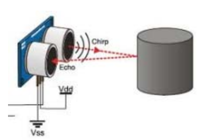
NAME _______________________
ESE406 - SPRING 2015 – Final EXAM
CLOSED NOTES & CLOSED BOOK : NO CALCULATORS

- Choose the one best answer for each question and *enter it on your answer sheet*.
- A correct answer is worth 3 points.
- No answer is worth 1 points.
- An incorrect answer is worth 0 points. Random guessing will lower your grade, on average.
- You must work completely independently.

SUBMIT YOUR ANSWER SHEET BEFORE YOU LEAVE THE ROOM
TAKE THIS EXAM WITH YOU AND SUBMIT "REVISED / COMPLETED" ANSWERS ONLINE FOR 1-POINT EACH

1. $\dfrac{(1+j)}{e^{j\pi/4}}$ is equal to...

   A. $\sqrt{2}$
   B. $\sqrt{2}j$
   C. $\sqrt{2}e^{j3\pi/4}$
   D. $-\dfrac{\sqrt{2}}{2}$

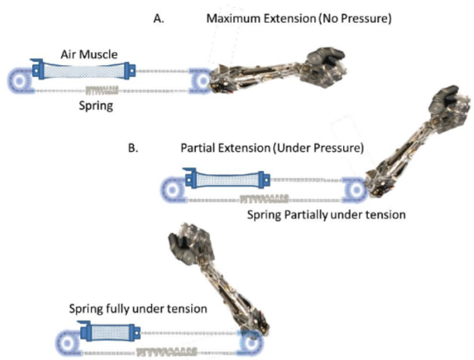


2. The Parallax PING device, shown above, is an example of which type of system element?

   A. Sensor
   B. Actuator
   C. Plant
   D. Compensator

3. Lyapunov's Second Method...

   A. ...is used to establish stability of equilibria of nonlinear dynamic systems.
   B. ...is nice because it does not require an explicit solution of the ODE.
   C. ...can be challenging because it requires the analyst to divine a suitable Lyapunov function (often some generalization of a total energy function).
   D. All of the above.



4. The pneumatic device that moves the robotic arm in the figure above[1] is an example of what type of system element?

   A. Sensor
   B. Actuator
   C. Plant
   D. Compensator

5. An engineer uses a PD compensator, $G_C(s) = K_P + K_D s$ to improve the stability of a closed-loop system. But she finds that derivative feedback creates undesired amplification of high-frequency noise in the system. So, she decides to low-pass filter the derivative feedback, using $G_C(s) = K_P + \dfrac{K_D s}{\tau s + 1}$. This filtered PD compensation is equivalent to...

   A. Lead Compensation
   B. Lag Compensation
   C. Notch Filter
   D. Bang-Bang Control

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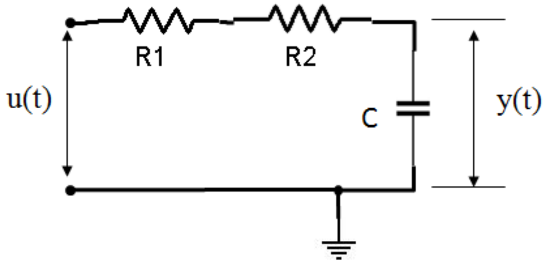
[1] http://sreal.eecs.ucf.edu/people/phd/rpillatproject8.php



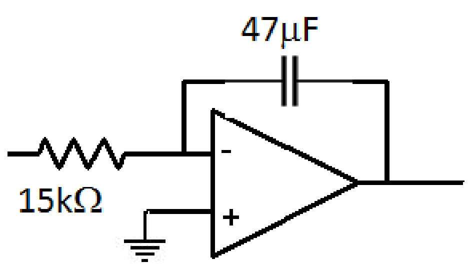
6. The ODE describing the circuit shown above is...

   A. $C\dfrac{d^2y}{dt^2}+R_2y=R_1u$

   B. $R_1C\dfrac{d^2y}{dt^2}+R_2y=R_2u$

   C. $C\dfrac{dy}{dt}+\left(R_1+R_2\right)y=\left(R_1+R_2\right)u$

   D. $\left(R_1+R_2\right)C\dfrac{dy}{dt}+y=u$



7. The op-amp circuit shown above has a transfer function given by...

   A. $\dfrac{1.4}{s}$

   B. $\dfrac{1}{1.4s+1}$

   C. $\dfrac{s}{1.4}$

   D. $\dfrac{s-1.4}{s+1.4}$

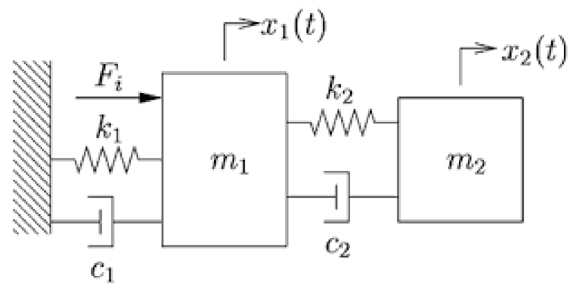
8. The Laplace Transform of $\left[y(t)\right]^2$ ...

   A. ...is equal to $\left[Y(s)\right]^2$

   B. ...is equal to $s^2Y(s)$

   C. ...is equal to $\sqrt{Y(s)}$

   D. ...cannot generally be expressed simply in terms of $Y(s)$.



9. For the system shown above, how many poles are in the transfer function $\dfrac{X_2(s)}{F_i(s)}$?

   A. 1
   B. 2
   C. 4
   D. 8

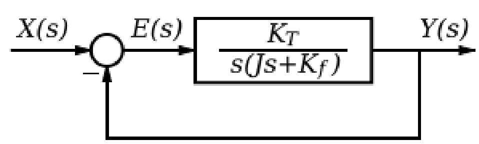
10. What transfer function corresponds to the differential equation $RC\dfrac{dy}{dt}+y=RC\dfrac{du}{dt}$?

    A. $\dfrac{RCs}{RCs+1}$

    B. $\dfrac{RC}{RC-s}$

    C. $\dfrac{1}{s+RC}$

    D. We need initial conditions to determine a transfer function.



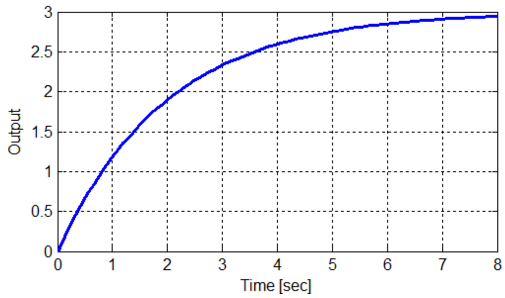
11. The figure above represents a position-control system for a DC motor. The closed-loop transfer function, $\dfrac{Y(s)}{X(s)}$, is...

    A. $\dfrac{1-K_T}{Js^2+K_fs}$

    B. $\dfrac{K_T}{Js^2+K_fs+K_T}$

    C. $\dfrac{K_T+1}{Js^2+K_fs+1}$

    D. None of the Above



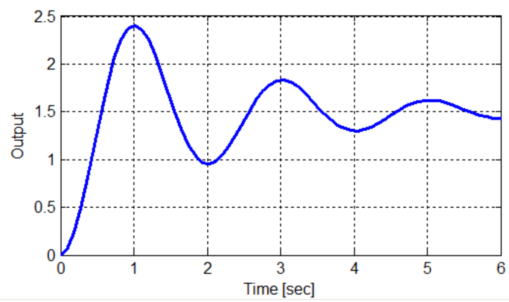
12. Which of the following transfer functions could MOST REASONABLY be thought to have the unit step response shown above?

    A. $\dfrac{2}{3s+1}$

    B. $\dfrac{1}{s+3}$

    C. $\dfrac{3}{2s+1}$

    D. $\dfrac{3}{s+2}$



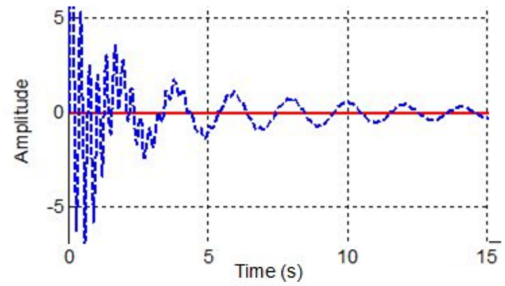
13. Which of the following transfer functions could MOST REASONABLY be thought to have the unit step response shown above?

    A. $\dfrac{3}{s+2}$

    B. $\dfrac{3}{s^2+2}$

    C. $\dfrac{15}{s^2+s+10}$

    D. $\dfrac{6}{s^2+s+4}$



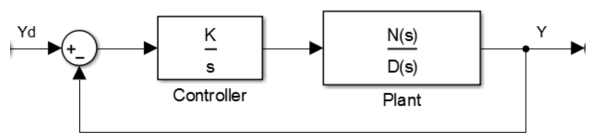
14. The figure above[2] shows the response of an electromechanical system to a momentary disturbance input at t=0. There are clearly two modes in the response. The mode with lower frequency corresponds MOST NEARLY to a pole located in the complex plane at...

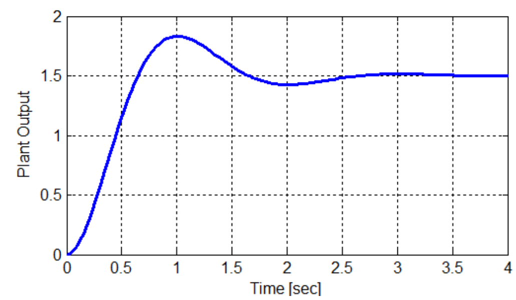
    A. $1 \pm 3j$

    B. $-0.1 \pm 3j$

    C. $-3 \pm j$

    D. $-3 \pm 0.1j$





15. The figure above shows the open-loop unit step response for the *plant only*. Which of the following is MOST ACCURATE about the use of Integral Feedback, as shown in the figure above, for this plant?

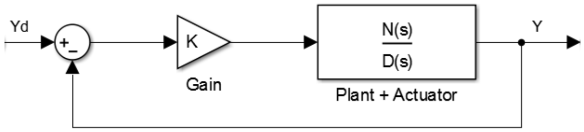
    A. There will be a value of $K_u > 0$ such that the closed-loop system will be unstable for $K > K_u$.

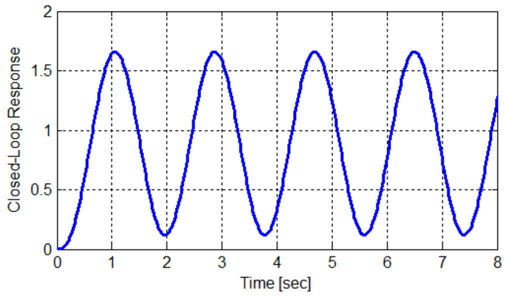
    B. If the closed-loop system is stable, the steady-state error will be zero.

    C. Both A and B.

    D. Neither A nor B.

[2] *Hierarchical Fuzzy Control*, By Carlos André Guerra Fonseca, Fábio Meneghetti Ugulino de Araújo and Marconi Câmara Rodrigues





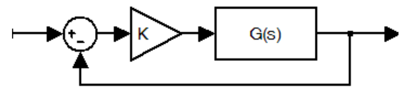
16. The figure above shows the closed-loop unit step response for the system shown in the block diagram, for some value of the proportional gain, K. The "Plant + Actuator" is stable open-loop. Which of the following is MOST ACCURATE about this system?

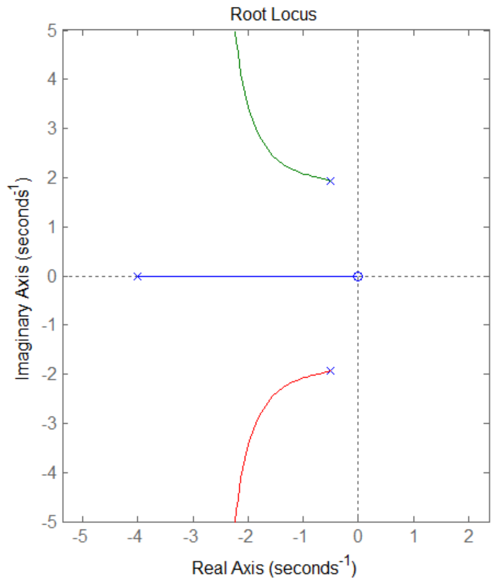
    A. The chosen value of K results in neutral stability of the closed-loop system.
    B. The system would be closed-loop stable for some smaller value of K.
    C. Adding derivative feedback would likely be helpful in achieving closed-loop stability.
    D. All of the above.

Ziegler–Nichols method[1]			
Control Type	K_p	K_i	K_d
P	$0.5K_u$	-	-
PI	$0.45K_u$	$1.2K_p/T_u$	-
PD	$0.8K_u$	-	$K_pT_u/8$
classic PID[2]	$0.60K_u$	$2K_p/T_u$	$K_pT_u/8$

17. Given that $K = 10$ was the gain used in the previous problem, if we replaced proportional control with a PD controller, using the Ziegler-Nichols rules shown above, what would be the transfer function of the new controller?

    A. $1.8s + 8$
    B. $8s + 1.8$
    C. $1.8 + \frac{8}{s}$
    D. $\frac{s+1.8}{s+8}$



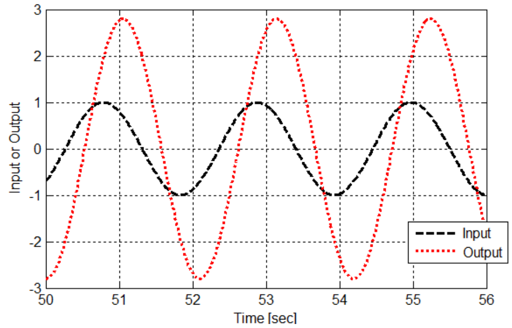


18. Which of the following is the MOST ACCURATE inference about the damping ratio of the oscillatory poles in the root locus shown above?

    A. The maximum closed-loop damping ratio is about 0.15.
    B. The maximum closed-loop damping ratio is about 0.55.
    C. The maximum closed-loop damping ratio is about 0.95.
    D. There is no maximum damping ratio of the closed-loop poles, because they go to infinity as the gain goes to infinity.

19. The MOST ACCURATE inference from the root locus of the previous problem about the effect of large gain is...

    A. The closed-loop system will have zero steady-state error when the gain is large.
    B. The closed-loop system will be stable regardless of how much the gain is increased.
    C. The closed-loop system is unstable for gain larger than about 2.2.
    D. None of the above is reasonable.



20. The figure above shows the response of a system to a sinusoidal input after the transient response has decayed to very nearly zero. The frequency of the input is...

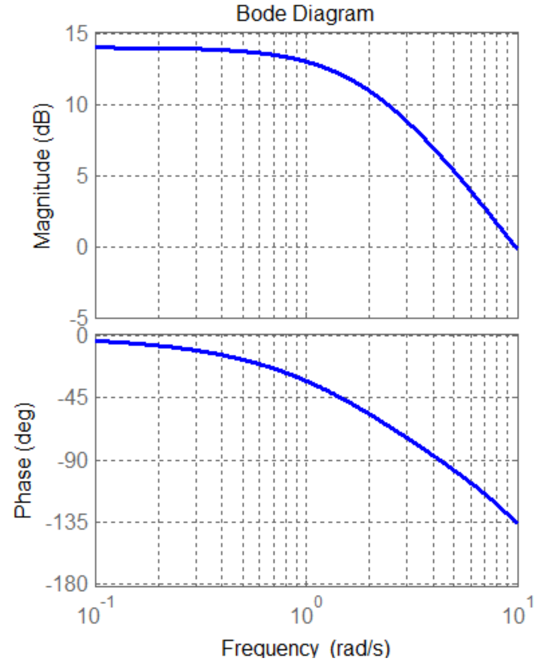
    A. About 0.5 rad/sec
    B. About 1.5 rad/sec
    C. About 3.0 rad/sec
    D. About 56 rad/sec

21. Continuing with the frequency response of the previous problem, the magnitude at this frequency is...

    A. About -3 dB
    B. About +3 dB
    C. About +6 dB
    D. About +9 dB

22. Continuing with the frequency response of the previous problem, phase at this frequency is...

    A. About +45 degrees
    B. About -45 degrees
    C. About -90 degrees
    D. About -180 degrees

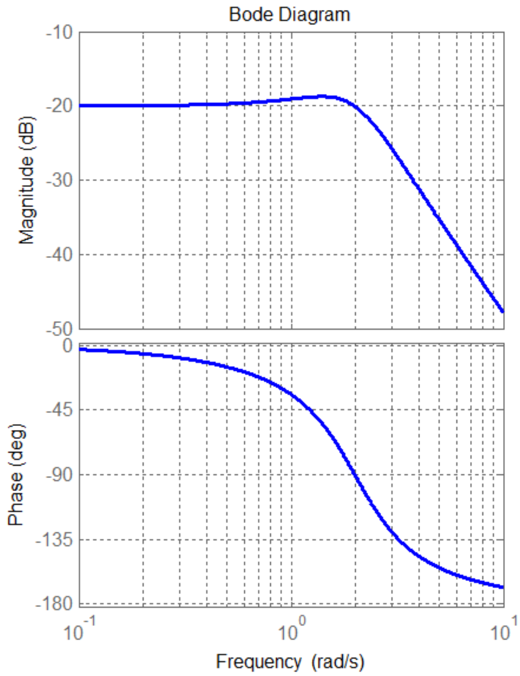


23. The bode plot shown above corresponds to a first-order system with time delay--that is, a transfer function of the form $\frac{Ae^{-Ts}}{\tau s+1}$. The MOST REASONABLE estimate of A is...

    A. $A \approx 14$
    B. $A \approx 9$
    C. $A \approx 5$
    D. $A \approx 1$

24. For the system in the previous problem, the MOST REASONABLE estimate of the time delay, T, is...

    A. $T \approx 0.1 \sec$
    B. $T \approx 0.25 \sec$
    C. $T \approx 0.5 \sec$
    D. Since the bode plot does not cross -180 in the frequency range shown, the time delay is sufficiently small that it can be approximated as zero.



25. The bode plot shown above corresponds to a second-order system whose transfer function is $\dfrac{A}{s^2 + 2\zeta\omega_n s + \omega_n^2}$. The MOST REASONABLE estimate of ω_n is...

   A. $\omega_n = 1rps$
   B. $\omega_n = 2rps$
   C. $\omega_n = 4rps$
   D. $\omega_n = 8rps$

26. The MOST REASONABLE estimate of the damping ratio in the previous problem is...

   A. $\varsigma = -0.2$
   B. $\varsigma = 0.0$
   C. $\varsigma = 0.2$
   D. $\varsigma = 0.5$

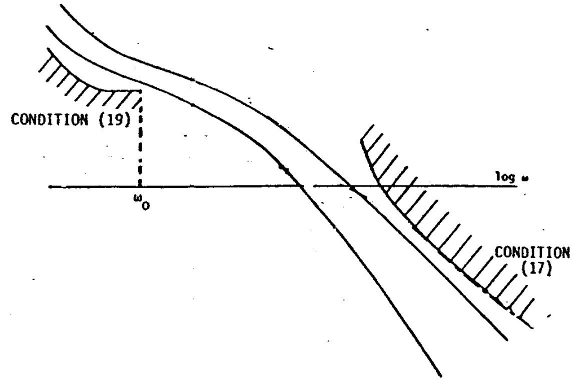


Fig. 3. The design tradeoff for *GK*.

27. The figure above[3] shows the design requirements for the loop transfer function frequency response magnitude as a function of frequency. The two curves in the center represent a "corridor" of acceptable designs. Based on ideas we discussed in class, the boundary denoted by "Condition (19)" at low frequency is MOST LIKELY...

   A. ...to ensure that sensor noise is easily visible in the closed-loop response.
   B. ...to ensure that the closed-loop system is stable.
   C. ...to ensure good tracking and disturbance rejection.
   D. All of the above.

28. Continuing with the figure in the previous question, based on ideas we discussed in class, the boundary denoted by "Condition (17)" at high frequency is MOST LIKELY...

   A. ...to ensure adequate noise rejection.
   B. ...to ensure zero steady-state error.
   C. ...to ensure closed-loop damping ratio greater than 0.5.
   D. All of the above.

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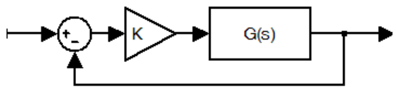
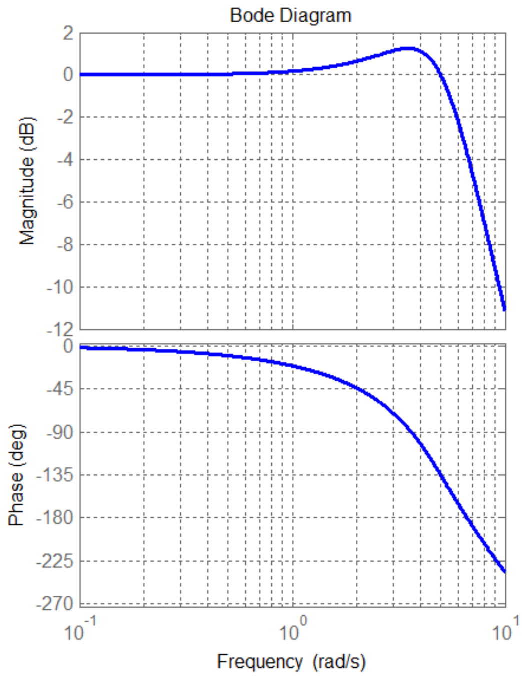
[3] John C. Doyle & Gunter Stein, "Multivariable Feedback Design: Concepts for a Classical/Modern Synthesis", 1981. This paper very important and widely read. The application here is simplified and not totally accurate, but still reasonable.





29. The bode plot shows $KG(s)$ for the block diagram above with $K = 5$. Given that $G(s)$ is open-loop stable, what is the gain margin of the system when $K = 5$?

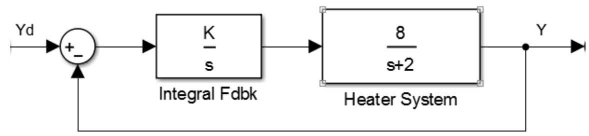
   A. There is no gain margin for this system, because the phase is always negative.
   B. About 4 dB
   C. About 12 dB
   D. The system is closed-loop unstable with $K = 5$.

30. For the previous problem, what value of K results in neutral stability of the closed-loop system?

   A. $K \approx 0.6$
   B. $K \approx 3$
   C. $K \approx 8$
   D. $K \approx 20$

31. For the system of the previous 2 problems, what is the phase margin when $K = 5$?

   A. About 45 degrees
   B. About 90 degrees
   C. About 180 degrees
   D. This system has no phase margin, because the gain is 0dB at low frequency.



32. For the system shown above, approximately what value of K results in a 45-deg phase margin?

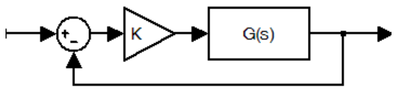
   A. $K \approx 0.7$
   B. $K \approx 2.8$
   C. $K \approx 12.6$
   D. The phase margin is greater than 45 degrees for any $K > 0$.

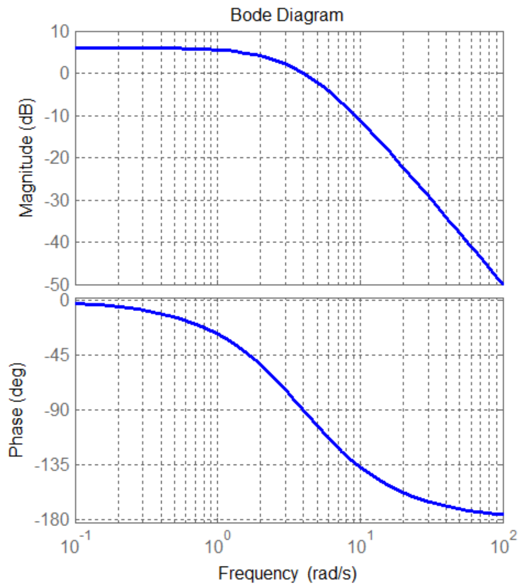
33. In previous problem, suppose that gain chosen to provide 45 degrees of phase margin does not result in sufficiently large K_V. Which design change could be used to increase K_V while maintaining the phase margin?

   A. Add lag compensation with a small reduction in K.
   B. Replace pure integral feedback with P+I feedback, $\left(G_C(s) = K_P + \frac{K_I}{s} \right)$, and then use $K_I > K$, with whatever value of K_P is required to achieve the required phase margin.
   C. Neither of the above.
   D. Both of the above.

34. This problem is not related to the previous two problems. Using a lag compensator of the form $G_C(s) = K\frac{s+z}{s+p}$, an engineer chooses an initial set of values for K, $z > p$, and $p > 0$. With this system, he finds that the steady-state error for a unit step input is 10 percent. What design change would reduce the steady error to zero, assuming that the closed-loop system remained stable?

   A. Increase K by a factor of 10.
   B. Set $z = 0$.
   C. Set $p = 0$.
   D. Any of the above would reduce the steady error to zero.





35. The graph shows the bode plot of $G(s)$ for the block diagram shown above. For what value of K will the gain margin be approximately 6dB?

A. $K \approx 0.5$
B. $K \approx 2$
C. $K \approx 8$
D. None of the other answers.

36. If the proportional feedback, K, of the previous problem is replaced with integral feedback, $\dfrac{K}{s}$, for what value of K will the gain margin be approximately 6dB?

A. $K \approx 0.5$
B. $K \approx 2$
C. $K \approx 8$
D. None of the other answers.

37. Which of the following could be the A matrix in a state-space representation of a system that is governed by the equation
$\dfrac{d^2y}{dt^2} + 4\dfrac{dy}{dt} - 5y = 6u$?

A. $A = \begin{bmatrix} 0 & 1 \\ 5 & -4 \end{bmatrix}$
B. $A = \begin{bmatrix} 0 & 6 \\ 4 & -5 \end{bmatrix}$
C. $A = \begin{bmatrix} 0 & -5 \\ 4 & 0 \end{bmatrix}$
D. This system has second-order derivatives and cannot be represented with the first-order state-space form.

38. Why did the previous question say "*could be* the A matrix" instead of "*is* the A matrix"?

A. The A matrix is not unique, because we can use a "change of basis" for the state vector, $x = Tz$, to find a new A matrix (which will have the same eigenvalues).
B. The professor was getting tired while writing exam questions and his use of the English language was a little sloppy.
C. We can't know if any given matrix is *the* A matrix until it is certified by the United Nations.
D. All of the above.

39. Which of the following is an eigenvalue-eigenvector pair of the matrix $A = \begin{bmatrix} -1 & 0 \\ 1 & -3 \end{bmatrix}$?

A. $\lambda = 1 \quad q = \begin{bmatrix} 1 \\ 2 \end{bmatrix}$
B. $\lambda = 0 \quad q = \begin{bmatrix} -1 \\ -3 \end{bmatrix}$
C. $\lambda = -1 \quad q = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$
D. $\lambda = -3 \quad q = \begin{bmatrix} -1 \\ 2 \end{bmatrix}$

40. Suppose a system has the A matrix of the previous problem and has $B = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$. Which of the following is MOST ACCURATE about what can be achieved with control?

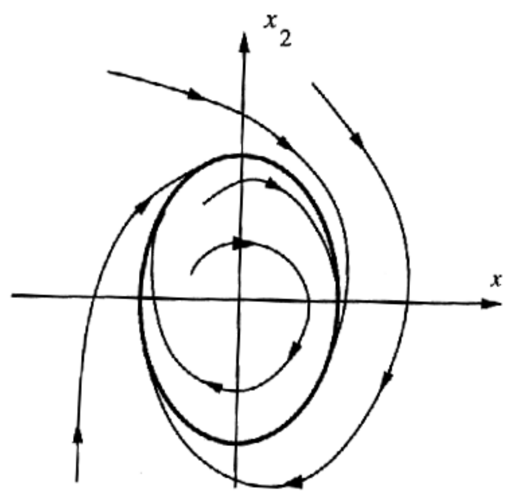
A. Finite control can be used to move the state from an arbitrary initial value to an arbitrary final value in finite time.
B. Proportional state feedback can be used to achieve an arbitrary closed-loop characteristic equation (pole placement).
C. Both of the above
D. Neither of the above

41. Consider a state-space system with the following matrices:
$$A = \begin{bmatrix} -2 & 0 \\ 0 & -4 \end{bmatrix},\ B = \begin{bmatrix} 4 \\ 2 \end{bmatrix},\ C = \begin{bmatrix} 1 & 1 \end{bmatrix}$$
What is the corresponding transfer function?

A. $\dfrac{6s+18}{s^2+6s+9}$
B. $\dfrac{6s+20}{s^2+6s+8}$
C. $\dfrac{6s-18}{s^2-6s+9}$
D. $\dfrac{20}{s^2+6}$

42. Which of the following is MOST ACCURATE about a linear state observer of the form $\dfrac{d\hat{x}}{dt} = A\hat{x} + Bu + L\left(y - \hat{y}\right)$, where $\hat{y} = C\hat{x}$?

A. If the matrix pair $\left(A, C\right)$ is observable, then the characteristic equation of the observer, whose roots are the eigenvalues of $A - LC$, can be chosen arbitrarily (observer pole placement).
B. We typically implement the observer so that we can use the measurements (y) to obtain an estimate of the state, for use in feedback control, such as proportional state feedback, $u = -K\hat{x}$.
C. Both of the above.
D. Neither of the above.



43. Which of the following is MOST ACCURATE about the phase portrait, shown above, of a second-order dynamic system?

A. The system has 3 stable equilibrium points on the positive x_1 axis.
B. The system has 4 unstable equilibrium points on the negative x_2 axis.
C. The system has a limit cycle to which all trajectories converge.
D. All of the above.

44. If the dynamics of the system in the previous question are governed by $\dot{\underline{x}} = \underline{f}(\underline{x})$, then...

A. ...the system is linear, $\underline{f}(\underline{x}) = A\underline{x}$, with A having real eigenvalues.
B. ...the system is linear, $\underline{f}(\underline{x}) = A\underline{x}$, with A having imaginary eigenvalues.
C. ...the system is nonlinear.
D. ...the system has a singularity at the origin, with $\lim_{\underline{x} \to \underline{0}} \left| \underline{f}(\underline{x}) \right| \to \infty$