ME Ph.D. Qualifying Examination — System Dynamics and Controls, Spring 2009

Choose **3** of the following **4** questions to answer.

Problem 1

Consider a unity-feedback PID controlled system with the open-loop transfer function:

$$G(s) = \frac{K}{s(1+0.1s)(1+0.2s)}.$$

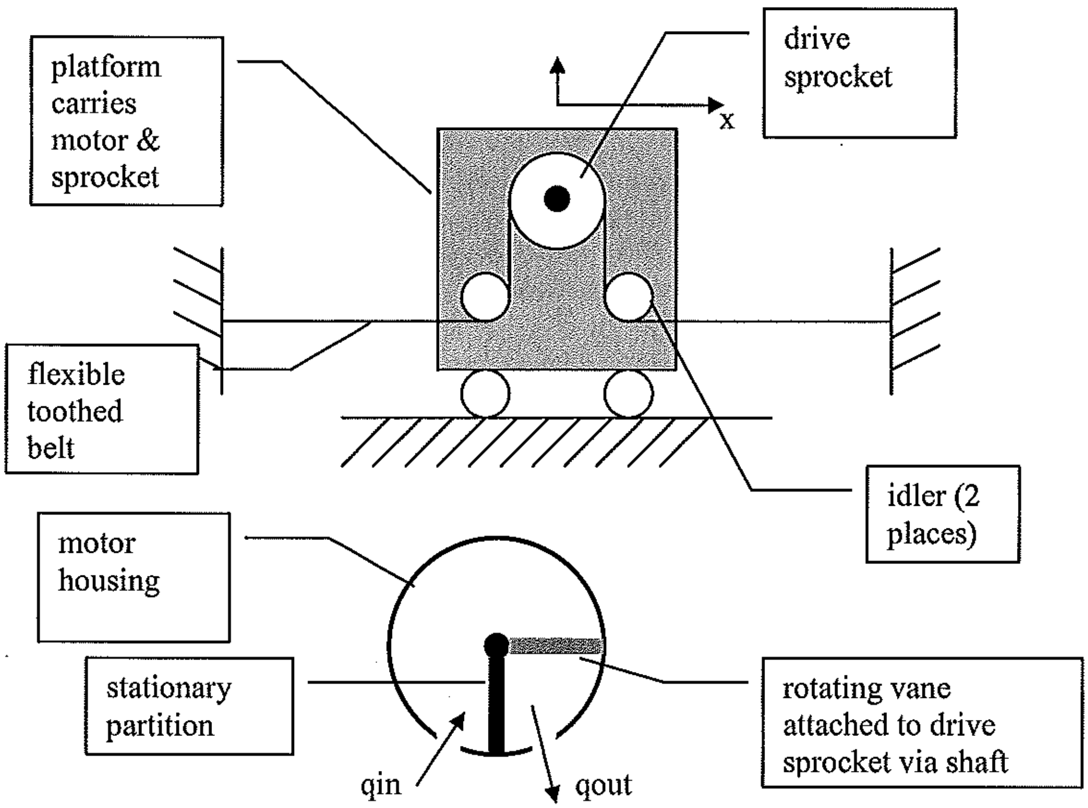
Starting with a simple proportional controller with the gain K_p=1, an engineer designs the K value for the mechanical hardware so that the ramp-error constant of the system is 100. He then realizes that the closed-loop system (with only K_p=1) is unstable since the pair of complex poles are $3.8 \pm j14.4$.

(a) In an attempt to improve the system with a PD controller, he introduces a derivative gain K_d while keeping K=100 and K_p=1 to achieve a reasonable transient response; say, the dominant complex poles $-a \pm jb$ have a relative damping ratio of 0.7 and $a > 7.5$. Use a root locus plot to illustrate the effect of K_d on the closed loop poles.

(b) Design a PID controller (using root locus OR bode diagrams) to achieve the above specification (in terms of the ramp error constant and dominant closed-loop poles). Show your approach clearly but NO detailed numerical calculation is required.

Problem 2

Shown schematically below is an "omega drive" arrangement for moving a platform via a sprocket engaging a flexible toothed belt. The drive sprocket is powered by a vane type hydraulic actuator diagrammed separately. Flow qin is the input into the actuator is controlled by a servovalve that is not part of the system you are to model. The total length of the belt is L, the drive sprocket has radius r_s and the inner radius of the motor is r_p and its depth out of the page is d. You can assume negligible flow losses. The compliance of the belt per meter of length is c_b. qin is the volumetric rate of flow into the motor as shown, with positive qin resulting in a positive change in platform position x. x is measured from the midpoint position as shown. Total mass of the platform is M.



(a) Without deriving equations of motion, determine the order of the system above and explain why this is the order you expect (without deriving equations).

(b) Derive the nonlinear equations of motion of the system as defined above. The equations should yield x as the output with qin as the input. State any assumptions beyond those made above.

(c) Linearize these equations of motion about zero velocity at x = L/5.

(d) A more detailed model could include the compressibility of the fluid. It is determined that with a change of pressure of dp the volume of fluid decreases by dv/dp = c_f. Now what are the dynamic equation(s) of the system?

Problem 3

Consider a unity-feedback control system whose feedforward portion

$$G(s) = \frac{K(s+1)}{(s-1)(s+2)}$$

Use the Nyquist stability criterion to determine the range of K such that the closed-loop system is stable.

Problem 4
With ever-increasing fuel costs and laziness, there is an emerging market for personal human transporters. Perhaps the most widely-known such product is the Segway, shown in Figure 1. Unfortunately, the Segway falls over without active feedback control. This property makes the device dangerous – especially for those riders who do not have good jumping, landing, and falling skills. Therefore, numerous other human transporters have been developed that have 3 or more wheels, such as the Eco-Stand Scooter shown in Figure 2.

Figure 1: Segway Human Transporter.

Figure 2: Eco-Stand-Up Scooter
http://www.ihumantransporter.com/

1) Using simple models and equations, explain why the Segway naturally falls over and the Eco-Scooter does not (assume no feedback control for either machine and do NOT include a human passenger.)
2) Now, add a human operator to the system and explain what effect they have on the stability of both machines.
3) Develop a simple controller that would stabilize the Segway.
4) What type of sensors, and how many, would be required for your controller? What noise sources, or problems would you expect with your sensors?
5) What tests would you run and what performance data would you collect to compare the Segway and the Eco-Scooter?
6) Sketch the time responses of both machines to a "Go Forward" command from the operator.