INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

LABORATORY REPORT SHEET

Name

Name of Lab Partner : [redacted]

Section :

Date of Experiment : [redacted]

Date of Submission : [redacted]

Experiment :

Subject : [redacted]

Roll No. :

Instructor :

Remarks by the Instructor :

Pre Lab 1

Q1. Taking $T_L(s) = 0$ $L_a = 0$

$K_p = 25.5 \times 10^{-3}$ Nm

$K_b = 1/374$ V/rpm $= \frac{30}{\pi} \times \frac{1}{374}$ $\frac{V}{rad/s}$, $J = 13\ gcm^2 = 13 \times 10^{-7}\ kgm^2$

$R_E = 90.4\ \Omega$ $B = 2.9374 \times 10^{-6}$ Nm/(rad/s)

$$\left(\frac{V_s - \omega(s) K_b}{R}\right)\frac{K_p}{Js+B} = \omega(s)$$

$$\frac{V_s K_p}{Js+B} - \frac{\omega(s) K_b K_p}{Js+B} = \omega(s) R$$

$$\frac{V_s K_p}{Js+B} = \omega_s \left(\frac{K_b K_p}{Js+B} + R\right)$$

$$\frac{\omega_s}{V_s} = \frac{\frac{K_p}{Js+B}}{\frac{K_b K_p}{Js+B} + R}$$

2

$$\frac{\omega_s}{V_s} = \frac{K_p / RB + K_p K_b}{\left(\frac{SRJ}{RB + K_p K_b}\right) + 1}$$

$\therefore$ $K_m = \frac{K_p}{RB + K_p K_b}$ $\tau_m = \frac{RJ}{RB + K_b K_p}$

$$= \frac{25.5 \times 10^{-3}}{40.4 \times 2.937 \times 10^{-3} + \frac{25.5 \times 10^{-3} \times 30}{\pi\, 374}} = 33\ rad/s$$

[redacted]

$$T_m = \frac{13 \times 40.4}{40.4 \times 2.937 \times 10^{-6} + \frac{25.5 \times 10^{-3} \times 30}{\pi \times 374}} = 0.068 \text{ rad/s}$$

Q3.

2

$$\therefore \frac{W(s)}{V(s)} = \frac{33}{0.068s+1}$$

Q4

Q2. $T_s = 0.5s \pm 2\%$

$T_s = \frac{4}{G \cdot w_{gcp}}$ and $e^{-\left(\frac{G\pi}{\sqrt{1-G^2}}\right)} \le \frac{20}{100}$

$T_s \le 0.5 \Rightarrow \frac{4}{G w_{gcf}} \le 0.5 \Rightarrow G \le 0.45$

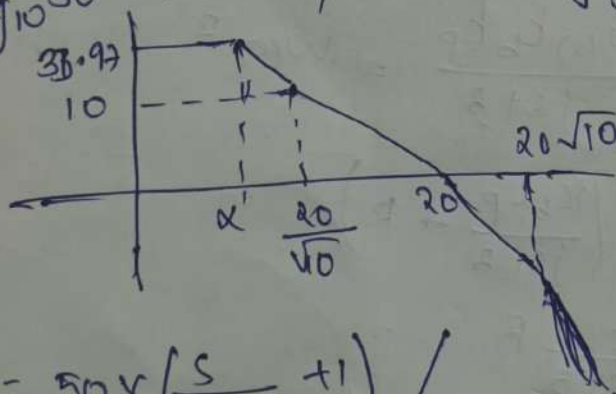
err $\le 2\% \Rightarrow \frac{1}{K_p} \le 2\% \Rightarrow K_p \ge 50$

$M_p \le 20\%$

$DD = \frac{PM}{45}$ $\quad PM = G(100) = 45$

$DD = 1$

$20\log_{10} 50 = 33.97$, Take $w_{gcf} \le 20$



1

$$T_f = 50 \times \left(\frac{s}{20/\sqrt{10}} + 1\right) \Big/ \left(\frac{s}{\frac{40}{(10)^{1.1}}} + 1\right)^2 \left(\frac{s}{20\sqrt{10}} + 1\right)$$

$$\frac{33.97}{40} \simeq 0.6$$

$$\alpha = \frac{20}{\sqrt{10}} + \frac{1}{10^{0.6}} = \frac{20}{10^{1.1}}$$

Finally,

$$T(s) = \frac{k(s+p)}{s+b}$$

$$\text{Controller} = \frac{50 \times \left(\frac{s}{20/\sqrt{10}} + 1\right)\left(\frac{s \times 0.068}{33}\right)}{\left(\frac{s}{\frac{20}{(10)^{1.1}}} + 1\right)^2 \left(\frac{s}{20\sqrt{10}} + 1\right)}$$

$$\approx \frac{50}{(1+5s)}$$

~~2nd order~~

$\boxed{\therefore 1^{st} \text{ order}}$

[redacted]

Q3. S = tf('s')

2

$$sys = \frac{33.164}{(1+0.07055)};$$

$$sys\text{-}c = 1.505\left(\frac{1+0.07055s}{1+5s}\right);$$

step(feedback(sys*sys-c,1));

Q4. Controller is

$$C_{R2} = \frac{31.62s + 2\times10^4}{2.55s^3 + 161.3s^2 + 202s + 63.25}$$

$$= \frac{a_1 s + a_0}{b_3 s^3 + b_2 s^2 + b_1 s + b_0}$$

1

$$= \frac{Y(s)}{U(s)} = \frac{Y(s)}{X(s)} \times \frac{X(s)}{U(s)}$$

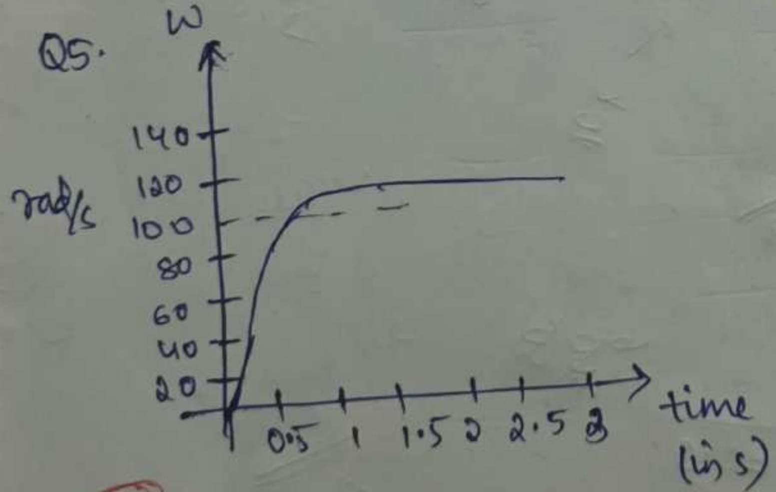
$$\frac{X(s)}{U(s)} = \frac{1}{s^3 + \frac{b_2}{b_3}s^2 + \frac{b_1}{b_3}s + \frac{b_0}{b_3}}$$

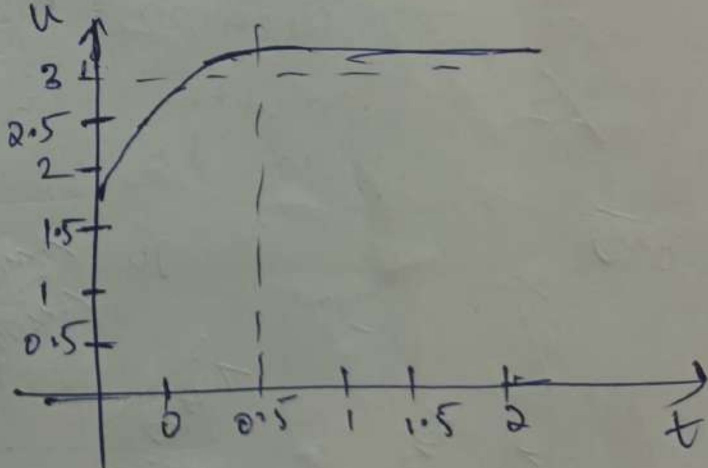
$$\frac{Y(s)}{X(s)} = \frac{a_1}{b_3}s + \frac{a_0}{b_3}$$

$$Y(s) = \frac{a_1}{b_3}sX(s) + \frac{a_0}{b_3}X(s)$$

$$s^3X(s) = U(s) - \frac{b_2}{b_3}s^2X(s) - \frac{b_1}{b_3}X(s) - \frac{b_0}{b_3}X(s)$$

Q5.





2

[redacted]

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = x_3$$
$$\dot{x}_3 = U - \frac{b_0}{b_3} x_1 - \frac{b_1}{b_3} x_2 - \frac{b_2}{b_3} x_3$$

$$y = x_1 \frac{a_0}{b_3} + x_2 \frac{a_1}{b_3} + x_3 \frac{a}{b_3}$$

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \qquad \dot{x} = \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix}$$

$$\dot{x} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -\frac{b_0}{b_3} & -\frac{b_1}{b_3} & -\frac{b_2}{b_3} \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} U$$

$$\dot{x} = Ax + BU$$
$$x(k+1) = [A T_s + I]\, x(k) + B T_s U(k)$$

Q6. $C(s) = \frac{C^{des}}{C^{Plant}} = 1.5 \left(\frac{0.06ks+1}{6.25s+1} \right)$

float b0 = ...;

$V_c = (wref - speed)$

$V = cx + dU_c$

$x = (1 + a T_s) x + b T_s V_c$

$x = ax + bv$

$y = cx + dv$

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

LABORATORY REPORT SHEET

~~9½~~/10

Name : [redacted]

Name of Lab Partner : [redacted]

Section : [redacted]

Subject : EE380

Roll No. : [redacted]

Instructor :

9½/10

Date of Experiment :

Date of Submission : [redacted]

Remarks by the Instructor :

Experiment : CS Prelab-2

Q1) Mathematical model

$$G_r = \frac{\omega}{V} = \frac{35.714}{0.0348s+1}$$ ①

Q2) $e_{ss} << 2\%$

$k_p \approx 50$

First order system

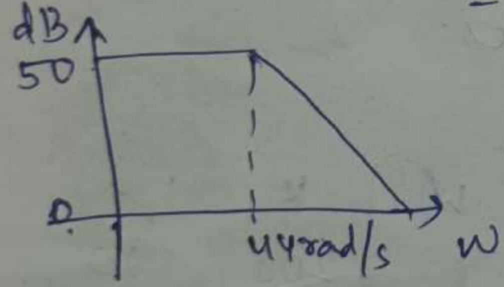
$$\therefore G_p(s) = \frac{50}{\tau s+1} = \frac{k_p}{\tau s+1}$$

$e_{ss} = \frac{1}{k_p}$

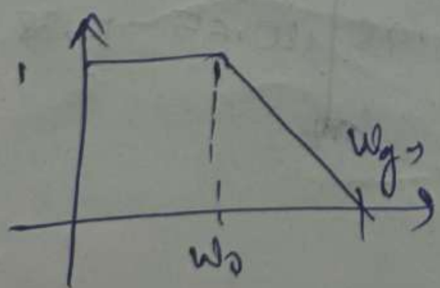
$\omega_0 = 2\pi f = 2\pi \times 7$

$= 44 \text{ rad/s}$

$\boxed{\tau = \frac{1}{\omega}} \Rightarrow \boxed{\tau = \frac{1}{44}}$



$$\left| \frac{50}{\frac{s}{44}+1} \right| = 1$$



$$\left| \frac{50}{\frac{3\omega_g}{44}+1} \right| = 1$$

$\Rightarrow \omega_g \approx 2500 \text{ rad/s}$

$\therefore \tau = 0.4 \text{ ms}$

Settling time, $t_s = 4\tau = 4 \times 0.40 \text{ ms}$

$= 1.6 \text{ ms}$

[redacted]

$$\text{Controller} = \frac{50}{\frac{s}{44}+1} \times \frac{0.0348s+1}{38.714} = \frac{as+b}{as+d} = \frac{a.s+b}{cs+d}$$

2

num = [a b]
den = [c d]
tf = [num, den] (Y)
[a b c d] = tf2ss(Y)

4) $$T(s) = \frac{0.048s + 1.4}{0.0227s + 1} = \frac{Y(s)}{U(s)}.$$

a = −43.936
b = −7.0989
c = 4.3956
d = 2.1099

1/2

(rad/s)

5)

Frequency (Hz)	Amplitude	Controller amplitude (V)
1	147.3107	3.9520
3	149.0368	6.0560
5	151.3114	8.9723
7	153.3029	12.1730

2

6) Just change a_c b_c c_c d_c in main-program C 1

7) sysidm is doing good enough job for ~~measuring~~ estimating supplied ~~voltae~~ values.

Values	K	a	b	K	a	b	K	a	b
Actual	100	5	10	50	2	8	200	20	40
Estimated	97.7	4.22	9.8[illegible]	49.6	1.33	7.98	180.65	17.38	36.[illegible]8.

1

8) On PC

2.

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Section	:	**Instructor**	:
Date of Experiment	:		
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Experiment	:		

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1) $\dfrac{\omega(s)}{V(s)} = \dfrac{27.85}{0.037s+1}$ 1

~~6~~ 8

2) $G(s) \cdot H(s) = \dfrac{807.65}{0.037s^3 + 1.37s^2 + 11.073s + 29}$ 1

3) Value of $K_\sigma \rightarrow$ from rlocus – 0.4701
from simulation – 0.4712

Value of $P_\sigma[s] \rightarrow$ from rlocus – 0.363
from simulation – 0.359 1

4)

	C(s)	
P (K_P)	PI ($K_P + \frac{K_I}{s}$)	PID
$0.5K_{cr}$ $= 0.23505$	$0.45K_{cr}\left[1 + \frac{1.2}{P_{cr} \times s}\right]$ $= 0.211545 + \frac{0.253554}{0.3635}$ $= 0.211545 + \frac{0.6973}{s}$	$0.6K_{cr}\left[1 + \frac{2}{P_{cr} \cdot s} + \frac{P_{cr} \times 0.125s}{\tau s+1}\right]$ $= 0.28206 + \frac{1.554}{s} + \frac{0.012794s}{\tau s+1}$

1

τ can be b/w $0.1T_0$ & $0.2T_0$. Choose $\tau = 0.1T_0$
$\therefore \tau = 0.00453$

5)

	Value of C(s)	t_s [s] for 2% tube	e_{ss} [%]	M_p[%]	$\frac{2^{nd}\text{ overshoot}}{1^{st}\text{ overshoot}}$
P	0.23505	0.82	13.252	38.581	0.210
PI	$0.211545 + \frac{0.6973}{s}$	2.1	0.013	79.198	0.307
PID	$0.28206 + \frac{1.554}{s} + \frac{0.012794s}{0.004535s+1}$	0.47	2.0833	76.878	0.478

1

6) PI has a large Ts, so there might be some problems with the stability. But except that, the CL system should be stable. 9

7)

	Value of C(s)	ts[s] (for 2% tube)	ess [%]	Mp [%]	2nd overshoot / 1st overshoot
P	0.23505	0.81	12.2	38.56	0.241
PI	$0.211545 + \frac{0.0993}{s}$	2.3	0.07	78.31	0.421
PID	$0.28700 + \frac{1.554}{s} + \frac{0.012798}{0.004535 s+1}$	0.53	1.86	77.82	0.529

1

0.2.

8) we should select controller P because it gives a lower Mp and satisfies the QAD condition. 0

9) QAD is satisfied by the P Controller. $\left[\frac{2^{nd}\ ON}{1^{st}\ ON} \approx 0.24\right]$ 0
PID.

10)

P → double E1 (double U) { return 0.23505 * u; }

PI → double E2 (double u, double prev_u, double T) {
double a = 0.6993 * T * prev_u; return 0.21545 * u + a; }

PID → double E3 (double u, double prev_u, double prev_y, double T) {
double a = 1.554 * T * prev_u; double b = 0.012798 * (1 - 2(-T/0.004535)) * prev_y / (1 + of (-T/0.004535)^2 - 1);
Return 0.28706 * u + a + b;

0 1

PI:

a = 1
b = 0.03125
c = 0.02792
d = 0.1248

PID:

$A = \begin{bmatrix} 1.315 & -0.8152 \\ 1 & 0 \end{bmatrix}$

$B = \begin{bmatrix} 2 \\ 0 \end{bmatrix}$

$C = [-0.6153 \quad 0.61552]$

D = 6.844

P

$A = \begin{bmatrix} 1.98 & -9.802 \\ 1 & 0 \end{bmatrix}$

$B = \begin{bmatrix} 0.007812 \\ 0 \end{bmatrix}$

$C = [0.007775 \quad 0.007328]$

D = 0

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Subject : EE380

Roll No. : [redacted]

Instructor :

Remarks by the Instructor :

9

1. $R_\Sigma = 26 \cancel{k}\,k\Omega$

$B = 3.436 \times 10^{-5}$ Nm/rad/s

Pkg load symbolic

km = 27.85; Tm = 0.037;

J = 13 × 10^-7 % in kgm^2

kf = 25.5 × 10^-3; % in Nm/A

kB = (2*pi)/(37*60);

syms B R_sigma;

eq1 = km == kf/(R_sigma*B + kt*kB);

eq2 = Tau_m == (R_sigma*J)/(R_sigma*B + kt*kB);

solution = solve([eq1, eq2], [B, R_Σ]);

R_solution = double(solution.B)

R_sigma_solution = double(solution.R_sigma)

(1)

2. $C(s) = \dfrac{11.75 + \cancel{37.6}\ 316.2}{1100.8s + 27.85}$ (1)

3.1 $P.I = k_p\left[1 + \dfrac{1}{T_i s}\right] = k_p + \dfrac{k_i}{s}$ where $k_i = \dfrac{k_p}{T_i}$

In the file it is given $k_p = 0.6$; $k_i = 10$

$$T.F = \frac{0.6s + 10}{s}$$

(1)

3.2 we will modify V_R-hat = $I_f * \underbrace{26}_{R_E} + \underbrace{0.0255}_{K_B}$ speed to our R_E. (1)

3.3 using ~~wash.dec~~ Vout.tx funct, ~~R~~ u is modified to be send as a 2 digit number.
Also, speed (rpm) is sent over Vout to Pc (1)

4.1

$u = au_c^2 + bu_c + c \rightarrow 2^{nd}$ order polynomial

$\Rightarrow a = 0.058$

$b = 0.324$

$c = 2.196$

from exp 9 saam log

1

4.2 $I_r = AD\_value()$

$I_v = 5*(511 + I_v)/1022$

$I_s = I_v/4.7$

// estimates $I_F = (1 - 5.0*T)*I_F + 5.0*7*I_c$

$u_{hat} = \dfrac{V_c - I_F * R}{k_b}$

// controller

error = R - uhat

$V_c = cc*x + dc*$error

$x = ac*x + bc*$error

// Compensator

$V = a*V_c*V_c + b*V_c + c$

1

4.3

into main-prog.c

main-prog-exp9.c is only used to estimate the compensator 1

4.4 Atleast 32s to obtain 16 steps of 2s each.

1

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LABORATORY REPORT SHEET

Name : [redacted]

Name of Lab Partner : [redacted]

Section :

Date of Experiment :

Date of Submission :

Experiment : [redacted] Control of ~~Speed~~ ~~Using~~ armature current.

Subject : EE380 : CS Lab

Roll No. : [redacted]

Instructor :

Remarks by the Instructor :

9

1. Given $V = 7V$; $T_L = 0$

$$J \cdot \underbrace{\frac{dw}{dt}}_{0} = -Bw + T - T_L \quad (T = k_t i)$$

$$\Rightarrow \boxed{w = \frac{k_t i - T_L}{B}}$$

$$V = L\underbrace{\frac{di}{dt}}_{0} + Ri + E$$

$$\rightarrow \boxed{V = Ri + k_b w}$$

$$i = \frac{7B}{BR + k_b k_t}$$

$$\Rightarrow \boxed{i_{d_1} = 0.03454 \text{ A}}.$$

$k_b = 0.0255 = k_t$

$\boxed{R_2 = 36.637}$

$\boxed{B = 3.917 \times 10^{-6}}$

2. Using $V = 7V$ and $T_L = 0.003$

$$i_{d_2} = \frac{BV + k_b T_L}{BR + k_b k_t} = 0.1309 \text{ A}$$

$$\Rightarrow \boxed{i_{d_2} = 130.9 \text{ mA}}.$$

3. $$i = \frac{u(Js + B) + k_b T_L}{k_b k_t + (sL + R)(Js + B)}$$

~~ignoring~~ ignoring T_L to obtain TF

$$\frac{i}{u} = \frac{Js + B}{k_b k_t + (sL + R)(Js + B)}$$

$L=0$

$$\Rightarrow \boxed{\frac{i}{u} = \frac{Js+B}{K_bK_t + RJs + RB}}$$

4.

Values of (K_p, K_t)	(20,0)	(250,0)	(250,100)	(20,100)	(20,500)	(20,1500)	(0,1500)
Approx settling time t_s[s]	1.45	2	10	10	4	3	2
Tracking error $e_{0^+} = i_d(0^+) - i(0^+)$ [A] using initial value theorem.	4.704 e-5	4.0 e-5	4e-5	0.02	0.02	0.02	0.04
Tracking error $e_0 = i_d(0^+) - i(0^+)$ [A] from plot	4.703 e-5	0.004	0.04	0.02	0.02	0.02	0.04
Steady state error e_{ss}[A]	0.03	0.01	0.002	0	0	0	0
Max. control effort [V]	0.6287	3.865	6.4	6.5	6.7	6.7	6.8

5.

Values of (K_p, K_t)	(20,0)	(250,0)	(250,100)	(20,100)	(20,500)	(20,1500)	(0,1500)
Approx settling time t_s[s]	0.4	NA	NA	4	2	1	1
Tracking error $e_{0^+} = i_d(0^+) - i(0^+)$	0.02	-0.3	-0.3	0.03	0.02	0.01	0.01
Steady state error e_{ss}[A]	0.04	NA	NA	0.003	0	0	0
Max. control effort [V]	0.73	11	10	6.4	7	6	7

[redacted]

7. Best controller $\Rightarrow K_p + \frac{K_I}{s} = 0 + \frac{1500}{s} = \frac{1500}{s}$.

6. Max. control effort are somewhat same for all and steady-state error also coming out to be same from Q4 & Q5.

Initial taking do clearly don't match due to k_p term there's an initial control effect given w.r.t initial error.

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Date of Experiment : [redacted]

Date of Submission : [redacted]

Experiment :

Subject : EE380 / CS -Lab

Roll No. : [redacted]

Instructor :

Remarks by the Instructor : 7

[redacted]

open loop $\frac{\hat{T}_L}{T_L} = \frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\tau s+1} + \frac{T}{T_L} \times \frac{\hat{k}_t}{\tau s+1}\left[\frac{1}{k_t} - \frac{\hat{J}s+\hat{B}}{Js+B} \cdot \frac{1}{\hat{k}_t}\right] - \frac{n\hat{k}_t}{\tau s+1}(J\hat{s}+\hat{B})$

$T = i_s k_t$

block diagram?

Q1.1

closed loop $\frac{\hat{T}_L}{T_L}$ (same)

$$= \frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\tau s+1} + \frac{T}{T_L} \times \frac{\hat{k}_t}{\tau s+1}\left[\frac{1}{k_t} - \frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\hat{k}_t}\right] - \frac{n\hat{k}_t}{\tau s+1}(\hat{J}s+\hat{B})$$

no change in transfer function, only T changes

new $T = \left(i_s + \frac{\hat{T}_L}{\hat{k}_t}\right) k_t$

$$\therefore \frac{\hat{T}_L}{T_L} = \frac{\frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\tau s+1} + \frac{i_s}{T_L} \times \frac{k_t \cdot \hat{k}_t}{\tau s+1}\left[\frac{1}{k_t} - \frac{(\hat{J}s+\hat{B})}{Js+B} \times \frac{1}{\hat{k}_t}\right] - \frac{n\hat{k}_t}{\tau s+1}(\hat{J}s+\hat{B})}{1 - \frac{k_t}{\hat{k}_t}\left[\frac{1}{k_t} - \frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\hat{k}_t}\right] \times \frac{1}{\tau s+1}}$$

Q1.2) when τ is small

1.) OLTF

$$\frac{\hat{T}_L}{T_L} = \frac{\hat{J}s+\hat{B}}{Js+B} + \frac{i_s k_t \hat{k}_t}{T_L}\left[\frac{1}{k_t} - \frac{\hat{J}s+\hat{B}}{Js+B} \times \frac{1}{\hat{k}_t}\right] - n(\hat{J}s+\hat{B})$$

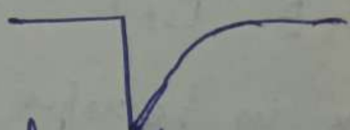
2) CLTF: $\dfrac{OLTF}{1-K_t\left[\dfrac{1}{K_t} - \dfrac{\hat{J}s+\hat{B}}{Js+B} \times \dfrac{1}{\hat{K}_t}\right]} = \dfrac{OLTF}{\dfrac{K_t}{\hat{K}_t} \times \dfrac{\hat{J}s+\hat{B}}{Js+B}}$

T should be such that to reject high frequency noise n.

$$\frac{1}{T} >> \frac{B}{J}$$

so $\boxed{T << \frac{J}{B}}$.

Q 1.3) closed loop scheme

Q 2.1) $w \rightarrow$  $u \rightarrow$ 

Both w and i_m settle around desired values. w settles around 100 & i_m around 0.7 ($i_m \approx 0.07$)

Q2.2) w and i_m settle, but ~~i_m~~ i_m settles better around 0.7

~~Q2.3)~~ There's a lot of noise though

Q 2.4) Increasing T decreases noise but degraded settles i_m & w

Decreased T → increased noise but improved settle value of i_m & w

2.3) Now motor reduces to speed control only without taking care of disturbance rejection

Section

Experiment

Submission : [redacted]

Q2.5)

Q3) Done

Q4) Yes