請於答案卷上作答，於試題卷上作答者，不予計分。

1. An electromechanical position control system is shown in the following figure. The motor has an electrical constant K_e, a torque constant K_t, an armature inductance L_a and a resistance R_a. The rotor has an inertia J_1 and a viscous friction B. The load has an inertia J_2. The two inertias are connected by a shaft with a spring constant k and an equivalent viscous damping b.

   (a) Write the equations of motion (10%)

   (b) Write the equation as a set of simultaneous first-order equations in state-variable form. Use the state vector $\mathbf{x} = [\theta_2\ \dot{\theta}_2\ \theta_1\ \dot{\theta}_1\ i_a]^T$ (10%)

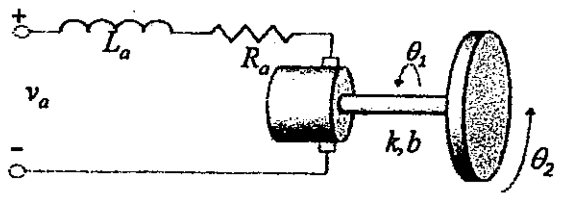
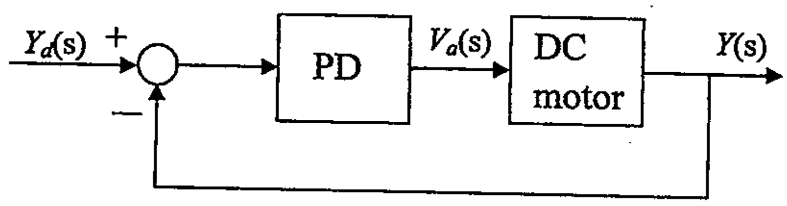


Figure for Problem 1

2. If a DC motor is modeled as:

$$Y(s) = \frac{A}{(\tau_1 s+1)(\tau_2 s+1)} V_a(s)$$

Please derive a PD controller ($k_p + k_d s$) so that the poles of the closed-loop system are as shown in the following Figure. Express k_p, k_d in terms of three parameters related to the pole placement ζ (damping ratio) and ω_n (undamped natural frequency). (20%)



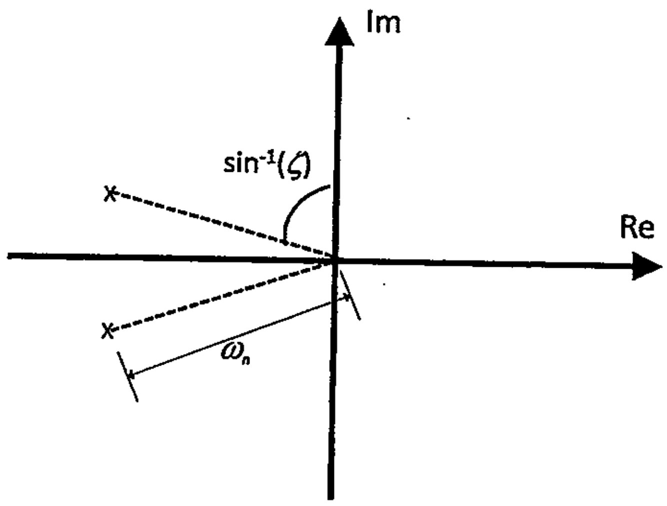


Figure for Problem 2

3. Please discuss the capabilities of external disturbance rejection for an open-loop control system and a closed-loop control system. (10%)

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4. The block diagram of a liquid-level control system is shown in the following figure. The following data are given: $K_a = 50$, $K_I = 50$, $K_b = 0.0706$, $J = 0.006$, $R_a = 10$, $K_i = 10$, $K_o = 40$, and $n = 1/100$. Let N and A be the variable parameters.
   (a) Find the ranges of N and A so that the closed-loop system is asymptotically stable. Indicate the region in the N versus A plane in which the system is stable. Use the fact that N is an integer. **(10%)**
   (b) If A is infinitely large, what is the maximum value of N (integer) for stability. **(5%)**

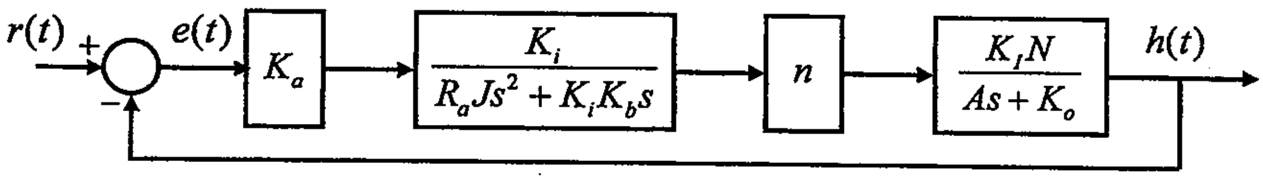

Figure for Problem 4

5. The state diagram of a control system containing a motor coupled to a tachometer and an inertial load is shown in the following figure.
   (a) Write the state equations of the system using θ_L, ω_L, θ_t, ω_t, θ_m, and ω_m as the state variables (in the listed order). The motor torque T_m is the input. **(6%)**
   (b) Find the following transfer functions: $\dfrac{\Theta_L(s)}{T_m(s)}$, $\dfrac{\Theta_t(s)}{T_m(s)}$, and $\dfrac{\Theta_m(s)}{T_m(s)}$. **(9%)**

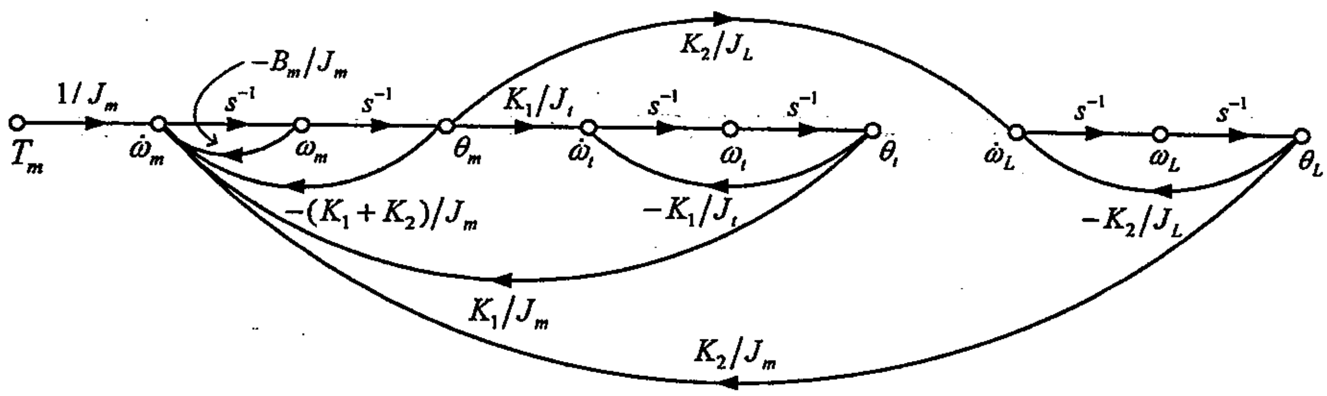

Figure for Problem 5

6. Refer to the figure of Problem 4, but the parameter values are now given as: $K_a = 50$, $K_I = 10$, $K_b = 0.0706$, $J = 0.006$, $R_a = 10$, $K_i = 10$, $K_o = 50$, $A = 50$, $N = 1$, and $n = 1/100$. (a) Find the transfer functions $M_H(s) = H(s)/R(s)$. **(2%)** (b) The transfer function $M_H(s)$ is to be approximated by a second-order system with the closed-loop transfer function $M_L(s) = \dfrac{G_L(s)}{1+G_L(s)} = \dfrac{1}{1+d_1 s + d_2 s^2}$, where d_1 and d_2 are real constants . Find d_1 and d_2. **(8%)** <**Hint:** The criterion of finding the low-order $M_L(s)$, given $M_H(s)$, is that the following relation should be satisfied as closely as possible: $|M_H(j\omega)|^2 / |M_L(j\omega)|^2 = 1$, for $0 \le \omega \le \infty$.> (c) For the approximated second-order system, find the performance indices in time domain for the system, i.e., the time that the maximum overshoot (MO) occurs, $t_{\max}$; percentage of MO, $\mathrm{MO}\,\%$; delay time, t_d; rising time, t_r; and settling time, t_s. **(10%)**

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