Industrial Instrumentation

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Date: __/__/__

Page: ____

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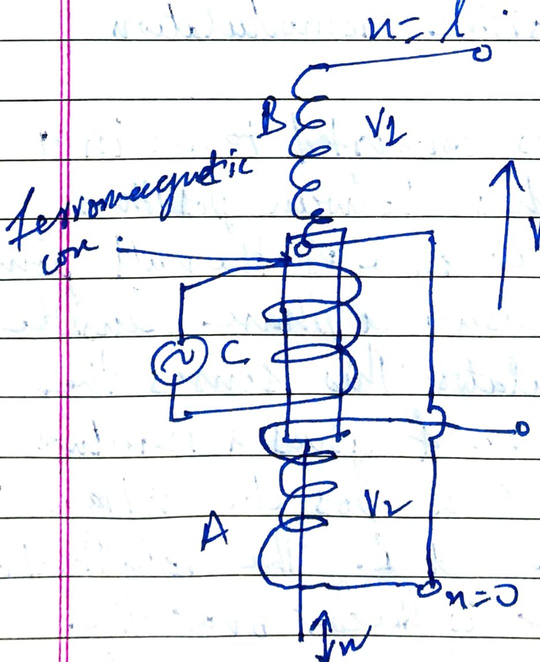
1SEE3 SD14

Q1. (a) LVDT (Linear Variable Differential Transformer) sensor converts linear movement of the object it is coupled to and converts to electrical signal proportional to the movement.

Operation:

It is a transformer with a single primary & two identical secondary windings wound on a tubular ferromagnetic former.



$V_1 - V_2 = \hat{V}_{OUT} \sin(2\pi f t + \phi)$

Date: ___/___/___
Page: ______

The primary winding is energized by an ac voltage of amplitude $\hat{V}_1$ & freq f Hz;

The two secondaries are connected in series opposition so that the output voltage

$\hat{V}_{out} \sin(2\pi f t + \phi)$ is the difference of $(V_1 - V_2)$ of the voltages induced in the secondary coils. A ferromagnetic core moves inside the former; this alters the mutual inductance between the primaries & secondaries. With the core in the former, V_1 & V_2 change with core position x, causing amplitude $\hat{V}_{out}$ & phase ϕ to change.

Need for Phase sensitive demodulation

The a.c. voltage $V_1 - V_2$ is converted to d.c in a way which distinguishes between positions such as A & B either side of the null point C. This is done using a phase sensitive detector or demodulator. This senses the 180° phase difference & gives a negative d.c voltage at A & a pos d.c voltage of equal magnitude at B. The relationship between V_{DC} & x is linear over the central portion of the range 0 to l, but non-linear effects occur at either end (D & E) as the core moves to the edge. This non-linearity can be reduced by using central portion.

Date: __/__/__
Page: ____

(b). Clearly $V_D = V_B$ when $V_C = \text{High}$ — (i).

Assuming +ve terminal of A_3 to be at V_{bias} & the gain resistance to be R_p. Also, assuming the number of turns in all the coils the same.

For ideal opamp,

$$\frac{V_B}{V_A} = \frac{-R_3}{R_A} \quad \left[\because \text{it is in inverting amp}\right]. \quad \text{— (ii)}$$

Since A_1 is in open loop configuration it acts as a comparator.

When $V_s > 0$: V_c = Low or ground (V_{ss}).

$V_s < 0$: V_c = High or V_{cc}. — (iii)

From (i) . $V_D = V_B$. when $V_s < 0$

$V_D = V_{bias}$ when $V_s > 0$ — (iv)

When $V_D = V_{bias}$, as V_D is open circuit, no current flows through R_p & R_4 & R_6 too.

Thus, V_0/V_E is open circuited & pulled to ground by X_{C_2}.

When $V_D = V_B$,

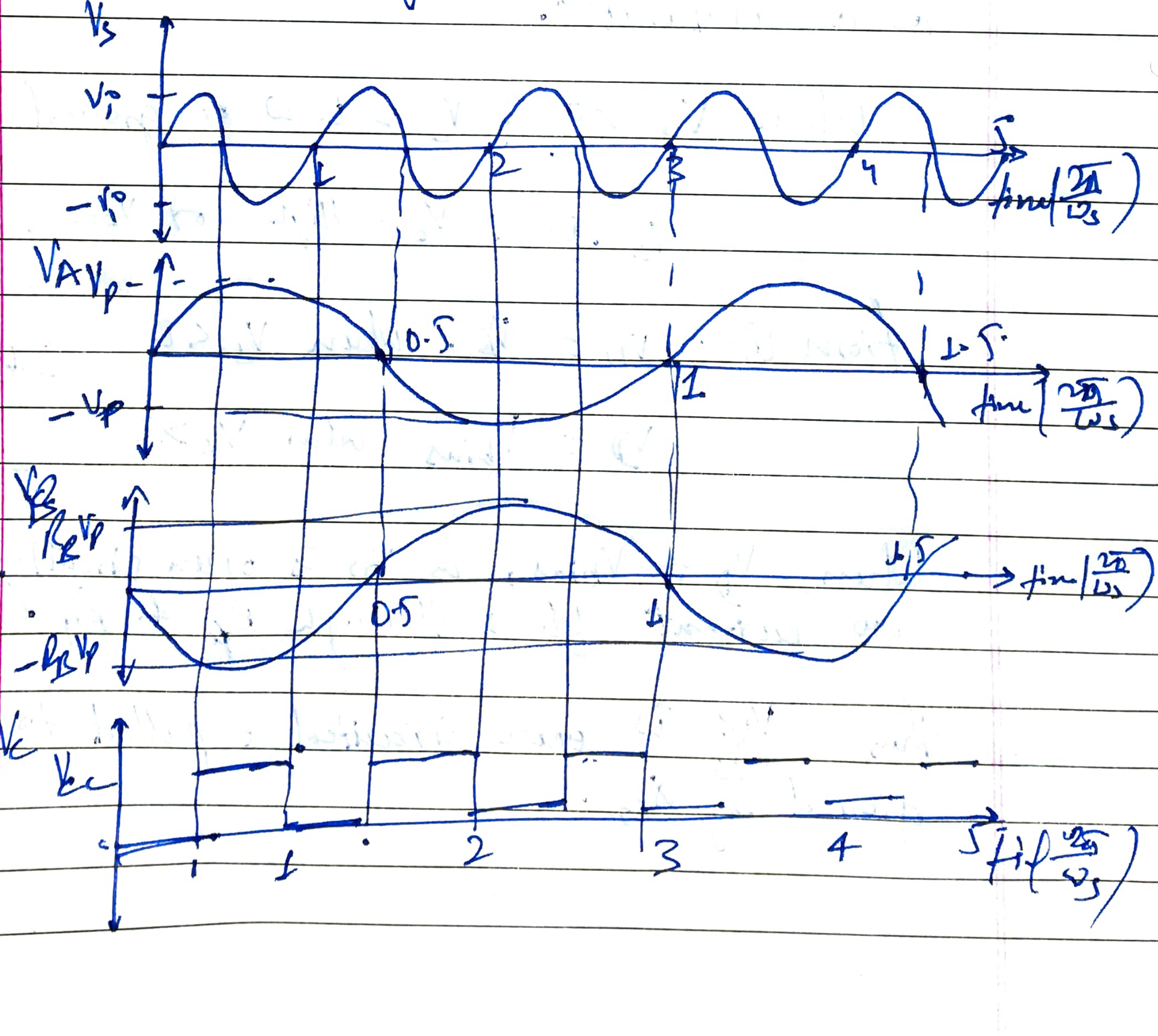
$$V_{C1} = \left(1 + \frac{R_f}{R_4}\right) V_{bias} - \frac{R_f}{R_4} V_B \quad \text{— (iv)}$$

as A_3 is in difference amplifier configuration.

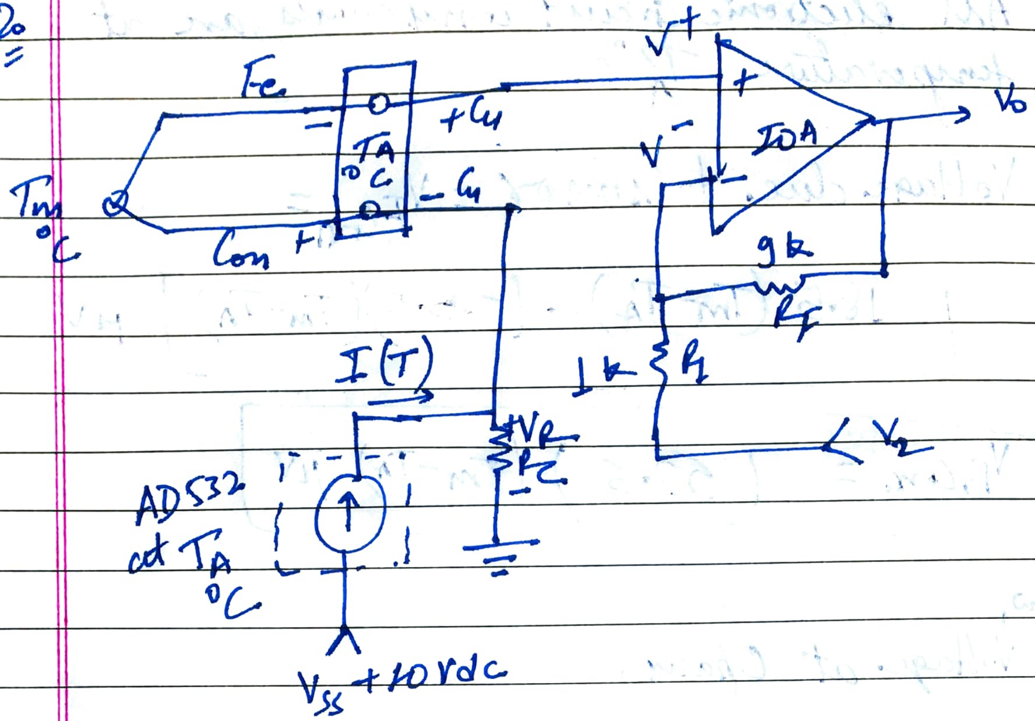
Finally V_E is passed through the low pass filter comprising X_{C2} & R_2; with

$X_{C2} = \frac{1}{\omega_m C_2}$; $V_E = b V_D \angle -\theta$ with $b \in (0,1)$; $\theta > 0°$.

From above theory & equations,



Q2.



In question, information given,

→ $I(T) = (T+273)\,10^{-6}\,A$

→ $V_R = [I(T)] \times [R_C]$

→ Ideal Opamp.

→ $R_f = 9\,k\Omega$, $R_1 = 1\,k\Omega$

→ Thermoelectric Sensitivity

$S_{Fe} = 18.5\,\mu V/°C$

$S_{con} = -35.0\,\mu V/°C$

$S_{Cu} = 6.5\,\mu V/°C$

→ Material Sensitivities constant over the range of measurement.

Date: __/__/__
Page: ____

→ All electronic circuit components are at temperature T_A °C

(a) Voltage due to sensor $= V_{F,Com} =$

$$\left[18.5\,(T_m - T_A) - (-35.0)(T_m - T_A)\right] \mu V$$

$$\boxed{V_{F,Com} = (53.5)(T_m - T_A)\ \mu V}$$

Now,
Voltage at Opamp,

$$V^+ = V_R + V_{F,Com}$$

$$= \left[\left[I(T_A) \times R_c\right] + (53.5)(T_m - T_A) \times 10^{-6}\right] V$$

Substituting value of $I(T_A)$

$$V^+ = \left[R_c\,(T_A + 273) + \cancel{2}\ 53.5\,(T_m - T_A)\right] \mu V$$

Since opamp is ideal,

$$V^+ = V^- \quad \{ \text{~~virtual ground~~} \}$$

$$\Rightarrow \frac{V_o - V^-}{R_f} = \frac{V^- - V_2}{R_1}$$

$$\Rightarrow \boxed{V_o = V^-\left(1 + \frac{R_f}{R_1}\right) - \frac{R_f}{R_1} V_2}$$

Date: ___/___/___
Page: ________

Putting values from above,

$$V_0 = \left[R_c(T_A+273) + 53.5(T_m - T_A)\right]\mu V \times \left(1+\frac{9k\Omega}{1k\Omega}\right) - \frac{9k\Omega}{1k\Omega} \times V_2$$

$$\Rightarrow \boxed{V_0 = \left[10\left[R_c(T_A+273) + 53.5(T_m - T_A)\right]\times 10^{-6} - 9V_2\right] V}$$

(b) Now,

V_0 can be written as,

$$V_0 = \left[\cancel{10 R_c}\left[(10)\left[R_c - 53.5\right]T_A + 535\,T_m + 2730\,R_c\right]\times 10^{-6} - 9V_2\right] V$$

To make V_0 independent of T_A.

$$R_c - 53.5 = 0$$

$$\boxed{R_c = 53.5\,\Omega}$$

Also, to eliminate offset,

$$2730 \times R_c \times 10^{-6} - 9V_2 = 0$$

$$\Rightarrow V_2 = \frac{2730 \times R_c \times 10^{-6}}{9}$$

Date: __/__/__

Page: ____

$$\Rightarrow V_2 = \frac{2730 \times 52.5 \times 10^{-6}}{9} V$$

$$\Rightarrow V_2 = 0.016228 V$$

$$\boxed{V_2 = 16.228 mV}$$

(C) $V_0 = 535 \times T_m \times 10^{-6}$ (V)

Comparing it with,

$V_0 = kT_m$.

We will get,

$$\boxed{k = 535 \times 10^{-6}}$$

unit will be V/°C.