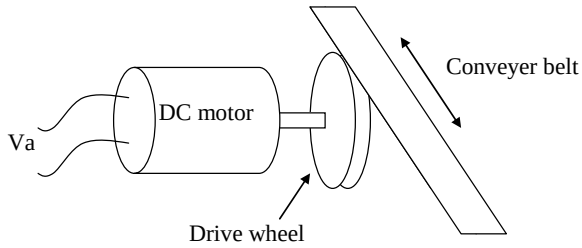
Fall 2007 EE128 Midterm Exam

- You must show your work. Correct answer without work shown will receive no credit.
- No question answered. If you think the problem is not clear, you may solve the problem based on your assumption. In such a case, you must write down your assumption.
- All transfer functions in this test, unless given specifically, are proper transfer functions (i.e., the order of the numerator is not higher than the order of the denominator).

(1) A DC motor is used for driving a conveyer belt as shown in the following figure. The parameters of the motor and load force exerted on the drive wheel are given below:

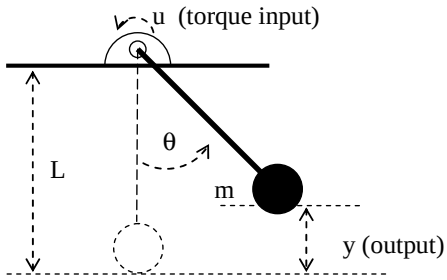


- Armature winding resistance (Ra): 1 Ohm
- Winding inductance: negligible
- Back emf constant (K_{bemf}): 0.5 V/ (rad/sec)
- Torque constant (K_t): 0.5 NM/amp (Newton-meter per amp)
- Inertia of the motor rotor and the drive wheel (J): 1 kg-meter^2
- Viscous friction constant (K_f): 0.01 NM/(rad/second)
- Conveyer belt load force (always against the moving direction) (F): 10 Newton.
- Drive wheel radius (r): 0.1 meter.

(1.a) Sketch a block diagram (using only integrator, gain, and summing junction blocks) for this system. For each gain block, give a symbolic expression of the gain. The inputs to the system are: (i) the voltage Va (voltage across the armature winding) and (ii) the load force F (can be thought of as a 'disturbance'). The output of the system is the linear speed of the conveyer belt. (15%)

(1.b) If 10 volt is applied across the armature winding (and the load force), what is the steady state speed of the convey belt? (15%)

(2) Consider the following pendulum system where a point mass of m kg is connected to a rotary joint by a massless rod of length L. The input to the system is the torque (u) acting on rod at the joint. The pendulum swings on a vertical plan (and hence, gravity must be taken into account in the analysis). The output of the system is the vertical position (y) of the point mass as shown in the figure. You may use $J=mL^2$ as the effective inertial of the system about the pivot point .



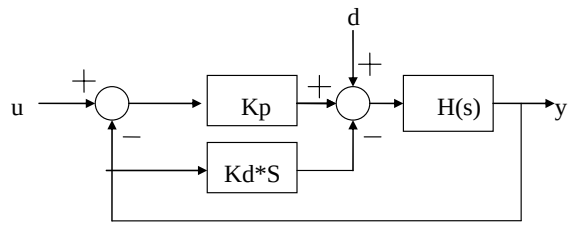
(2.a) Write a nonlinear <u>state equation</u> for this pendulum system. (5%)

(2.b) Linearize the system at $\theta=3\pi/4$ (i.e. 135°) and design a stabilizing controller (give a complete expression of 'u') for the system for maintaining the angle at $\theta=3\pi/4$. Your design only needs to make

the system stable, i.e., no need to worry about other specification such as overshoot, etc.. For simplicity, let m=1kg, L=1 meter. (15%)

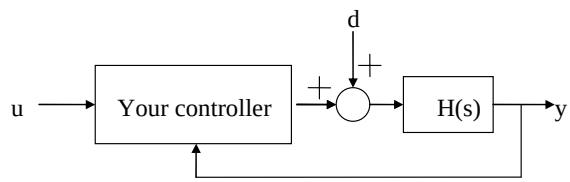
(3) Design a PD controller for the following system so that, with a unit step input, the steady state error (u-y) is 0.02. Also, the system should have about 5% output overshoot (damping ratio = 0.7) when a step is applied to the input u. (15%)

$$H(s) = \frac{1}{(s+1)^2}.$$

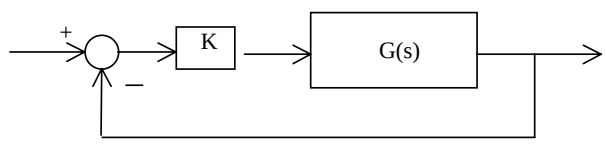


(4) Design a controller for the following feedback controller where $H(s) = \frac{1}{(s+2)}$. Your design must satisfy the following requirements: (15%) (Hint: The structure of the controller may be simpler than you think.)

- The controller should be able to reject a constant disturbance such that the steady state output due to a unit step disturbance is less than 0.05.
- The system should not have any overshoot when a step is applied to the input.
- The system should have a DC gain of 2 from u to y.
- The system should be stable.



(5) Consider the closed loop system shown below where $H(s) = \frac{s+1}{s^2(s+2)^2}$



Sketch the root locus for the system as K goes from 0 to positive infinite. Specifically, show the root locus based on the real axis root locus and, for the complex portion, based on the asymptotes (show angles and intersections of asymptotes). No other feature is necessary. (10%)

(6) Consider the unity feedback system shown in Problem (5) above. Assume G(s) is a transfer function of relative degree 2 (i.e., the order of the numerator is 2 less than the order of the denominator. Give the condition on the poles and zeros of G(s) such that this system can be stabilized by positive K. Give the condition as general as possible. (Hint: think root locus). (10%)