GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Spring Quarter 1996

SYSTEM DYNAMICS & CONTROLS
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

-- **Please sign your name on the back of this page** --

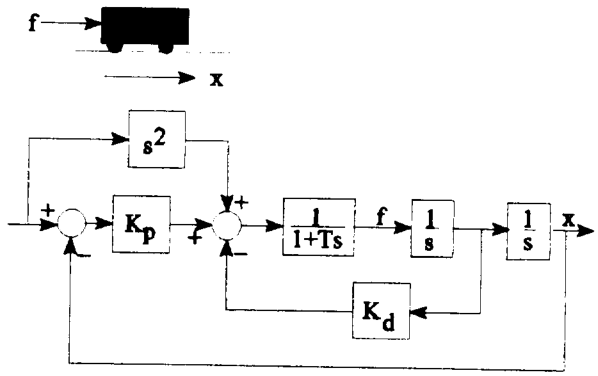
Dynamics and Control Qualifier

There are three problems attached, so you have an average of 40 minutes to work on each problem. We are trying to determine your understanding rather than your memory of obscure formulas or your ability to calculate a particular result. Therefore, it is important that you make clear the method you are using and the reasoning process. Try to show an orderly approach. Please, make the text easy to read. Cross out errors rather than try to erase. If a problem seems to require a difficult set of calculations, you are probably attempting the wrong approach or attempting to generate too precise a result. E.g., plots and drawings don't need to have much precision. Some questions don't require numbers at all but rather a very short discussion.

Don't let a particular problem or subsections of a problem take too much time. Go on to something else and come back.

Qualifier Question for Spring 1996

QUESTION ONE:



A simple position control of a mass has a transfer function expression relating the force on the mass, f, to the position of the mass, x, of

$$x = \frac{1}{s^2} f$$

We control the position with a feedback and feedforward system as shown here. Please answer the following seven questions relating to this system.

Question 1 (10%)
Are K_d and K_p the usual derivative and proportional feedback terms, respectively? If no, explain briefly.

Question 2 (20%)
What damping ratio does this system have if T=0, $K_d = 2$ and $K_p = 1$?

Question 3 (20%)
The term with T in it is shown because most controllers have some type of delay in them. T represents this delay. Set up the characteristic equation for a root locus analysis where T is the variable to be varied. Assume $K_d = 2$ and $K_p = 1$ as in Question 2.

Question 4 (15%)
Sketch the form of the root locus and comment on what it shows about acceptable values of T. No mathematical analysis is called for here. You are not expected to give any **numerical** values for such things as values of T, break-in or out points, etc.

Question 5 (15%)
Does the feedforward term seem reasonable? Comment on things that are reasonable and things that may be unreasonable about this term.

Question 6 (10%)
Would you expect the feedforward term to effect the stability of the complete system? Explain briefly.

Question 7 (10%)
Would you expect the feedforward term to reduce the error signal on average? Why or why not? Be brief.

Mechanical Engineering
Qualification Examination (Modeling)

QUESTION TWO:

Spring 1996

You work for the Thi Sise Asy refinery. Figure 1 shows a classical, but simplified, fuel off-loading system between an oil tanker and your refinery. The pump located near the tanker should be considered a flow source with a volume flow rate of Q, and the long large pipe connecting the pump to the refinery has both inertance and resistance in it. There is an emergency valve located right at the entrance to the refinery. This valve is normally open; however, when there is a serious problem in the refinery, it can be shut quite fast (in fact you should consider it as instantaneous). At the instant that the valve is shut, the pump at the tanker is shut down so the driving source of the flow ceases. However, to avoid damaging the pump the flow is shunted around the pump, so the pump takes on no loading when it is shut down. Think of it as just venting the pipe at the output of the pump to the atmosphere.

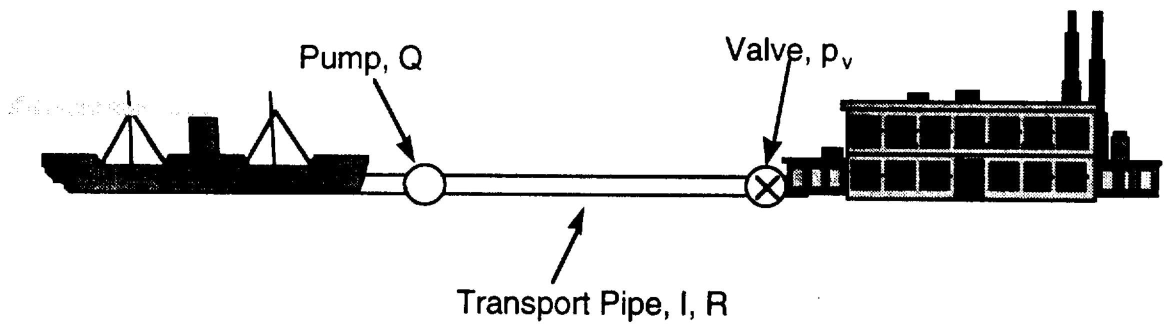


Figure 1. Crude Oil Transfer System.

Part A

Clearly, there is a problem with the system as stated this relates to the pressure experienced at the valve when it is shut off while crude oil is being transferred. In a few sentences (no more than 4) please discuss what is physically happening at the valve that should cause you some concern.

Part B

To alleviate this problem, it is recommended that a surge tank having a capacitance of C, be added to the pipe as shown in Figure 2. Your task is to determine where the tank should be attached to the pipe (*e.g.*, the beginning, the middle or the end of the pipe). In Figure 2, the tank is shown in the middle of the pipe length. You should make your recommendation based on the physics of the situation and then discuss your reasoning. To ensure that there is no ambiguity, please include a sketch of the system with the tank in your recommended position.

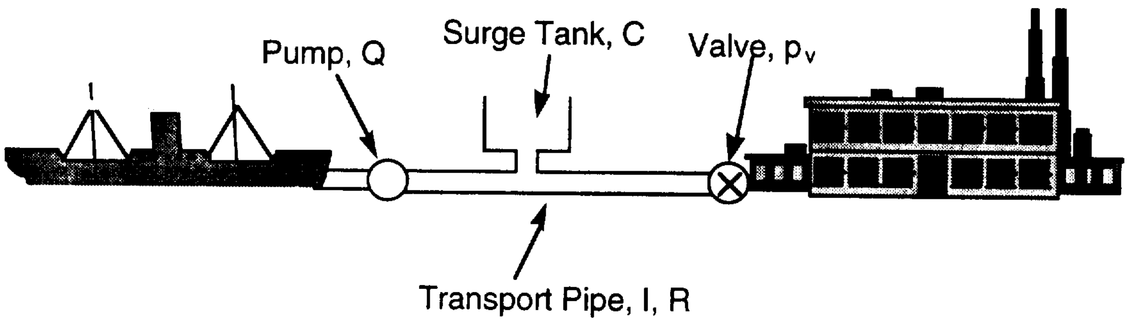


Figure 2. Crude Oil Transfer System with Safety Tank.

Part C

Based on your design please determine the maximum pressure that would be developed at the valve, p_v. Make sure that you provide enough details as to how you would arrive at your answer. Also, make sure that you provide a detailed discussion as to how you modeled the pipe (remember it contains resistance and inertance).

Part D

Please draw the mechanical translational equivalent of this system and discuss the relationships between each element and variable in your fluid system design and that of the mechanical system. Make sure to discuss the mechanical equivalent of the cut-off valve at the refinery.

Part E

Please draw the thermal equivalent of the system and discuss the relation of each element and variable in the thermal system to that of the fluid system.

Spring 1996 QUESTION THREE:

[1] Nyquist stability criterion relates the number of encirclements to the numbers of zeros and poles. Sometimes one may wonder how these seemingly different (encirclement: chicken; pole: monkey) quantities can be related. Please present a simple (but insightful) argument to show the Nyquist stability criterion. For this purpose, use the following open-loop transfer function for a unity-feedback system

$$G(s) = \frac{(s - z_1)(s - z_2)}{(s - p_1)(s - p_2)(s - p_3)}.$$

Here z_1 and z_2, which are complex conjugate, are on the right-half-plane. p_1 is on the left-half-plane. p_2 and p_3, which are complex conjugate, are both on the right-half-plane.

[2] Bode plot is sometimes obtained by using experimental data. One then tries to have a reasonably close approximation of the transfer function. Can one actually only use, *in principle*, the *dB vs. frequency* portion of the plot to retrieve the transfer function? If yes, how? If no, why?

[3] Can one only use the Bode plot (and not Nyquist or polar plot) to check the stability of a system? If yes, how? If no, why?