Dynamics Systems & Control Ph.D. Qualifying Exam
Fall 2015

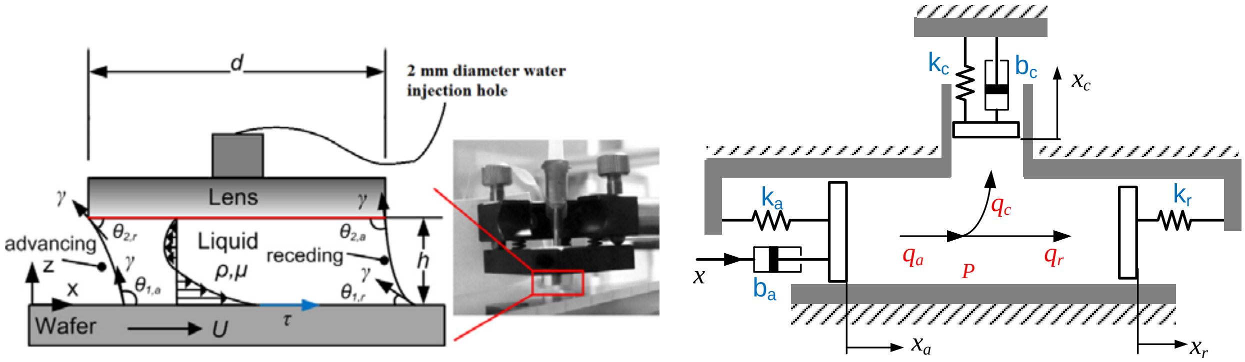
<u>Instructions</u>:

Please work 3 of the 4 problems on this exam. It is important that you clearly mark which three problems you wish to have graded. For the 3 problems that you select, show all your work in order to receive proper credit. You are allowed to use a calculator.

Be sure to budget your time; concentrate on setting up the problem solution first and leave algebra until the end. When necessary, you may leave your answers in terms of unevaluated numerical expressions. Good Luck!

Problem 1

Fig. 1(a) schematically illustrates the liquid dynamics between the lens and wafer in the plane of symmetry for immersion lithography in wafer fabrication. As the wafer moves with a speed $u = dx/dt$, the viscous effect becomes the dominant force driving the liquid in the gap. The effect of wafer motion on the liquid is modeled in Fig. 1(b) approximately as a displacement input x through a damper (damping coefficient b_a). Surface tensions are spring-like forces modeled as massless mechanical springs (with stiffness k_a and k_r where the subscripts "*a*" and "*r*" denote the "advancing" and "receding" surface displacements, x_a and x_r, respectively. the surface tension effect of liquid flowing sideward is taken into account by the third massless spring k_c and damper b_c. Assuming that the mass of the liquid is negligible and the pressure within the liquid is uniform, derive the transfer function $X_a(s)/U(s)$.



a) Meniscus development during wafer motion b) Lumped-parameter dynamic model

Fig. 1 Illustrative schematics

Problem 2

Consider a unity feedback system whose open-loop (feedforward) portion is a proportional controller (P controller) followed by the system

$$G(s) = \frac{s^2 + s}{s^3 + a_1 s + a_2}.$$

Here a_1 and a_2 are constant system parameters. Their exact values are unknown but we know that

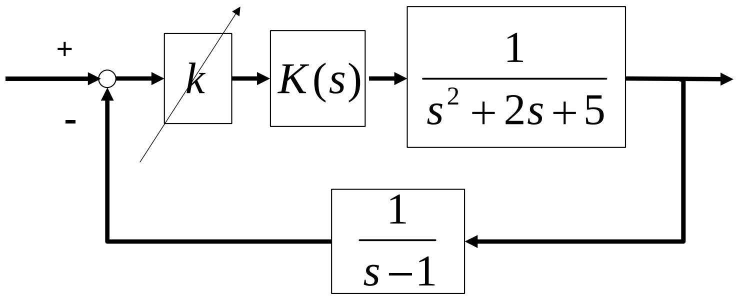
$$3 \le a_1 \le 4,\ 1 \le a_2 \le 4.$$

(1) Determine the range of the proportional gain K which assures the stability of the closed-loop system.

(2) Suppose K is selected to render the system stable, say $\bar{K}$. Suppose the reference input to the system is a unit-ramp function of time. Does the steady-state output exist? If yes, determine the maximum possible value of the steady-state output. If no, explain.

Problem 3

Consider the following feedback system with a loop gain *k* (>0).



a) Assume controller $K(s) = 1$ (i.e., proportional control).
   (a-1) Sketch the root-locus and discuss the stability of the feedback system with respect to *k*.
   (a-2) Determine the range of *k* for stability.

b) Assume $K(s) = s + z$ (i.e., PD control). Determine the range of *z* such that there exists a certain positive value $a > 0$ where the closed-loop system is always stable for any $k > a$.

c) Note: When sketching a root-locus plot, you don't need to determine the angle of departure from complex poles, intersection of the asymptotes, or break-in/away points. A general sketch is acceptable.

Problem 4

The nominal model for an unstable plant is given by $P(s) = \frac{s+20}{s^2-100}$.

a) Sketch the bode diagram of the plant.

b) Explain how the Bode diagram of P can be obtained experimentally.

c) Propose a suitable controller (e.g., P,PD,PI,PID,Lead,Lag,…) and outline a procedure for selecting its gains/parameters such that the compensated system shown in the block diagram below is critically damped, has no steady-state error to a constant r and d, and has a gain cross-over frequency (i.e., the frequency at which $|CG(j\omega_c)|=1$) of $\omega_c \geq 20$ rad/sec.