NAME OF STUDENT--------------------------- UNIV. NUMBER----------------

King Saud University
College of Engineering
Mechanical Engineering Department
First Semester Final Examination (1428/1429)

Subject: Mechanical Measurements-ME 302

Question # 1 (5+3)

Given the following calibration data for a hot wire anemometer measuring system:

U m/sec	*0.0*	*5*	*10*	*20*	*30*	*50*
E volt	**2.5**	**4.0**	**4.5**	**5.12**	**5.6**	**5.87**

The expected relation is King's Law: $\mathbf{E^2 - E_o^2 = b\,(U)^n}$

Where E_o is the voltage output when U= 0.0

- Transfer the above relation to straight line relation using log-log plotting and find the values of constants b and n.
- Draw the relation between U and the static sensitivity of the system.

Question #2 (2+3)

A thermocouple is used to monitor the temperature of a fluid in a heated tank. The heating element in the tank cycles on and off, causing the actual temperature of the fluid to vary approximately sinusoidal such that;

$$T = 100 \sin (0.3\, \pi\, t).$$

The thermocouple has a time constant of 0.9 sec.

- Calculate the temperature variation that the thermocouple will measure.
- Sketch the temperature variation that the thermocouple will measure

Question # 3 (3+2)

(i) Draw a 3-bits D/A converter find its output.

(ii) A pressure signal is given by
P= 10 sin (628t) + 8 sin (3140t) + 5 sin (6280t).

- Draw its frequency spectrum.
- Determine a proper sampling frequency and number of points for the signal.

Question # 4 **(5)**

The following input signal V_{in} is applied to a low pass filter that consists of a circuit resistance R= 20 kΩ and capacitance C= 0.2 μF. Determine the output of the filter.

$V_{in} = 5 \sin(20\pi t) + 2 \cos(400 \pi t)$.

Question # 5 **(2+3)**

(i) A combination pressure and temperature probe of temperature recovery factor 0.5 is immersed in a gas stream having pressure and temperature as 300 kPa and 727^0C. Find the indicated temperature by the probe and the bias errors for a Mach number of 0.8. Take k = 1.33.

(ii) A Pitot- static tube is used to measure velocity of an aircraft. The air temperature and pressure are -5^0C and 85 kPa respectively. If the dynamic pressure reading is 500 mm of water calculate the velocity of aircraft taking

- Flow as incompressible.
- Flow as compressible.

Take density of water as $1000 kg/m^3$, k= 1.4 and R =$287 J/kg\text{-}^0C$.

Question # 6 **(9+3)**

(a) The following experimental measurements are recorded:

- Sound rms pressure $\mathbf{P_{rms}} = 20 \pm 2\%$ Pa
- Distance from sound source r = 2 m ± 1%
- Sound velocity c = 340 ± 10 m/sec.
- Air density ρ = 1.16 ± 0.02 kg/m^3

Given

$$\frac{W}{4\pi * r^2} = \frac{(P_{rms})^2}{\rho c}$$

Find :

(1) The sound power (W) in watt and its uncertainty

(2) The sound power level SWL in dB (ref. 10^{-12} watt)

(3) The sound pressure level SPL in dB (ref. 2×10^{-5} Pascal)

(b) What is the sound pressure level for 3 identical pumps in dB, given that each of the pumps has sound pressure level of 80 dB.

Final - ME302 - 1428-29 Solution

Q1

$$E^2 = E_0^2 + bU^n$$

$$2 \log E = 2 \log E_0 + n \log U + \log b$$

U	0	5	10	20	30	50
E	2.5	4.0	4.5	5.12	5.6	5.87
log U	∞	0.599	1.0	1.3010	1.4771	1.699
log E	0.398	0.6020	0.6532	0.7093	0.7482	0.7686

$\log b = 5.1$ $\qquad b = 3.235$

$$n = \frac{1.6}{5.0} = 0.32$$

$$K = \frac{dE}{dU}$$

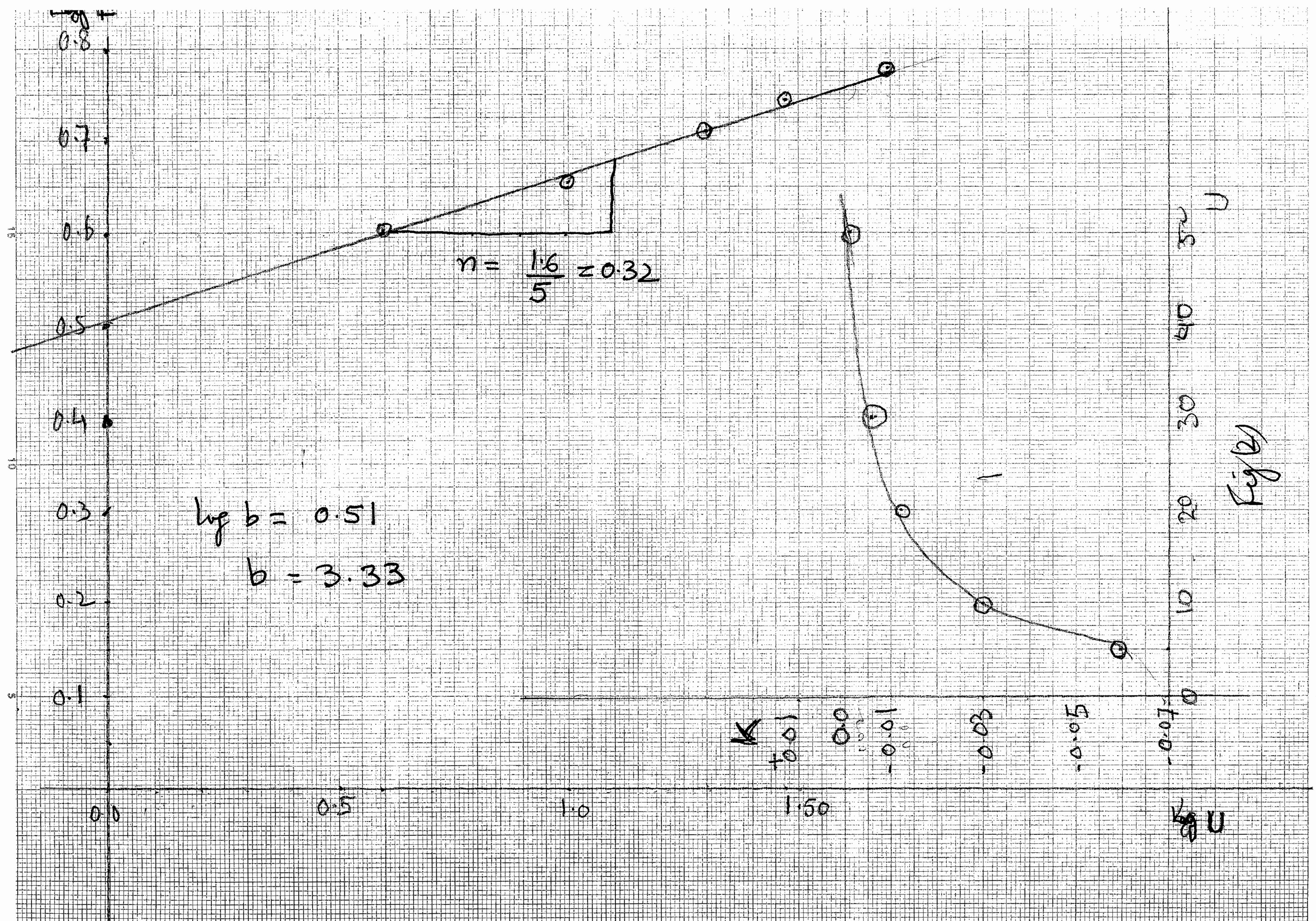
$$2E\,dE = b n U^{n-1} dU$$

$$K = \frac{dE}{dU} = \frac{bnU^{n-1}}{2E} = \frac{bnU^{n-1}}{2[E_0 - bU^n]}$$

U	0	5	10	20	30	50
K	∞	-0.06	-0.05	-0.011	-0.007	-0.004

$$K = \frac{3.235 \times 0.32\, U^{0.}}{2 \times U^{1-n}[E_0 - bU^n]}$$

$$= \frac{3.235 \times 0.16}{E_0 \times U^{0.68} - 3.235 \times U} = \frac{0.518}{2.5\,U^{0.68} - 3.235U}$$



log f
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.5
1.0
1.50
log U
$n = \frac{1.6}{5} = 0.32$
log b = 0.51
b = 3.33
U
50
40
30
20
10
0
-0.07
-0.05
-0.03
-0.01
0.0
+0.01
Fig(2)

Q2

$T = 100 \sin(0.3\pi t)$

$T_s = 100°C$

$T_i = 100 \sin(2 \times 0.15 \pi t)$

$T = 6.67 sec$ $f = 0.15 Hz$ $\omega = 0.3\pi$ rad/s

$\tau = 0.9 sec$

$$\frac{T_d}{T_s} = \frac{1}{\sqrt{1+(\omega\tau)^2}} = \frac{1}{\sqrt{1+(0.3\pi \times 0.9)^2}} = 0.7$$

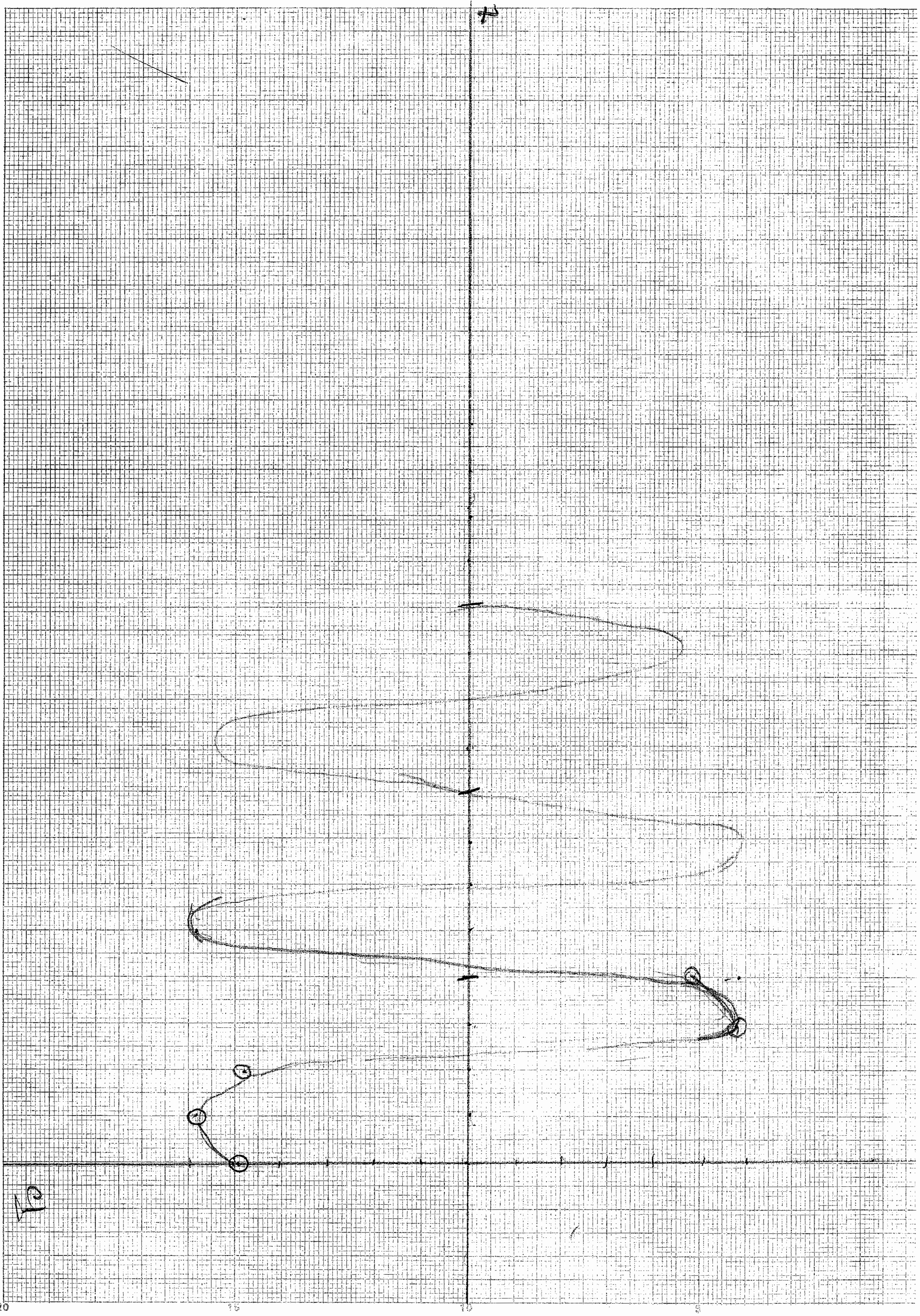
$T_d = 76.28°C$

$\phi = \tan^{-1}(\omega\tau)$

$\phi = ~~40.29°~~$ 0.703

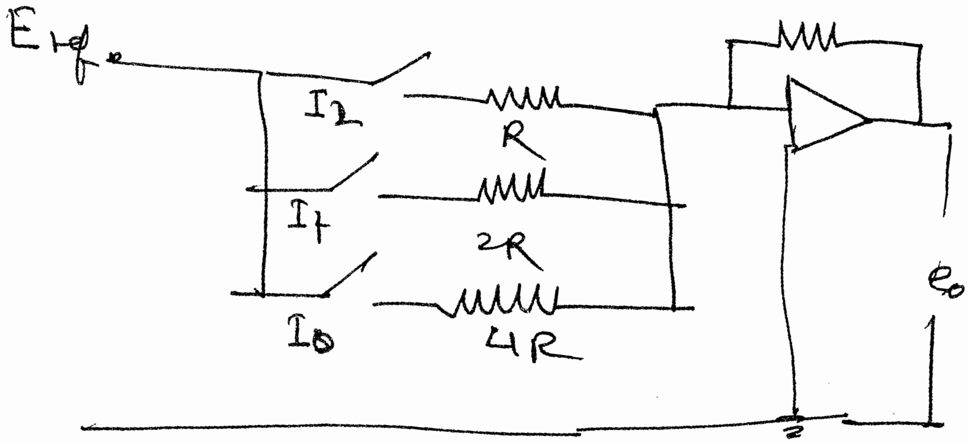
$\therefore T_o = 76.28 \sin(0.3\pi t - 0.703)$

t	T_o
0	49.31
1.67	58.31
3.34	+49.31
5.00	-58.07
6.67	-49.32
8.34	-58.31
10.01	+6.45
11.68	+58.07
13.35	+6.45
15.02	58.77
16.69	48.495


20
15
10
5

Q3

(a) $n = 3$ ∴ Resistances $4R, 2R, R$



$I_0 = \frac{E_{ref}}{4R}$ $I_1 \; \frac{E_{ref}}{2R}$ $I_2 \; \frac{E_{ref}}{R}$

$E_0 = -\frac{R_G E_{ref}}{R}\left[b_0 + \frac{b_1}{2} + \frac{b_2}{4}\right]$

Total output $b_0 = b_1 = b_2 = 1$

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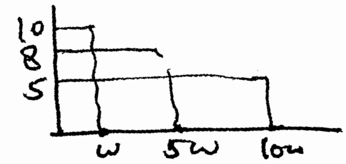
$E_0 = -\frac{R_G E_{ref}}{R}\left(1 + \frac{1}{2} + \frac{1}{4}\right)$

$$E_0 = -\frac{7 R_G E_{ref}}{4R}$$



(b) $P = 10\sin(628t) + 8\sin(3140t) + 5\sin(6280t)$

$\omega_1 = 628.$ $\omega_2 = 3140 = 5\omega_1$

$\omega_3 = 6280 = 10\omega_1$

$f_1 = \frac{\omega}{2\pi} = 100\,Hz$ $f_2 = 500\,Hz$ $f_3 = 1000\,Hz$

$f_{nyq} = f_h = 1000\,Hz$ ∴ $f_s > 2f_{nq} > 2000$ ∴ $f_s = 2100\,Hz$

$\Delta f = 100\,Hz$ ∴ $N = f_s/\Delta f = \frac{2100}{100} = 21$

(4) $V_{in} = 5\sin 20\pi t + 2\cos 400\pi t$

Low pass filter $R = 20\,k\Omega$

$C = 0.2\,\mu F$

$V_{i1} = 5\sin(20\pi t) \qquad f = 10\text{ Hz}$

$f_c = \frac{1}{2\pi RC} = 39.81\text{ Hz}$

$$\frac{V_{o1}}{V_{i1}} = \frac{1}{\sqrt{1+(f/f_c)^2}} = 0.894$$

$V_{o1} = 4.47$ volt.

$\phi_1 = \tan^{-1}\left(\frac{f_1}{f_c}\right) = 26.67^0 = 0.246$ radn.

$\therefore V_{o1} = 4.47\sin(20\pi t - 0.246)$

$V_{i2} = 2\cos 400\pi t \qquad f = 200\text{ Hz}$

$f_c = \frac{1}{2\pi RC} = 39.81\text{ Hz}$

$$\frac{V_{o2}}{V_{i2}} = \frac{1}{\sqrt{1+(f/f_c)^2}} = 0.195$$

$V_{o2} = 0.39$ volt

$\phi_2 = \tan^{-1}\left(\frac{f}{f_c}\right) = 1.37$ rad

$V_{o2} = 0.39\sin(200\pi t - 1.37)$

$\therefore V_o = V_{o1} + V_{o2}$

$V_o = 4.47\sin(20\pi t - 0.246) + 0.39\sin(200\pi t - 1.3$

Q5

(i)

$R = 0.5$

$P = 300 kPa$ $T = 727°C$.

T_1 ? $M = 0.8$

ΔT_1 $k = 1.33$

$T_s = 727$
$\underline{273}$
$1000 K$

$$\frac{T_0}{T_s} = 1 + \frac{k-1}{2} M^2$$

$$\frac{T_0}{1000} = 1 + \frac{1.33-1}{2}(0.8)^2.$$

$$T_0 = 1105.6 K$$

~~ΔU_T~~

$$R = 0.5 = \frac{T_1 - T_s}{T_0 - T_s} = \frac{T_1 - 1000}{1105.6 - 1000}$$

$$T_1 = 1052.8 K$$

$$\Delta U_T = (T_1 - T_s) = \underline{52.8 K} \quad 7.3\%$$

(ii)

$T_a = -5°C = 268 K$ $P_a = 85 kPa$ $R = 287 J/kg$.

$k = 1.4$

$\rho = 1000 kg/m^3$

$\Delta h = 500 mm$
$= 0.5 m$

$$\rho_{air} = \frac{P}{RT} = \frac{85}{0.287 \times 268}$$

$$\rho_{air} = 1.105 kg/m^3$$

$$V_{air} = \sqrt{\frac{2\Delta P}{\rho_{air}}} = \sqrt{\frac{2\rho_w g \Delta h}{\rho_{air}}} = 94.22 m/s$$

$$\boxed{V_{incomp} = 94.22 m/s}$$

$$\frac{P_0}{P_s} = \left(1 + \frac{k-1}{2} M^2\right)^{\frac{k-1}{k}}$$

$$\frac{P_0}{P_s} - 1 = \left(1 + \frac{k-1}{2}M^2\right)^{\frac{k-1}{k}} - 1$$

$$\frac{P_0 - P_s}{P_s} = \left[1 + \frac{k-1}{2}M^2\right]^{\frac{k-1}{k}} - 1$$

$$\frac{\Delta P}{P_s} + 1 = \left[1 + \frac{k-1}{2}M^2\right]^{\frac{k-1}{k}}$$

$$\left[\frac{\rho_w g \Delta h}{P_s} + 1\right]^{\frac{k}{k-1}} = 1 + \frac{k-1}{2}M^2$$

$$M = \left\{\left[\left[\frac{\rho_w g \Delta h}{P_s} + 1\right]^{\frac{k}{k-1}} - 1\right] \frac{2}{k-1}\right\}^{\frac{1}{2}}$$

$$M = 0.284$$

$$a = \sqrt{kRT} = \sqrt{1.4 \times 287 \times 268} = 328.15 \text{ m/s}$$

$$\therefore V_{comp} = M \times a = 93.32 \text{ m/s}$$

(Q6)

$P_{rms} = 20 \pm 2\%$ Pa $\quad \frac{U_{P_{rms}}}{P_{rms}} = 0.02$

$r = 2m \pm 1\% \quad \frac{U_r}{r} = 0.01$

$c = 340 \pm 10$ m/s $\quad \frac{U_c}{c} = 0.029$

$\rho = 1.16 \pm 0.02$ kg/m³ $\quad \frac{U_\rho}{\rho} = 0.017$

$$W = \frac{P_{rms}^2 A}{\rho c} = \frac{P_{rms}^2 4\pi r^2}{\rho \times c}$$

$W = 50.95$ Watt

$$\frac{U_w}{W} = \sqrt{\left(2\frac{U_{P_{rms}}}{P_{rms}}\right)^2 + \left(2\frac{U_r}{r}\right)^2 + \left(\frac{U_\rho}{\rho}\right)^2 + \left(\frac{U_c}{c}\right)^2}$$

(1) $\boxed{\frac{U_w}{W} = 0.0559 = 5.59\%}$

$$SWL = 10 \log\left(\frac{W}{W_{ref}}\right) = 10 \log\left[\frac{50.95}{10^{-12}}\right]$$

(2) $\boxed{SWL = 102.93 \text{ dB}}$

$P_{rms} = 20$ Pa

$P = \sqrt{2}\, P_{rms} = 28.285$ Pa

$$\therefore SPL = 20 \log\left(\frac{P}{P_{ref}}\right) = 20 \log\left(\frac{28.285}{20 \times 10^{-6}}\right)$$

(3) $\boxed{SPL = 123.01 \text{ dB}}$

$$SPL \text{ of 3 Pumps} = 20 \log\left[\Sigma \text{ antilog} \frac{dB}{20}\right]$$
$$= 20 \log\left[3 \text{ antilog} \frac{80}{20}\right]$$

SPL = 89.[illegible]