# University of Wisconsin-Madison
## Department of Electrical and Computer Engineering
### ECE 332 - Feedback Control Systems, Fall Semester 1998
### Problem Set #11

Distributed: Wednesday, December 2

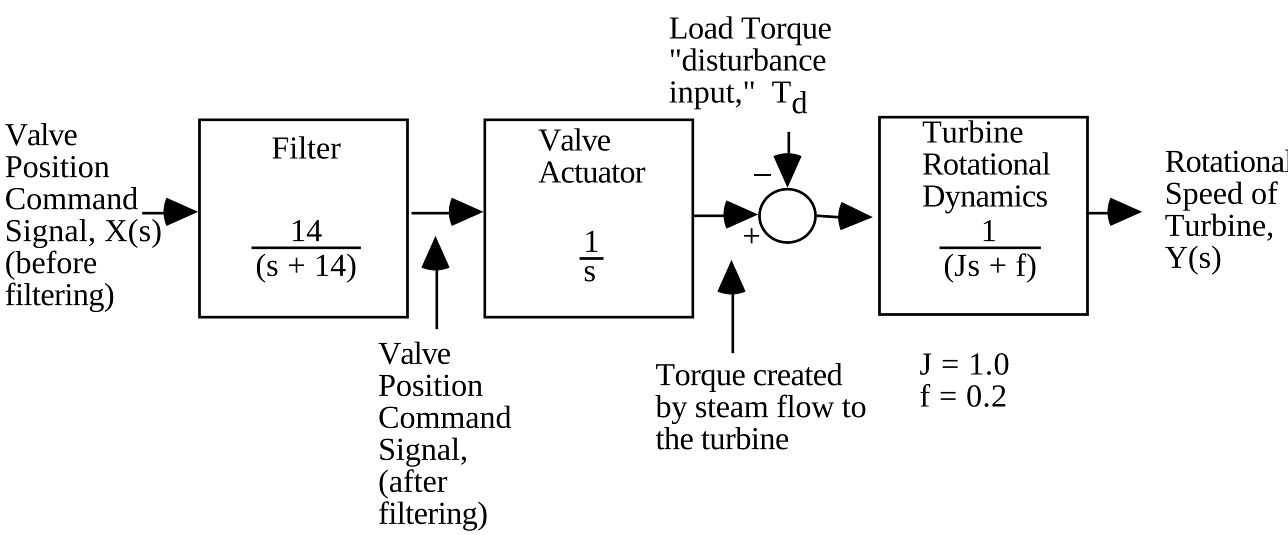
Due: Friday, December 11

**Reading:** These problems will make use of new material in Chapter 10 of Dorf, as well as some of the ideas of PID design via root locus from Chapter 7, and the "Q-Parameterization" ideas presented in the class handout early in the semester. From Ch 10, your main focus will be on sections10.4 (Lead compensation via Bode information), 10.8 (Lag compensation via Bode information), and 10.11 ("deadbeat design," which we will combine with the ideas from the Q-parameterization handout).

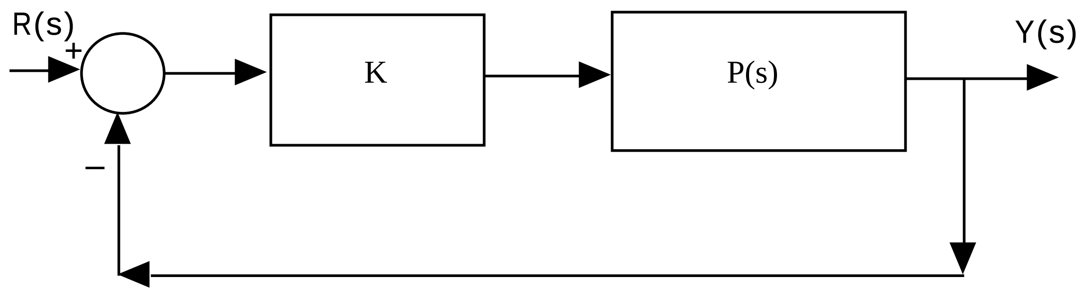
**Genral point:** The problems below are design problems. You are completely free to mix hand analysis and MATLAB computation as you find most convenient.

**Problem**

Consider a steam turbine system, described by the following block diagram:




For our initial analysis, we will ignore the effect of the disturbance torque, $T_d$. With $T_d = 0$, we may consider our given "forward path" transfer function to be P(s) = Y(s)/X(s), describing the response from the value position command signal (physically, this would be a voltage) to the mechanical speed (assumed to be in units of radians/sec rotational speed). Now, suppose we measure speed with a tachometer that produces a voltage that is fed back, to produce a unity gain feedback. For our first design, we put an adjustable gain (here it will be less than 1, so we may say "attenuator") in front of P(s). This produces our standard configuration:




a) Compute a positive value of K that produces a dominant second order pair of poles with damping ratio of approximately 0.707. Confirm that the second order pair produced is dominant (i.e., compute ratio of real parts), and estimate the 3% settling time for this system. Note: you should expect a small K, and poor settling time. THIS SHOULD BE EASY!

b) Now consider replacing the simple gain / attenuator "K" above with a PID controller, using the ideas of section 7.7 of the text. Recall that a PID design may be thought of as adding to the "open loop" transfer function one pole at the origin, and one pair of complex zeros which you are free to pick by design. Having chosen a location for the zeros, you then pick a leading gain constant for the system via root locus techniques, so as to produce "desirable" closed loop poles.

You are to design an idealize PID controller for this system, of the form

$$C(s) = \frac{K(s - z_1)(s - z_2)}{s}$$

You must select and specify the K, z1, z2 (note that z1 and z2 may be a complex conjugate pair) values in your design. Your goal is to produce a system whose transfer function from R(s) to Y(s) has no more than 10% overshoot in its step response. Moreover, you should attempt to produce a fast settling time in this step response (the quality of your design will be judged in part by how fast this time is). You may use MATLAB computations freely, but you must describe your reasoning in the design process, and minimize the number of plots you turn in with your solution (i.e., a solution which suggests that you just randomly experimented with K and z values until you achieved a good step response will not receive high marks!).

c) Now consider a phase lag compensator, in place of the PID controller above. Use of the Bode plot based design method of section 10.8 is recommended, though you may supplement this with root locus analysis of the type described in 10.7. Your design goal here is to obtain a phase margin of 30 degrees or more, while keeping a settling time that is not too large (experiment here - you should see a tradeoff; you have your settling time from (b) as a benchmark to compare against). Note that we do NOT have a steady state error specification here, which is what gives you an extra degree of freedom to trade off settling time versus phase margin. You should specify K, z, and p in your comensator , written in the form of (10.2) in the text. For comparison to (b), compute the closed loop step response that is produced by your design. You should report its percent overshoot and settling time as apart of your answer (turning in the MATLAB step response plot with these values sketched in is acceptable).

d) Now let us consider combining the ideas of sectioon 10.11 of the text with our "Q-Parameterization" method presented in the class handout from earlier in the semester. Section 10.11 should be considered nothing more than a collection of standard form, "desirable" closed loop transfer functions. For example, the 6th order entry of Table 10.2 gives a desirable transfer function T(s) of the form

$$T(s) = \frac{1}{s^6 + 3.15s^5 + 6.50s^4 + 8.70s^3 + 7.55s^2 + 4.05s + 1}$$

Suppose we take the technique of the handout, and slightly relax one of its requirements: we will allow Q(s) {and, as you will see, C(s)) to have order of numerator less than *or equal to* order of denominator. With this slight modification, the T(s) above becomes an acceptable "target" transfer function that you try to obtain. You are to compute the C(s) that produces this desired closed loop T(s). No need to compute the properties of the step response here, as the book already provides these in Table 10.2.

e) Finally, for each of the four controller designs you have considered, use MATLAB to compute two signals of interest:

(i) the output due to a step input at $T_d(s)$. Recall that by superposition, you will take R(s) = 0 for this computation.

(ii) It is physically reasonable that to expect that there will be limits on the acceptable magnitude of "valve position command signal" (after the filter). For a step input at R(s), with $T_d(s)=0$, use MATLAB to compute the time waveform that results at this point in the loop (to prepare for this MATLAB computation, you should first symbolically compute the transfer function from R(s) to this signal). Briefly discuss the differences in this signal between your four designs.