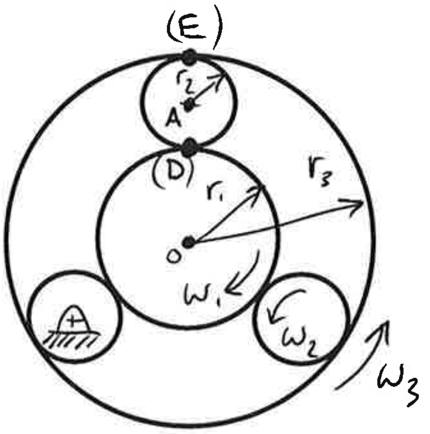
$Y_1 @ 0 = \frac{4000}{80000}$

$Y_2 @ 0 = \frac{2000}{80000}$

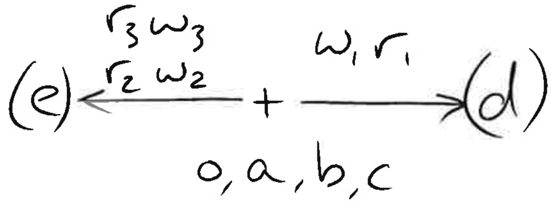
$Y_2 @ 20 = -0.05$

AS $\omega \to \infty$ $Y_2 \to 0$

12 a) "CONDITION 1"



VELOCITY DIAGRAM:



$r_1 = 2r_2$; $r_3 = r_1 + 2r_2$

$\therefore r_3 = 4r_2$

$r_2\omega_2 = r_1\omega_1 \quad \therefore \omega_2 = \dfrac{r_1\omega_1}{r_2}$

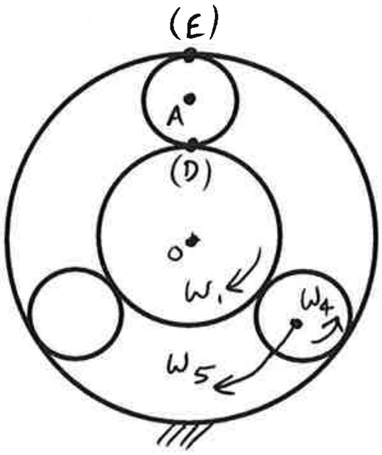
$\omega_2 = \dfrac{2r_2\omega_1}{r_2} = 2\omega_1$ ↺

$r_2\omega_2 = r_3\omega_3 \quad \therefore \omega_3 = \dfrac{r_2\omega_2}{r_3}$

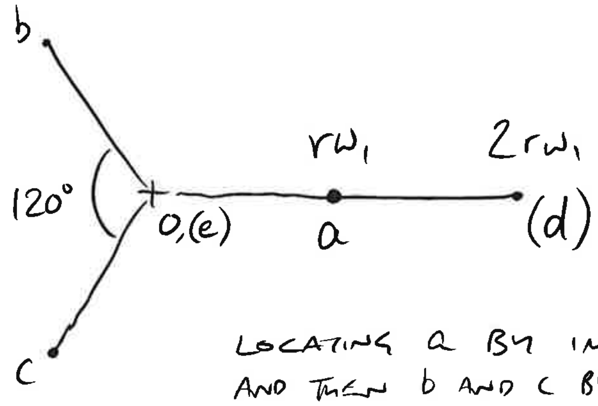
$\omega_3 = \dfrac{r_2\omega_2}{4r_2} = \dfrac{2\omega_1}{4} = \dfrac{\omega_1}{2}$ ↺ //

bi)

"CONDITION 2"



VELOCITY DIAGRAM:



LOCATING a BY IMAGE AND THEN b AND c BY IMAGE

bii)

$\omega_5 = \dfrac{oa}{OA} = \dfrac{\left(\frac{1}{2} r_1\omega_1\right)}{r_1 + r_2} = \dfrac{\omega_1}{3}$ ↻ //

[FOR LATER]

$\omega_4 = \dfrac{ae}{AE} = \dfrac{\frac{1}{2}(r_1\omega_1)}{r_2} = \omega_1$ ↺

c i) BY CONSERVATION OF POWER

(1) $12T\omega_1 = T_3 \omega_3 = T_3 \frac{\omega_1}{2}$

$\therefore T_3 = \frac{12T\omega_1}{\frac{1}{2}\omega_1} = 24T$

(2) $12T\omega_1 = T_5 \omega_5 = T_5 \frac{\omega_1}{3}$

$\therefore T_5 = \frac{12T\omega_1}{\frac{1}{3}\omega_1} = 36T$

$\therefore T_5 = \frac{3}{2} T_3$

c ii) FRICTIONAL LOSS (1) $= 3T\omega_2 = 6T\omega_1$

FRICTIONAL LOSS (2) $= 3T(\omega_4 + \omega_5) = 4T\omega_1$

BY CONSERVATION OF POWER

(1) $12T\omega_1 = \omega_3 T_3 + 6T\omega_1$

$= \frac{\omega_1}{2} T_3 + 6T\omega_1 \quad \therefore T_3 = 12T$

(2) $12T\omega_1 = \omega_5 T_5 + 4T\omega_1$

$= \frac{\omega_1}{3} T_5 + 4T\omega_1 \quad \therefore T_5 = 24T$

$\therefore T_5 = 2T_3$