Unit 2 poblems

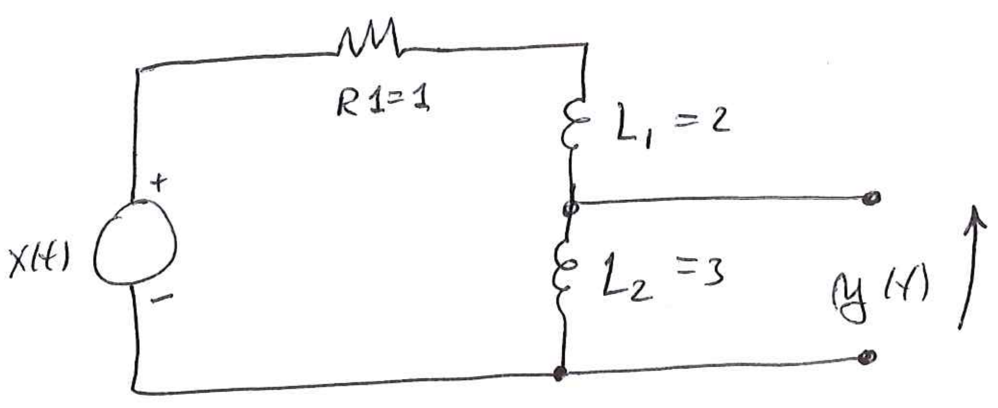
Quiz 2&3 prep

- Transfer functions of
  - electrical
  - translational
  - rotational
  - motors
  - gears

  } Quiz 2

  - mixed systems } Quiz 3

P1 Find transfer function of electrical network

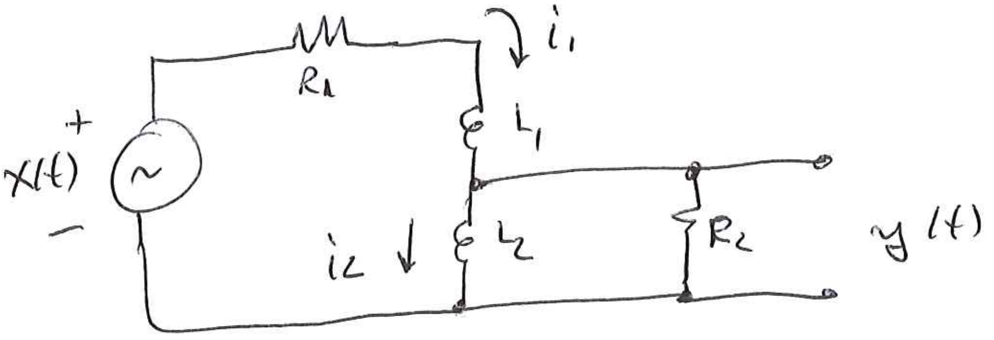


$y(0^-) = 0$

$\dot{y}(0^-) = 0$

$$H(s) = \frac{Y(s)}{X(s)} = \frac{sL_2}{sL_2 + sL_1 + R_1} = \frac{3s}{5s+1}$$

P2 Find state space system matrix



define two currents i_1 and i_2 as state variables.

$$L_1 \frac{di_1}{dt} + L_2 \frac{di_2}{dt} = x - R_1 i_1$$

$$L_2 \frac{di_2}{dt} = (i_1 - i_2) R_2$$

$$\underbrace{\begin{bmatrix} L_1 & L_2 \\ 0 & L_2 \end{bmatrix}} \begin{bmatrix} di_1/dt \\ di_2/dt \end{bmatrix} = \begin{bmatrix} -R_1 & 0 \\ R_2 & -R_2 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} x$$

take inverse $\Rightarrow$ $\frac{1}{L_1 L_2} \begin{bmatrix} L_2 & -L_2 \\ 0 & L_1 \end{bmatrix}$

State space formulation

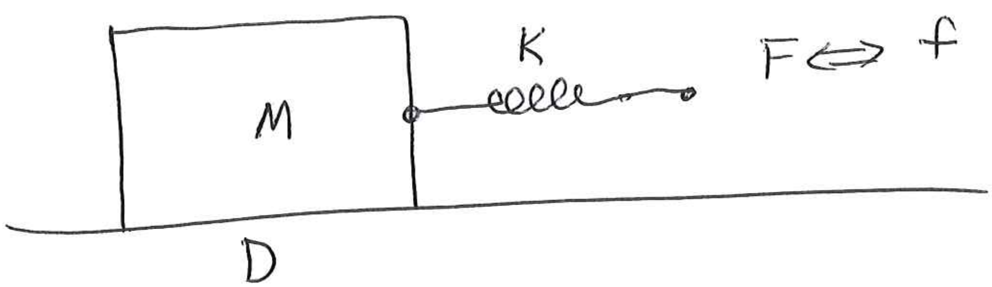
$$\begin{bmatrix} di_1/dt \\ di_2/dt \end{bmatrix} = A \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} + B x$$

$$A = \frac{1}{L_1 L_2} \begin{bmatrix} L_2 & -L_2 \\ 0 & L_1 \end{bmatrix} \begin{bmatrix} -R_1 & 0 \\ R_2 & -R_2 \end{bmatrix}$$

$$B = \frac{1}{L_1 L_2} \begin{bmatrix} L_2 & -L_2 \\ 0 & L_1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

P3 translation

Solve for the translation $x(t)$. Assume force of $f(t) = u(t)$.



D is the coefficient of friction such that the resistance force is $f_{friction} = D\dot{x}$

Note that the spring does not contribute to the problem as the stretch of the spring at:

$$\Delta X = \frac{f}{K}$$

is not relevant

Free body diagram

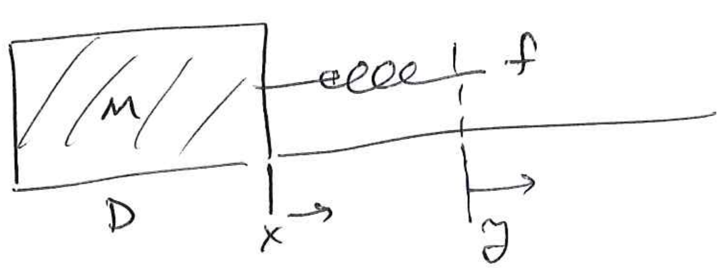
Therefore we have

$$(sD + s^2 M)\, X(s) = F(s)$$

Transfer function $\dfrac{X(s)}{F(s)} = \dfrac{1}{s(D+sM)} = \dfrac{1/M}{s(s + D/M)}$

Pole at $s = -D/M$

Now compute the transfer funct between $f(t)$ and the displacement of the tip of the spring (where f is applied)



$$y = x + \frac{f}{K}$$

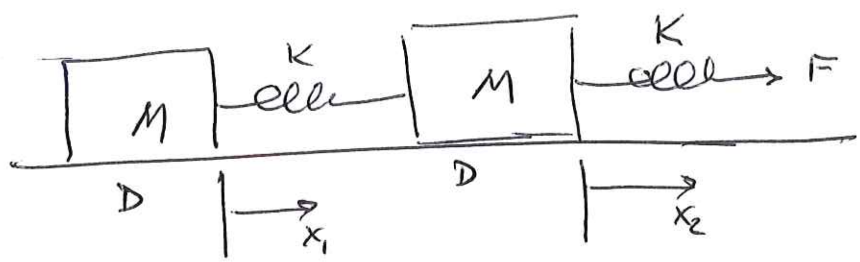
Therefore

$$Y(s) = X(s) + \frac{F(s)}{K}$$

$$= \left(\frac{X(s)}{F(s)} + \frac{1}{K} \right) F(s)$$

$$\frac{Y(s)}{F(s)} = \frac{1/M}{s(s + D/M)} + \frac{1}{K}$$

P4



① Find the transfer function of F to X_1

② State space formulation.

- Start with body diagrams
- note that the right spring is not necessary to include into calculation.

We have state variables

$$\begin{bmatrix} x_1 \\ \dot{x}_1 \\ x_2 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix}$$

state variable vector

From first body diagram

$$D\dot{x}_1 + M\ddot{x}_1 = K(x_2 - x_1)$$

$$Dz_2 + M\dot{z}_2 = Kz_3 - Kz_1$$

(1) $$\dot{z}_2 = -\frac{K}{M} z_1 - \frac{D}{M} z_2 - \frac{K}{M} z_3$$

From second body diagram

$$D\dot{x}_2 + M\ddot{x}_2 + K(x_2 - x_1) = F$$

$$Dz_4 + M\dot{z}_4 + Kz_3 - Kz_1 = F$$

(2) $$\dot{z}_4 = -\frac{K}{M} z_1 - \frac{K}{M} z_3 - \frac{D}{M} z_4 + F$$

we also have

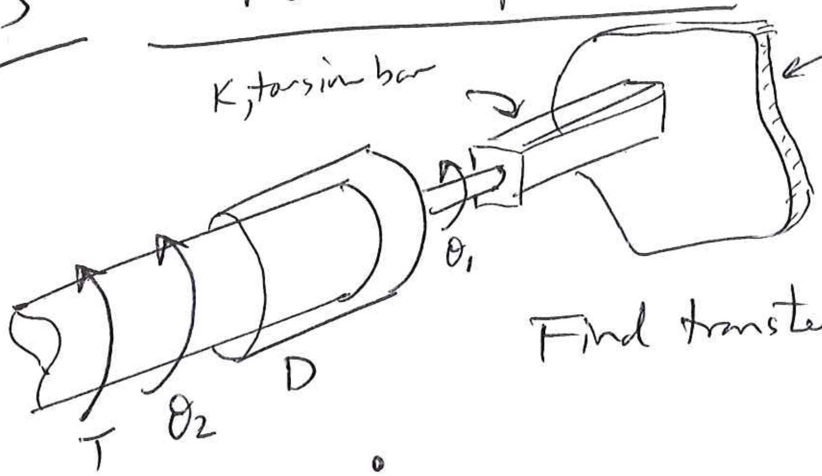
$$\dot{z}_1 = z_2 \quad (3)$$

$$\dot{z}_3 = z_4 \quad (4)$$

Combining these 4 equations

$$\frac{d}{dt}\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 & 0 & 0 \\ -K/M & -D/M & -K/M & 0 \\ 0 & 0 & 0 & 1 \\ -K/M & 0 & -K/M & -D/M \end{bmatrix}}_{A} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}}_{B} F$$

PS Rotation problem



Find transfer function between T and W_2

$$W_2 = \dot{\theta}_2$$

$T = (\dot{\theta}_2 - \dot{\theta}_1)D$ → through coupling

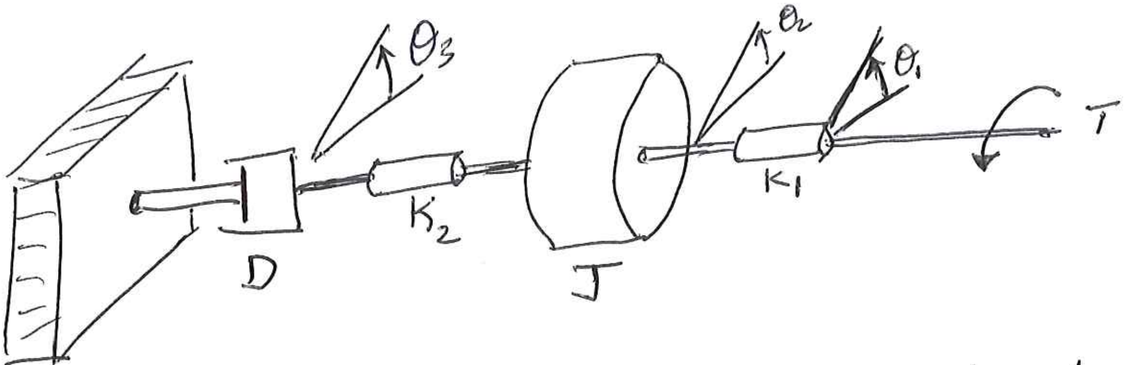
$T = K\theta_1$ → torque at torsion bar (same as there is no inertia)

$$\dot{T} = K\dot{\theta}_1$$

$$T = \dot{\theta}_2 D - \frac{\dot{T}}{K} D$$

$$W_2 = \frac{T}{D} + \frac{\dot{T}}{K}$$

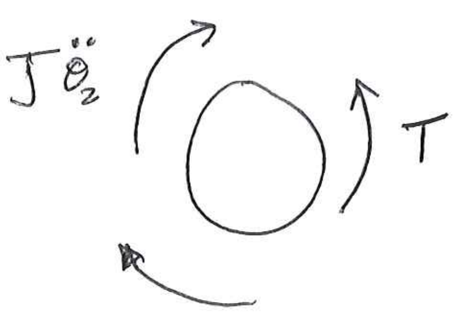
P6 Determine the system of coupled DEQ's for the following rotational system



First note that K_1 is not relevant except that $T = K_1(\theta_1 - \theta_2)$

K_1 does not change the torque applied to the Flywheel of inertia J.

Diagram for flywheel



$$T = J\ddot{\theta}_2 + K_2(\theta_2 - \theta_3)$$

$$D\dot{\theta}_3 = K_2(\theta_2 - \theta_3)$$

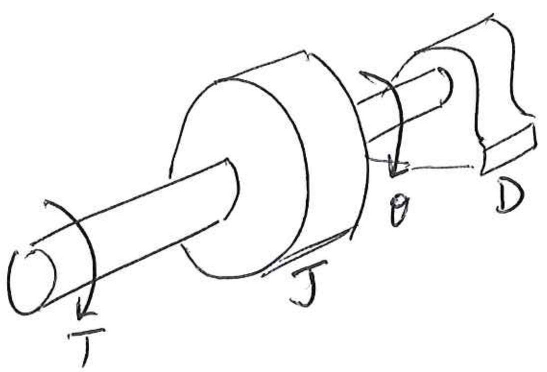
Let state variables be $x = \begin{bmatrix} \dot{\theta}_2 \\ \theta_2 \\ \theta_3 \end{bmatrix}$

Then

$$\frac{d}{dt}\begin{bmatrix}\dot{\theta}_2\\ \theta_2\\ \theta_3\end{bmatrix} = \begin{bmatrix}0 & -\frac{K_2}{J} & \frac{K_2}{J}\\ 1 & 0 & 0\\ 0 & \frac{K_2}{D} & -\frac{K_2}{D}\end{bmatrix}\begin{bmatrix}\dot{\theta}_2\\ \theta_2\\ \theta_3\end{bmatrix} + \begin{bmatrix}T/J\\ 0\\ 0\end{bmatrix}$$

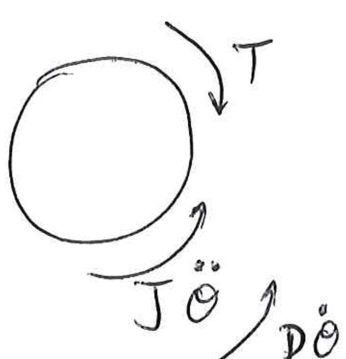
Which is the system of equations written in State space format.

P7 Find the response of the system from T to θ



$$T = J\ddot{\theta} + D\dot{\theta}$$

$$\frac{\Theta(s)}{T_L(s)} = \frac{1}{Js^2 + Ds}$$



notation
$T(t) \Leftrightarrow T_L(s)$

Repeat P7 but with output of w instead of θ

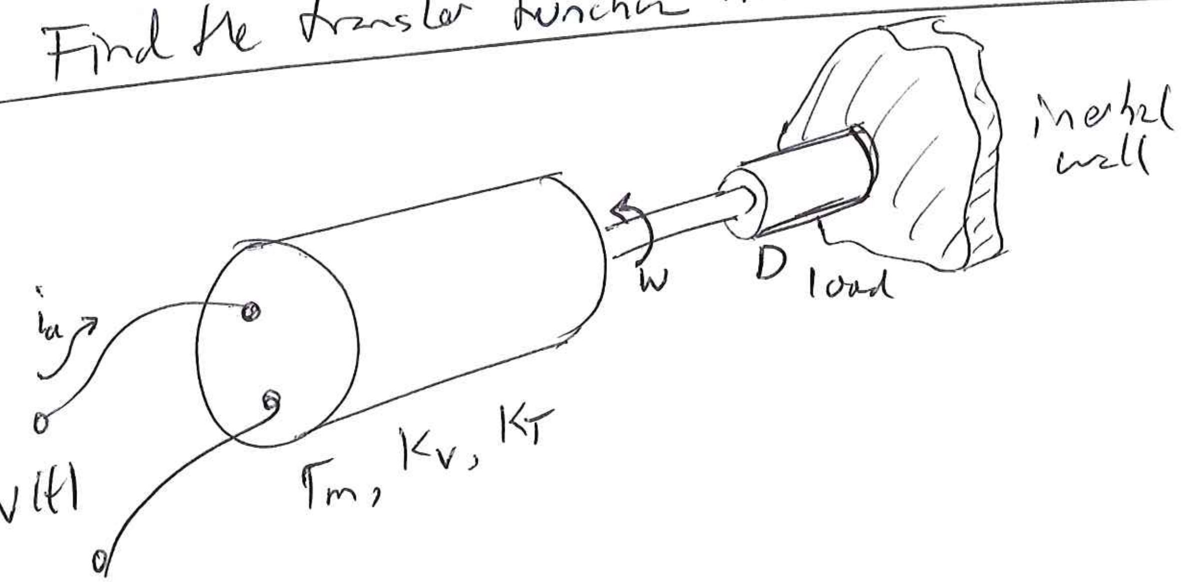
$w = \dot{\theta}$ $\therefore$ $T = J\dot{w} + Dw$

$$\frac{\Omega(s)}{T(s)} = \frac{1}{Js + D}$$

note that $\Omega(s) = s\,\Theta(s)$

$$\therefore \frac{\Omega(s)}{T(s)} = s\,\frac{\Theta(s)}{T(s)} = \frac{s}{Js^2 + Ds} = \frac{1}{Js + D}$$

P8) Find the transfer function from $v(t)$ to $w(t)$



i_a - armature current

$$i_a = \frac{v - K_v w}{r_m}$$

$$T = i_a K_T$$

$$T = Dw$$

$$i_a = -\frac{K_v}{r_m} w + \frac{1}{r_m} v$$

$$T = -\frac{K_v K_T}{r_m} w + \frac{K_T}{r_m} v$$

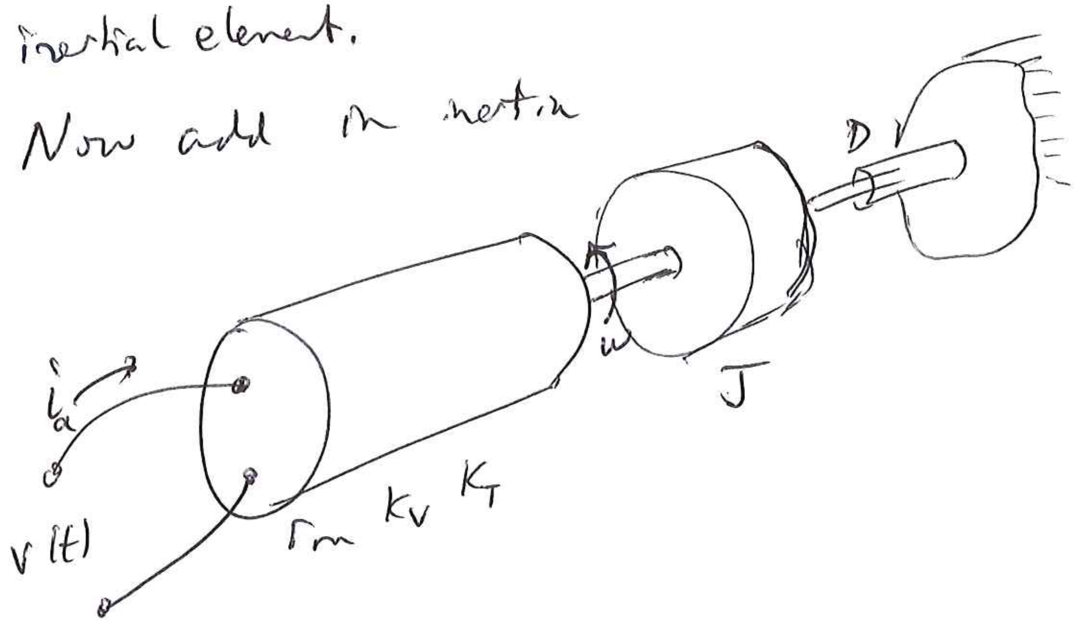
$$\left(D + \frac{K_v K_T}{r_m}\right) w = \frac{K_T}{r_m} v$$

$$W = \frac{(K_T D / r_m)}{D + \frac{K_V K_T}{r_m}} V$$

note this result indicates that w is proportional to v

There is no DEQ involved as there is no energy storage in an inertial element.

Now add in inertia



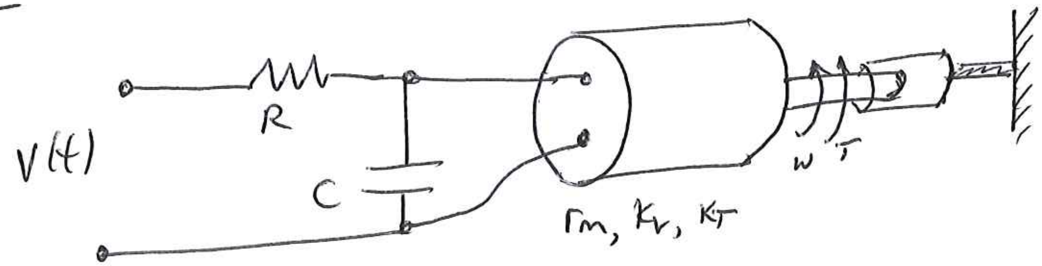
$$K_T \left(\frac{V - K_V W}{r_m} \right) = D\omega + \underbrace{J\dot{\omega}}_{\text{new}}$$

Transfer function replace $D \longrightarrow D + Js$

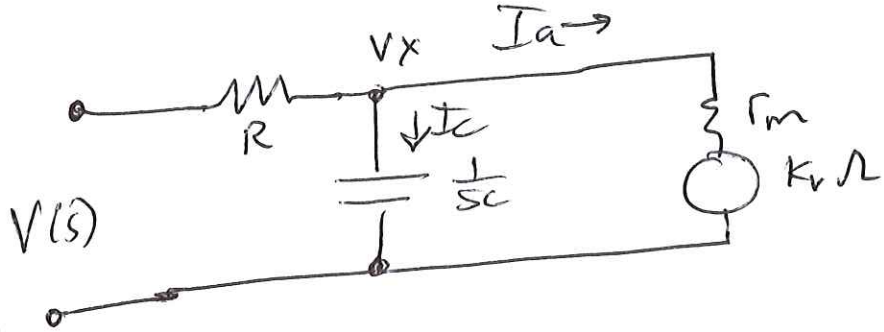
$$\Omega(s) = \frac{K_T D / r_m}{Js + D + \frac{K_V K_T}{r_m}} V(s)$$

Now we have a low pass response with a pole at $s = -\frac{1}{J}\left(D + \frac{K_V K_T}{r_m}\right)$

P9 Find transfer function between $v(t)$ and $\omega(t)$



Redraw the diagram and start with a new variable V_x, I_c



$$V_x = V - R\,(I_a + I_c)$$

$$V_x = V - R\,I_a - R\,V_x\,sC \quad (1)$$

$$V_x = I_a r_m + K_v \Omega \quad (2)$$

(2) = (1) $\Rightarrow$ eliminates V_x

$$I_a r_m + K_v \Omega = \frac{V - R I_a}{1 + RCs}$$

$$I_a \left(r_m + \frac{R}{1+RCs} \right) = -K_v \Omega + \frac{V}{1+RCs}$$

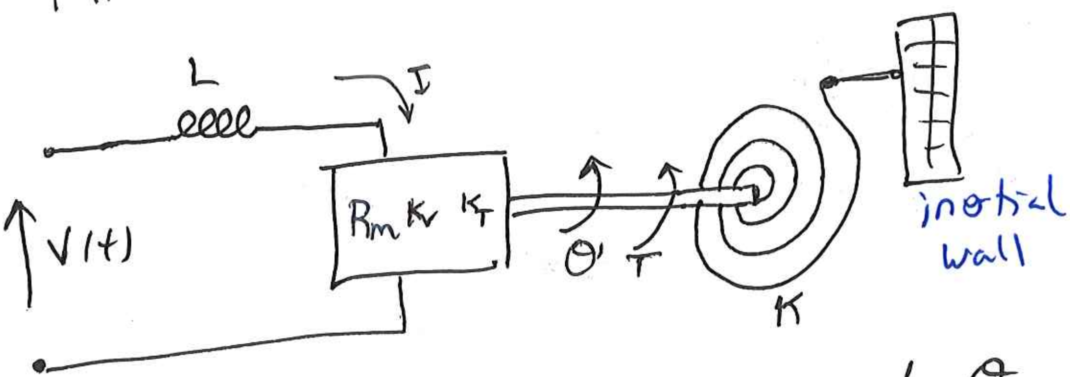
Torque $T = K_T I_a = D\Omega$

$$\frac{D\Omega}{K_T}\left(\Gamma m + \frac{R}{1+RCs}\right) = -K_V\Omega + \frac{V}{1+RCs}$$

$$\Omega\left(\frac{\Gamma m D}{K_T} + \frac{D}{K_T}\frac{R}{1+RCs} + K_V\right) = \frac{V}{1+RCs}$$

Which gives the relation that can be further simplified.

P 10) Find transfer function between $v(t)$ and $\theta(t)$



Find the relation between v and θ

$$V = sLI + R_m I + K_v s\Theta$$

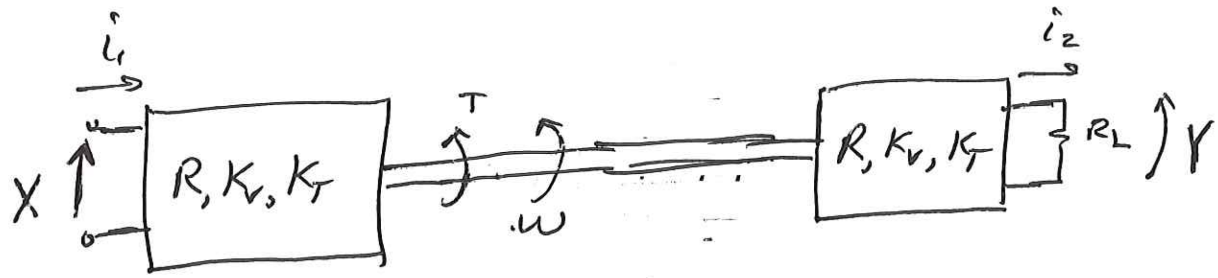
$$T = K_T I = K\Theta \Rightarrow I = \frac{K\Theta}{K_T}$$

$$V = (sL + R_m)\frac{K\Theta}{K_T} + K_v s\Theta$$

$$V = \left(s\left(\frac{LK}{K_T} + K_v\right) + \frac{R_m K}{K_T}\right)\Theta$$

$$\frac{\Theta(s)}{V(s)} = \frac{1}{\left(\frac{LK}{K_T} + K_v\right)\left(s + \frac{R_m K}{K_T} \Big/ \left(\frac{LK}{K_T} + K_v\right)\right)}$$

P11)



Voltage $x(t) \Leftrightarrow X(s)$ applied to motor

find output voltage $y(t) \Leftrightarrow Y(s)$

$i_1 = i_2$ as motor torque and generator torque the same.

$$I_1 K_T = T$$

$$I_1 R + K_v \Omega = X$$

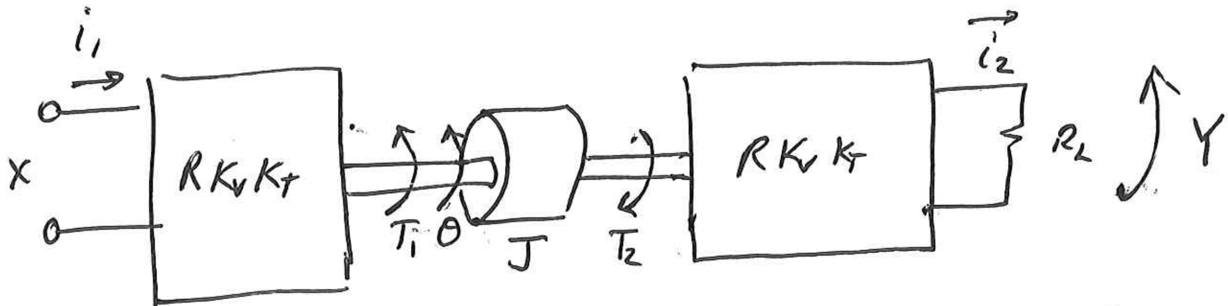
$$I_2 (R_L + R) = \Omega K_v \Rightarrow \Omega = \frac{I_2 (R_L + R)}{K_v}$$

$$I_1 R + \frac{K_v I_1 (R_L + R)}{K_v} = X \quad (\text{use } I_1 = I_2)$$

$$I_1 (2R + R_L) = X$$

$$Y = I_2 R_L = I_1 R_L = \frac{R_L}{2R + R_L} X$$

P12) Now Add a rotational inertial unit.



$i_1 \neq i_2$ since $T_1 \neq T_2$

$$I_1 K_T = T_1$$

$$I_1 R + K_v \Omega = X \quad (1)$$

$$I_2 (R_L + R) = \Omega K_v \qquad \therefore \Omega = I_2 \frac{(R_L + R)}{K_v} \quad (2)$$

$$T_1 = T_2 + J\ddot{\theta}$$

$$I_1 K_T = I_2 K_T + J s \Omega$$

$$\therefore I_1 = I_2 + \frac{J}{K_T} s \Omega \quad (3)$$

Put (2) and (3) into (1)

$$\therefore \left(I_2 + \frac{J}{K_T} s \Omega\right) R + K_v \left(I_2 \frac{(R_L + R)}{K_v}\right) = X$$

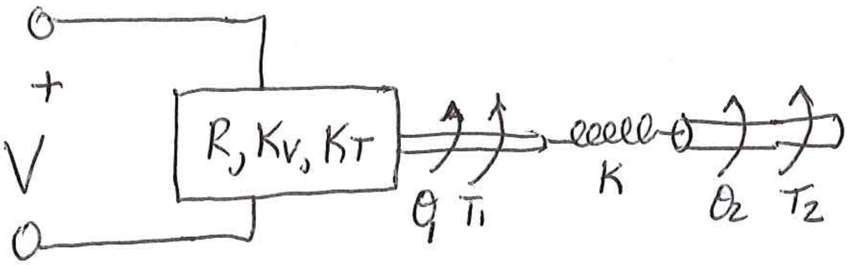
use (2)

$$I_2 \left(R + \frac{J}{K_T} s \frac{(R_L + R)}{K_v} R\right) + I_2 (R_L + R) = X$$

$$I_2\left[(2R+R_L) + s\left(\frac{J\ R(R_L+R)}{K_T\ K_V}\right)\right] = X$$

$$Y(s) = \frac{R_L}{2R+R_L + s\left(\frac{J\ R(R_L+R)}{K_T\ K_V}\right)}\ X(s)$$

P13)

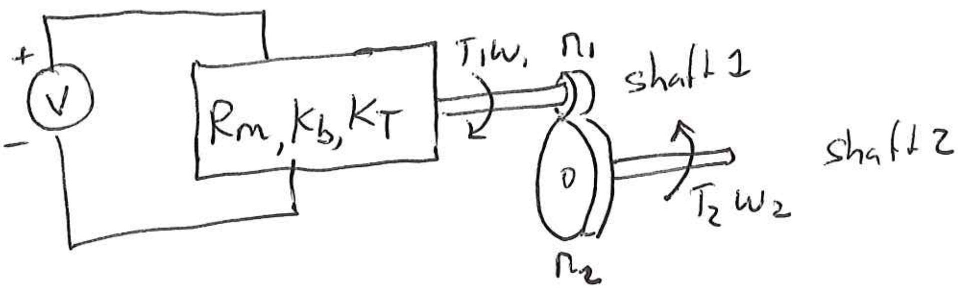


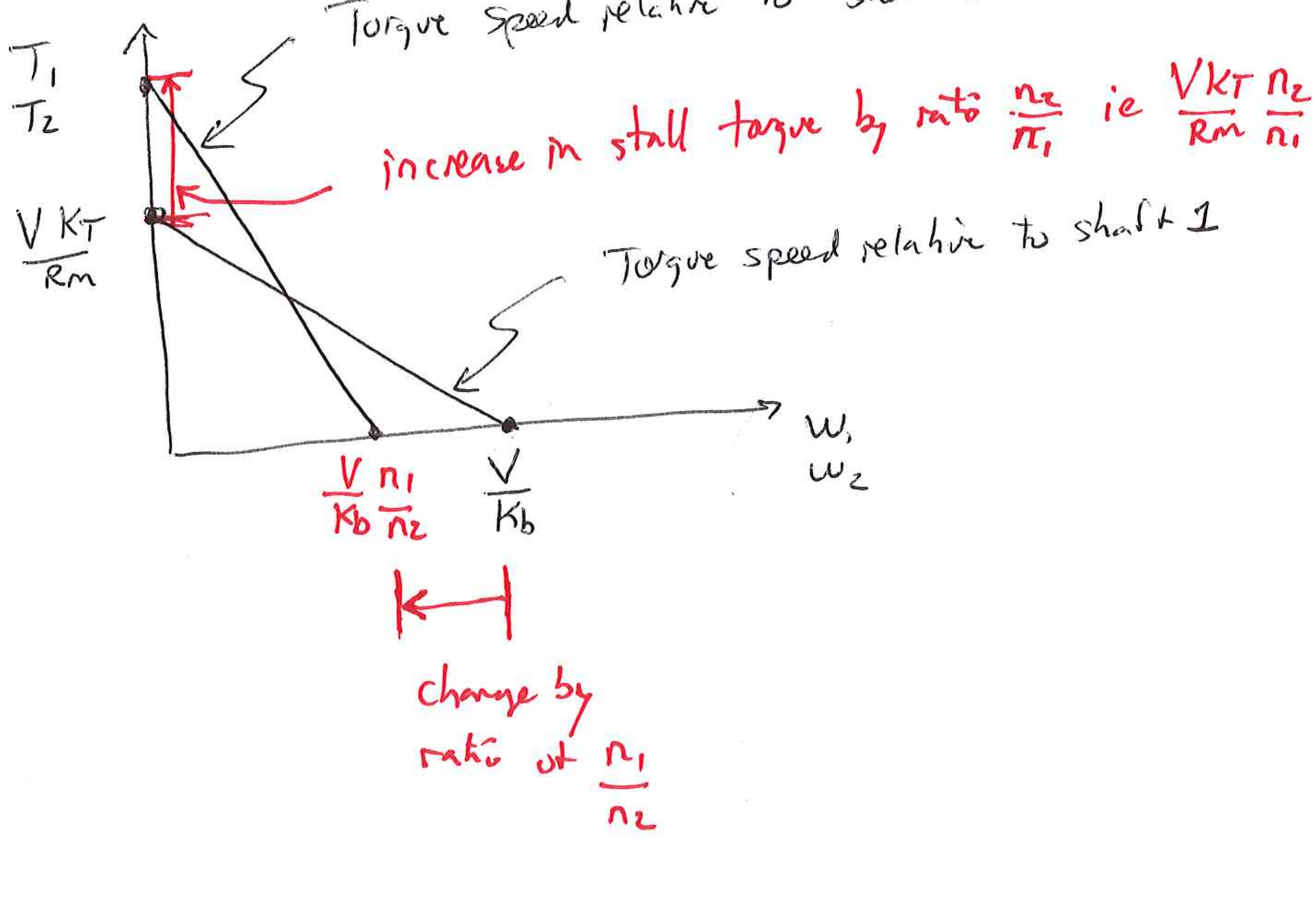
Find transfer from $V(s)$ to $\Theta_2(s)$

There is no load on second shaft so $T_1 = T_2 = 0$

$$\therefore\ \dot{\theta}_2 = \frac{V}{K_V}\ ,\quad \theta_1 = \theta_2$$

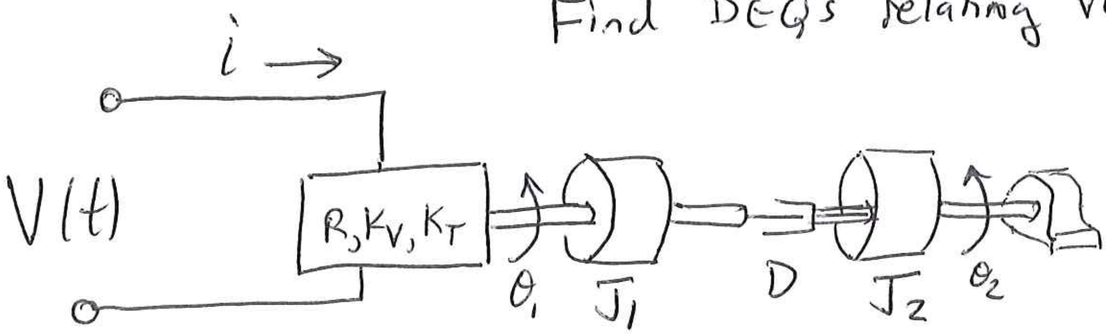
P14) Show the effect of a gear ratio of $\frac{n_1}{n_2}$ on the motor torque speed curve



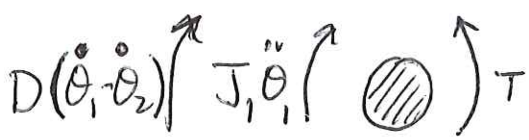


(P15) Mixed Problem

Find DEQ's relating $V(t)$, $\dot{\theta}_1$ and $\dot{\theta}_2$

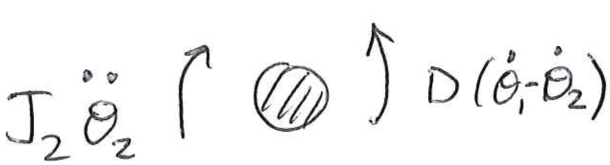


Shaft 1



$$T = J_1 \ddot{\theta}_1 + D(\dot{\theta}_1 - \dot{\theta}_2) \quad (1)$$

Shaft 2



$$\ddot{\theta}_2 = \frac{D}{J_2}\dot{\theta}_1 - \frac{D}{J_2}\dot{\theta}_2 \quad (2)$$

(1) Get rid of T

$$i = \frac{V - K_V \dot{\theta}_1}{R} = \frac{T}{K_T}$$

$$\frac{V K_T}{R} - \frac{K_V K_T}{R}\dot{\theta}_1 = J_1 \ddot{\theta}_1 + D\dot{\theta}_1 - D\dot{\theta}_2$$

1 becomes

$$\ddot{\theta}_1 = \frac{-D}{J_1}\dot{\theta}_1 + \frac{D}{J_1}\dot{\theta}_2 + \frac{k_T}{R}V - \frac{k_V k_T}{R}\dot{\theta}_1$$

1 and 2 relate $\dot{\theta}_1$ and $\dot{\theta}_2$ to V.

2015 Quiz 4

(20)

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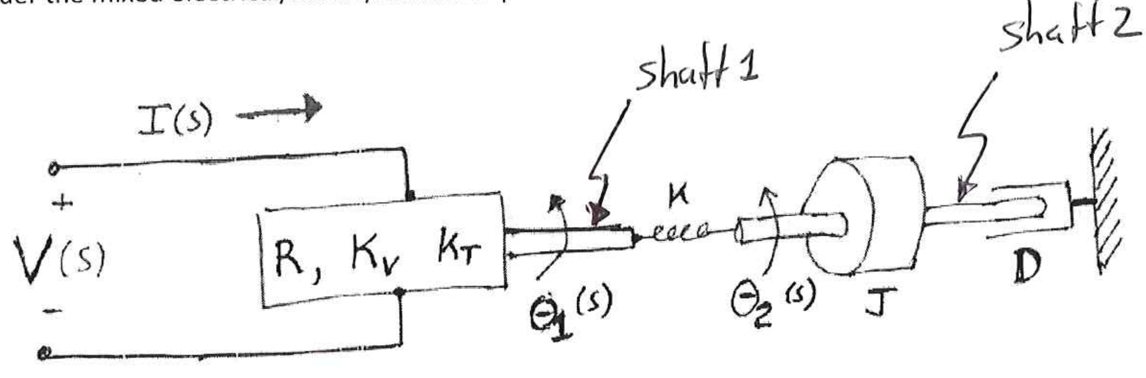
Consider the mixed electrical/motor/rotational problem shown below:



$\theta_1(t) \Leftrightarrow \Theta_1(s)$ rotation angle of shaft 1

$\theta_2(t) \Leftrightarrow \Theta_2(s)$ rotation angle of shaft 2

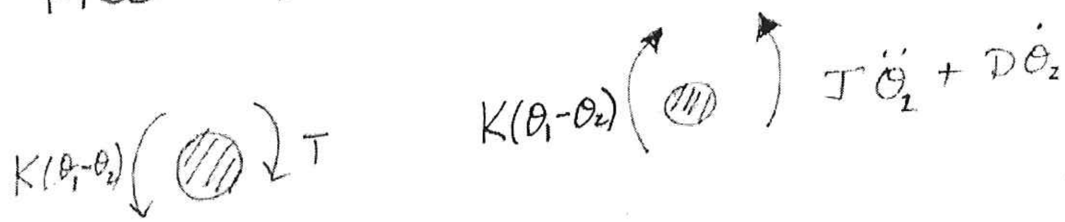
1.(5) Draw the two rotational body diagrams for shaft 1 and shaft 2 in terms of the variables and parameters shown in the figure above

$$V = IR + K_V \Omega_1$$

$$T = I K_T$$

$$T = \frac{V - K_V \Omega_1}{R}$$

Free Body Diagrams for shaft 1 and shaft 2



(21)

2. (5) Based on the two rotational body diagrams derived in part 1 state the two equations relating

$\Theta_1(s)$ and $\Theta_2(s)$ to $V(s)$ and the parameters K, J and D

$$K(\theta_1-\theta_2) = J\ddot{\theta}_2 + D\dot{\theta}_2$$

$$K(\theta_1-\theta_2) = \frac{V-K_v\dot{\theta}_1}{R}$$

Two Equations

Solution

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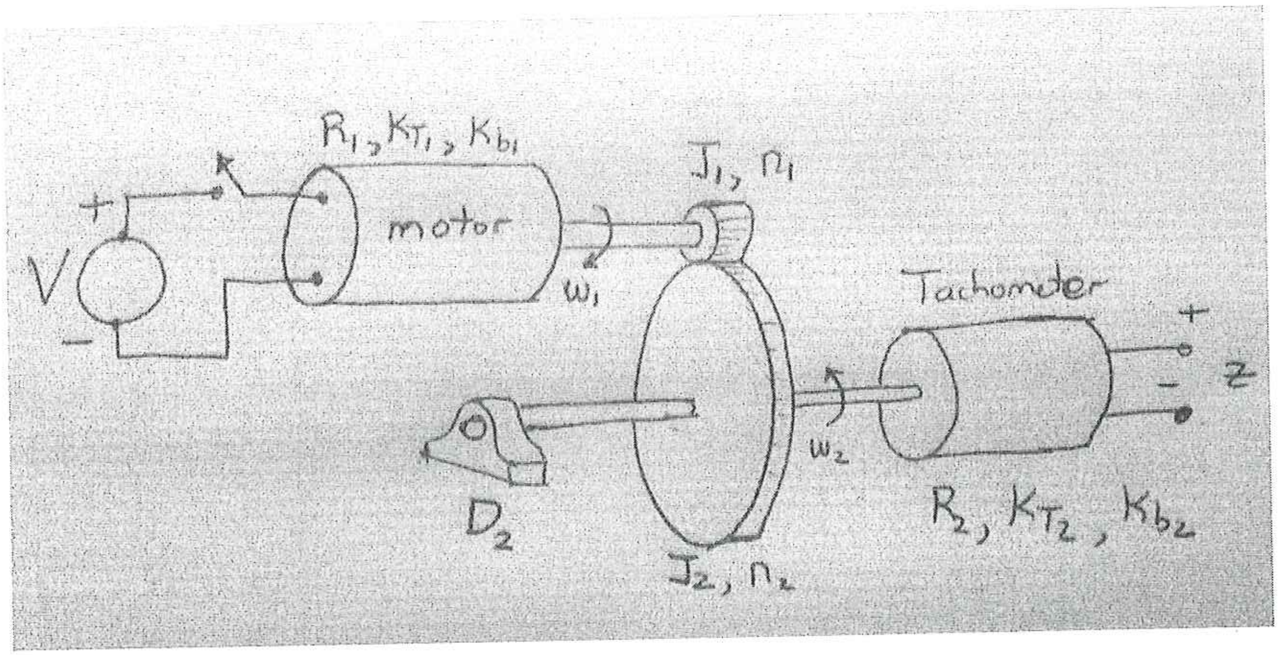
ENEL441 QUIZ 3 Oct 22, 2018

35 minutes

Consider the model of an electric motor driving a set of gears and a tachometer. A tachometer is just an electric motor run as a generator with no electrical load as shown in the figure below.



Assume that the voltage V is applied to the motor as represented as

$$v(t) = V_o u(t)$$

The motor is represented with a linear model with coefficients of $\{R_1, K_{T1}, K_{b1}\}$ which drives a primary gear of n1 teeth and a moment of inertia of J1. This small gear drives a bigger gear with n2 teeth and a moment of inertia of J2. The secondary shaft of the big gear is supported by a bearing with frictional loss of D2 and then drives the tachometer which is assumed to have no friction and no inertia. The output z is the open circuit voltage of the tachometer.

Q1 (15) Determine $z(t)$ as a function of the parameters given.

Q2 (5) Suppose that a load resistor was applied to the tachometer output terminals. Describe in a sentence or two discuss what would change in the output response of z(t) and why.

Solution

Q1 (15) Start with the tachometer which is an open circuit so no current flows and hence it does not consume any torque. Hence we have $z(t) = \omega_2 K_{b2}$. Write this in terms of the primary shaft as

$$z(t) = \frac{\omega_1 K_{b2} n_1}{n_2}$$

Now the inertia of the primary shaft is $J_1 + J_2\left(\frac{n_1}{n_2}\right)^2$ and the loss is $D_2\left(\frac{n_1}{n_2}\right)^2$. Since the tach does not consume torque we have

$$\left(J_1 + J_2\left(\frac{n_1}{n_2}\right)^2\right)\dot{\omega} + D_2\left(\frac{n_1}{n_2}\right)^2 \omega = T_1 = K_{T1}\frac{V - \omega K_{b1}}{R_1}$$

which reduces to

$$\left(\left(J_1 + J_2\left(\frac{n_1}{n_2}\right)^2\right)s + \left(D_2\left(\frac{n_1}{n_2}\right)^2 + \frac{K_{b1}K_{T1}}{R_1}\right)\right)\Omega(s) = V(s)\frac{K_{T1}}{R_1}$$

Putting this transfer function into the form of

$$H(s) = G\frac{1}{as+1}$$

we have a DC gain of

$$G = \frac{\frac{K_{T1}}{R_1}}{D_2\left(\frac{n_1}{n_2}\right)^2 + \frac{K_{b1}K_{T1}}{R_1}}$$

and a pole of

$$a = -\frac{\left(D_2\left(\frac{n_1}{n_2}\right)^2 + \frac{K_{b1}K_{T1}}{R_1}\right)}{\left(J_1 + J_2\left(\frac{n_1}{n_2}\right)^2\right)}$$

and a step response of

$$z(t) = G\left(1 - e^{-\frac{t}{a}}\right)$$

Q2 (5) Suppose that a load resistor was applied to the tachometer output terminals. Then a current will flow that is proportional to ω_1. But this will generate a torque that is equivalent to a loss term. Hence it is equivalent to increasing D_2. This will lower the gain G and will actually make the response a bit faster

Aid Sheet

One sided Laplace Transform $F(s) = \int_0^\infty f(t)e^{-st}dt$, $f(t) = \frac{1}{2\pi j}\int F(s)e^{st}ds$

$f(t)$	$F(s)$	$f(t)$	$F(s)$
1	$\delta(s)$	$\dot{f}$	$sF(s) - f(0^-)$
$\delta(t)$	1	$\ddot{f}$	$s^2F(s) - sf(0^-) - \dot{f}(0^-)$
$u(t)$	$1/s$	$\dddot{f}$	$s^3F(s) - s^2f(0^-) - s\dot{f}(0^-) - \ddot{f}(0^-)$
$t^m u(t)$	$m!/s^{m+1}$	$\int f(t)dt$	$F(s)/s$
$e^{-at}u(t)$	$1/(s+a)$	$\lim_{t\to\infty} f(t)$	$\lim_{s\to 0} sF(s)$
$\frac{1}{(m-1)!}t^{m-1}e^{-at}u(t)$	$1/(s+a)^m$	$\sin(at)u(t)$	$\frac{a}{s^2+a^2}$
$f(t-T)$	$F(s)e^{-sT}$	$\cos(at)u(t)$	$\frac{s}{s^2+a^2}$
$tf(t)$	$-\frac{d}{ds}F(s)$	$x(t)*y(t)$	$X(s)Y(s)$

$*$ implies convolution as $x(t)*y(t) = \int_{-\infty}^{\infty} x(\tau)y(t-\tau)d\tau$

Poles of second order system $s^2 + 2D\omega_n s + \omega_n^2 = 0$,

$s = -\sigma \pm j\omega_d \quad \sigma = D\omega_n \quad \omega_d = \omega_n\sqrt{1-D^2}$ rise time $\tau_r = \frac{2.2}{pole}$

State Space $\dot{x} = Ax + Br \quad y = Cx + Dr \quad H(s) = C(sI-A)^{-1}B + D$

Electric motor with parameters $\{R, K_T, K_b\}$, R internal resistance, current I flowing through motor gives torque $T = K_T I$, ω is rotation rate then induced back EMF voltage is $V_b = K_b \omega$

roots of quadratic $ax^2 + bx + c = 0$ $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

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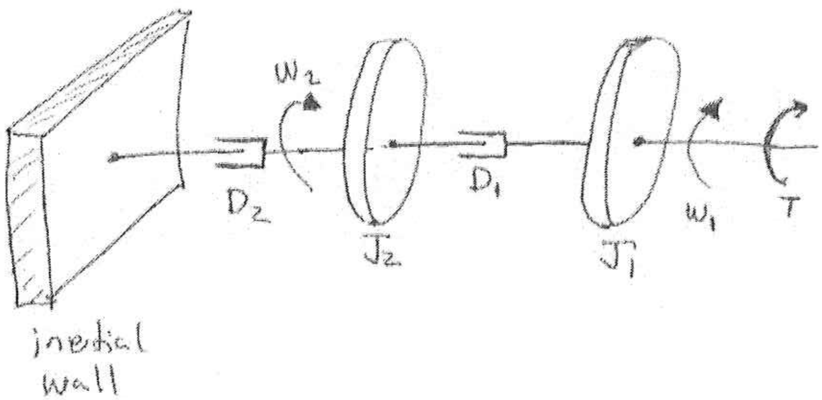
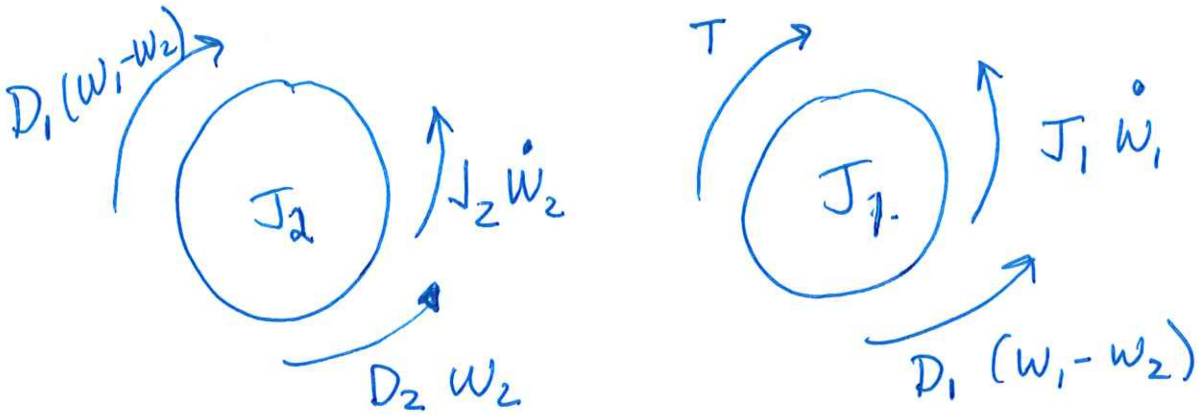
ENEL441 QUIZ 3 Name SOLUTION **UCID**

Consider the rotational system in the diagram below. Assume T(t) is an applied torque that results in rotations of the two flywheels with angular rotation rates of $\omega_1(t)$ and $\omega_2(t)$ as indicated.



Q1.(4) Determine the two free body diagrams showing the rotational forces for this system.



Q2. (4) Determine the two coupled DEQ's of this rotational system that relates T(t) to $\omega_1(t)$ and $\omega_2(t)$.

$$T(t) = J_1 \dot{w}_1 + D_1 (w_1 - w_2)$$

$$D_1 (w_1 - w_2) = D_2 w_2 + J_2 \dot{w}_2$$

Q3. (2) Transform the DEQ's of **Q2** assuming Laplace pairs of
$T(t) \Leftrightarrow T_s(s) \quad \omega_1(t) \Leftrightarrow \Omega_1(s) \quad \omega_2(t) \Leftrightarrow \Omega_2(s)$

$$T_s(s) = sJ_1 \Omega_1(s) + D_1(\Omega_1(s) - \Omega_2(s))$$

$$D_1 \Omega_1(s) - D_1 \Omega_2(s) = D_2 \Omega_2(s) + J_2 s \Omega_2(s)$$

Aid Sheet

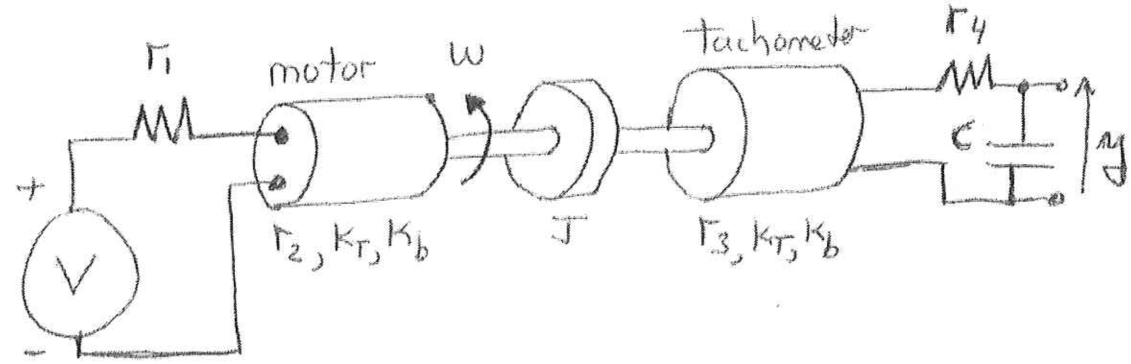
One sided Laplace Transform $F(s) = \int_0^\infty f(t)e^{-st}dt$, $f(t) = \frac{1}{2\pi j}\oint F(s)e^{st}ds$

$f(t)$	$F(s)$	$f(t)$	$F(s)$
1	$\delta(s)$	$\dot{f}$	$sF(s) - f(0^-)$
$\delta(t)$	1	$\ddot{f}$	$s^2F(s) - sf(0^-) - \dot{f}(0^-)$
$u(t)$	$1/s$	$\dddot{f}$	$s^3F(s) - s^2f(0^-) - s\dot{f}(0^-) - \ddot{f}(0^-)$
$t^m u(t)$	$m!/s^{m+1}$	$\int f(t)dt$	$F(s)/s$
$e^{-at}u(t)$	$1/(s+a)$	$\lim_{t\to\infty} f(t)$	$\lim_{s\to 0} sF(s)$
$\frac{1}{(m-1)!}t^{m-1}e^{-at}u(t)$	$1/(s+a)^m$	$\sin(at)u(t)$	$\frac{a}{s^2+a^2}$
$f(t-T)$	$F(s)e^{-sT}$	$\cos(at)u(t)$	$\frac{s}{s^2+a^2}$
$tf(t)$	$-\frac{d}{ds}F(s)$	$x(t) * y(t)$	$X(s)Y(s)$

$*$ implies convolution as $x(t) * y(t) = \int_{-\infty}^{\infty} x(\tau)y(t-\tau)d\tau$

ENEL441 QUIZ 4 Name 2016 UCID

Consider the model of a motor driving a tachometer as shown. The objective is to determine the filtered tachometer output y(t) as a function of the input voltage v(t). J models the rotational inertia of the motor.



Determine the state space system describing this model assuming the state variables of

$$x(t) = \begin{bmatrix} \omega(t) \\ y(t) \end{bmatrix}$$

That is determine the state space matrices A, B, C and D for this problem. Recall that

$$\frac{dx(t)}{dt} = Ax(t) + Bv(t) \text{ and } y(t) = Cx(t) + Dv(t)$$

Solution

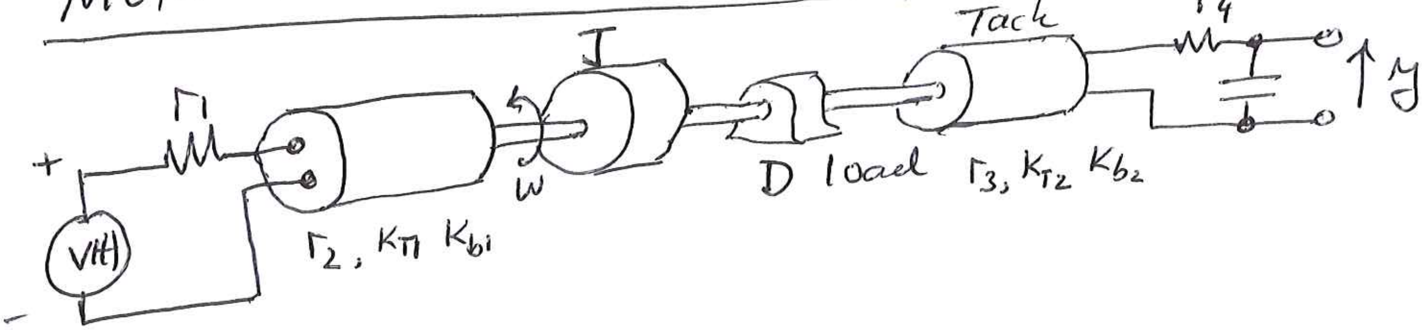
One possibility is to first write the currents of the motor and generator in terms of the state variables and input as

$$i_1 = \frac{v - k_b\omega}{r_1 + r_2}$$

$$i_2 = \frac{k_b\omega - y}{r_3 + r_4}$$

Then write the derivatives of the state variables in terms of the currents as

Motor with sensor Feedback

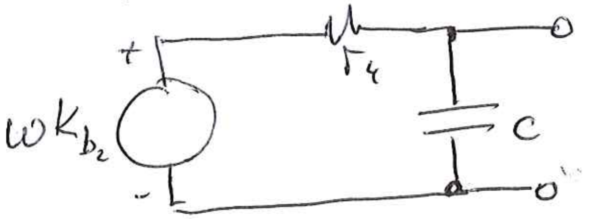


Transfer function from $v(t)$ to $y(t)$

Torque Tach ignore

$$\left(\frac{V - K_{b1}\omega}{r_1 + r_2}\right) K_{T1} = J\dot{\omega} + D\omega + T_T$$

Split up problem



$$\frac{\frac{1}{sC}}{\frac{1}{sC} + R_4}$$

Split up problem ① Transfer function v to ω

② ω to y