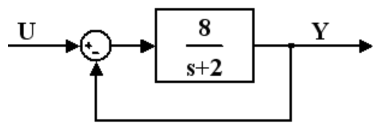
NAME ______________________

ESE406/505 & MEAM 513 - SPRING 2011 – Final EXAM
CLOSED NOTES & CLOSED BOOK

- Choose the one best answer for each question by *circling the letter*.
- A correct answer is worth 2 points.
- No answer is worth 0 points.
- An incorrect answer is worth -1 point. Random guessing will lower your grade, on average.



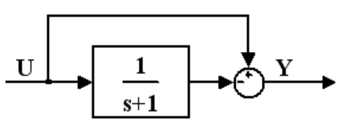
1. The transfer function corresponding to the above block diagram is…

A. $\frac{Y(s)}{U(s)} = \frac{8}{s+10}$

B. $\frac{Y(s)}{U(s)} = \frac{-s+6}{s+2}$

C. $\frac{Y(s)}{U(s)} = \frac{64}{s+16}$

D. None of the above.



2. The transfer function corresponding to the above block diagram is…

A. $\frac{Y(s)}{U(s)} = \frac{s+1}{s+2}$

B. $\frac{Y(s)}{U(s)} = \frac{1}{s+2}$

C. $\frac{Y(s)}{U(s)} = \frac{s}{s+1}$

D. None of the above.

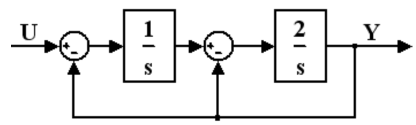
3. A transfer function, $G(s)$, represents a stable continuous-time system if…

A. …all of the poles of $G(s)$ lie in the left half-plane.

B. …all of the poles of $G(s)$ lie inside the unit circle.

C. …$|G(s)| < 1$ when $|s| < 1$.

D. …$|G(s)| \to 0$ as $|s| \to \infty$.



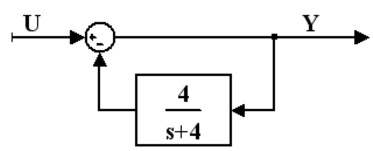
4. The transfer function corresponding to the above block diagram is…

A. $\frac{Y(s)}{U(s)} = \frac{2}{s^2+2}$

B. $\frac{Y(s)}{U(s)} = \frac{2}{s^2+2s+2}$

C. $\frac{Y(s)}{U(s)} = \frac{s+2}{s^2+s+2}$

D. None of the above.



5. The transfer function corresponding to the above block diagram is…

A. $\frac{Y(s)}{U(s)} = \frac{s+8}{s+4}$

B. $\frac{Y(s)}{U(s)} = \frac{s}{s+8}$

C. $\frac{Y(s)}{U(s)} = \frac{-1}{s+4}$

D. None of the above.

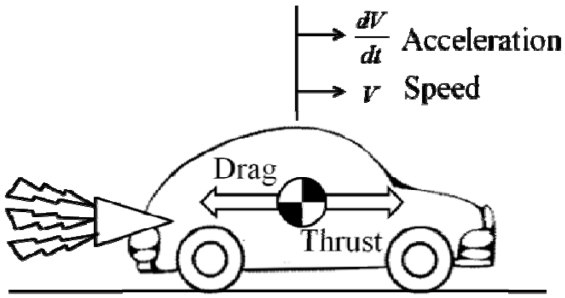
6. A transfer function, $G(z)$, represents a stable discrete-time system if…

A. …all of the poles of $G(z)$ lie in the left half-plane.

B. …all of the poles of $G(z)$ lie inside the unit circle.

C. …$|G(z)| < 1$ when $|z| < 1$.

D. …$|G(z)| \to 0$ as $|z| \to \infty$.



The questions on this page pertain to a cruise control design for the rocket-propelled car shown above. The mass of the car is m=400kg. The thrust in Newtons is 800*u, where u=throttle (control). The drag in Newtons is $2V^2$, when V is measured in meters per second.

7. Writing Newton's second law (F=ma) for this car results in which of the following ODEs?

   A. $800\dfrac{dV}{dt} = V^2 + 400u$

   B. $400\dfrac{dV}{dt} = -2V^2 + 800u$

   C. $400\dfrac{dV}{dt} = -800V^2 + 2u$

   D. None of the above.

8. If the trim speed of the car, V_o, is to be 20 m/s, what is the corresponding trim control?

   A. $u_o = 1$

   B. $u_o = 800$

   C. $u_o = 0$

   D. It depends on the trim value of $\dfrac{dV}{dt}$

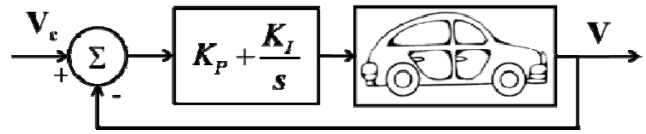
9. The transfer function for small changes in speed and small changes in control, relative to trim, is

   A. $\dfrac{\Delta V(s)}{\Delta U(s)} = \dfrac{800}{s+400}$

   B. $\dfrac{\Delta V(s)}{\Delta U(s)} = \dfrac{800}{400s+2}$

   C. $\dfrac{\Delta V(s)}{\Delta U(s)} = \dfrac{2}{s+0.2}$

   D. None of the above.



10. Which of the following corresponds to the closed-loop transfer function for the system shown above?

    A. $\dfrac{V(s)}{V_C(s)} = \dfrac{2K_P s + 2K_I}{s(s+0.2) + 2K_P s + 2K_I}$

    B. $\dfrac{V(s)}{V_C(s)} = \dfrac{K_I}{s(s+0.2) + K_I}$

    C. $\dfrac{V(s)}{V_C(s)} = \dfrac{2K_P s + 2K_I}{(s+0.2) + 2K_P s + 2K_I}$

    D. $\dfrac{V(s)}{V_C(s)} = \dfrac{2K_P (s+0.2)}{s(s+0.2) + 2K_I}$

11. Which of the following is CORRECT concerning the steady velocity response to a steady disturbance *at the input* for the controller shown above?

    A. The steady response will be a finite number because the plant is first-order.
    B. The steady response will be zero because of the integral feedback.
    C. The steady response will be unbounded because the closed-loop system is unstable.
    D. None of the above.

12. Which of the following pole locations most closely corresponds to requirements of settling time equal to 5 seconds and natural frequency equal to 2 rps?

    A. $-0.5 \pm 0.5j$

    B. $-1.5 \pm 3j$

    C. $-0.9 \pm 1.8j$

    D. $5 \pm 2j$

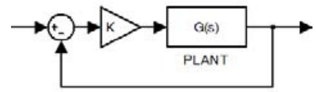
13. Which of the following gain settings most closely achieves the desired closed-loop poles from the previous problem?

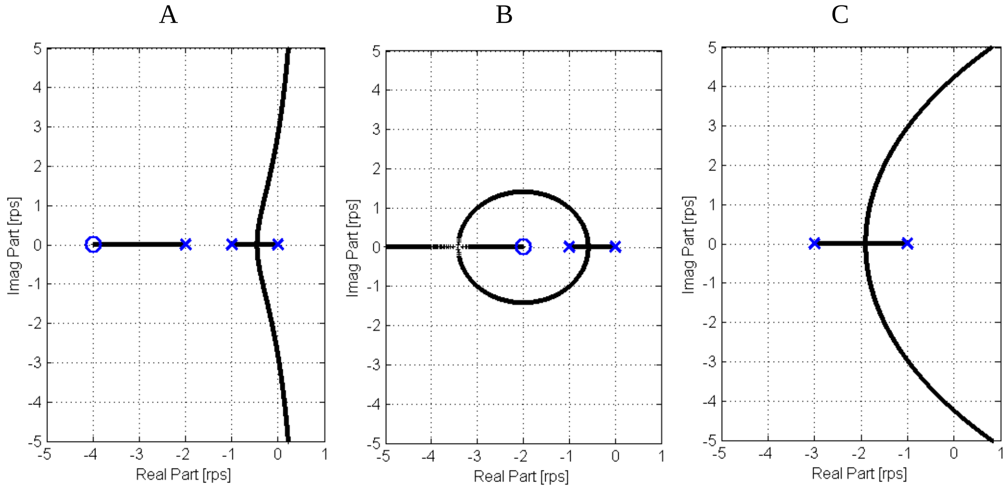
    A. $K_P = 0.8$ & $K_I = 2.0$

    B. $K_P = 2.0$ & $K_I = 0.1$

    C. $K_P = 0.4$ & $K_I = 4.5$

    D. $K_P = 0$ & $K_I = 1.0$

The questions on this page refer to the root loci for three different systems of the form 



14. In which case is the closed-loop system stable for all positive values of the gain K?
    A. System A
    B. System B
    C. System C
    D. All of the Above

15. In which case will the closed-loop system have at least one real pole for any positive value of the gain K?
    A. System A
    B. System B
    C. System C
    D. None of the Above

16. In which case would it be possible to replace the proportional feedback with integral feedback and have the closed-loop system be stable for small positive values of the integral feedback gain?
    A. System A
    B. System B
    C. System C
    D. None of the Above

17. In which case would oscillations with a period of just over 2 seconds correspond to neutral stability?
    A. System A
    B. System B
    C. System C
    D. All of the Above

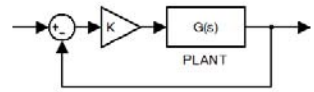
18. For which system is the MINIMUM closed-loop damping ratio approximately 0.7?
    A. System A
    B. System B
    C. System C
    D. None of the Above

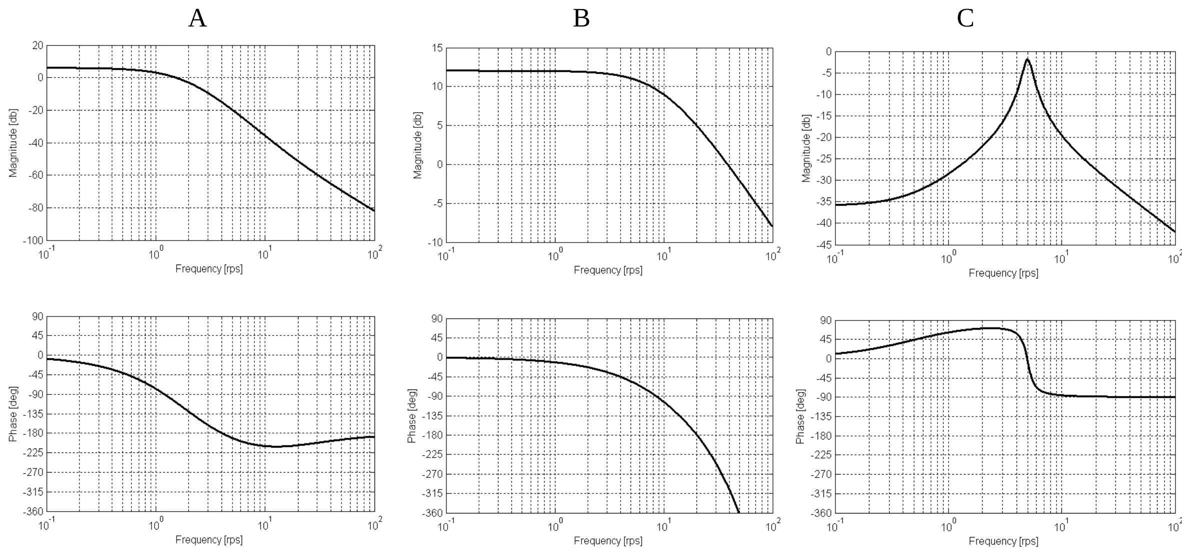
19. In which case can we be *CERTAIN* that the poles and zeros shown on the locus do not completely represent G(s)? (In other words, if we zoomed out, we would see additional poles and/or zeros.)
    A. System A
    B. System B
    C. System C
    D. All of the Above

20. For the system(s) you chose in the last question, which “missing” (not shown on the locus) elements of G(s) might reasonably be expected to explain the shape of the locus?
    A. G(s) having pure time delay, represented by a Pade approximation on the locus.
    B. G(s) having zeros in the right-half plane
    C. G(s) having additional pole(s) in the left-half plane.
    D. All of the Above

21. In which case will the closed-loop system NOT have zero steady-state error for a step input?
    A. System A
    B. System B
    C. System C
    D. All of the Above

The questions on this page consider the consequences of placing a plant in a unity-gain feedback system with proportional compensation, as shown at right. For all three of the plants whose frequency responses are shown below, all of the finite poles and zeros are in the left-half plane and are within the range of frequencies shown in the bode plots. Any time delay is shown exactly. Note that the frequency and phase scales are fixed, but the magnitude scales vary, to show more details.





22. With K=1, what is a reasonable estimate of the gain margin of System A?
    - A. About 15 dB
    - B. About 6 dB
    - C. About -6 dB
    - D. None of the above.

23. With K=1, what is a reasonable estimate of the phase margin of System A?
    - A. About 135 degrees
    - B. About 80 degrees
    - C. About 45 degrees
    - D. About 10 degrees

24. If a positive value of K were chosen for each system to ensure closed-loop stability, which system would have zero steady-state error for a unit step input?
    - A. System A
    - B. System B
    - C. System C
    - D. None of the Above

25. Which system will be closed-loop stable for any positive value of K?
    - A. System A
    - B. System B
    - C. System C
    - D. None of the Above

26. Which system will be closed-loop stable when K=1 with an arbitrary additional time delay?
    - A. System A
    - B. System B
    - C. System C
    - D. None of the Above

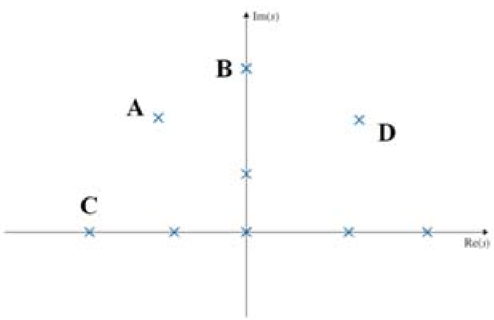
27. Which system will be closed-loop *unstable* for K=1?
    - A. System A
    - B. System B
    - C. System C
    - D. None of the Above

28. Which system will be closed-loop stable but have poor steady-state tracking with K=1?
    - A. System A
    - B. System B
    - C. System C
    - D. All of the Above

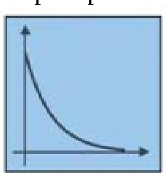
29. If proportional feedback were *replaced* by derivative feedback on System B, what would be the derivative gain for neutral stability?
    - A. About 2.5
    - B. About 0.25
    - C. About 0.025
    - D. About 0.0025

30. A system is designed with a very aggressive gain margin of just under 3dB. Which of the following statements is MOST ACCURATE about the closed-loop stability of the actual system?

   A. If the actual gain of the loop transfer function is greater than 3dB at any frequency, the closed-loop system will be unstable.
   B. If the actual gain of the loop transfer function is less than -3dB at any frequency, the closed-loop system will be unstable.
   C. If the actual gain of the system is larger than expected by a factor of 1.4 or more, the closed-loop system will be unstable.
   D. If the actual gain of the system is smaller than expected by a factor of 1.4 or more, the closed-loop system will be unstable.



31. Match the transient response shown below to the corresponding letter identifying a pole in the complex plane above.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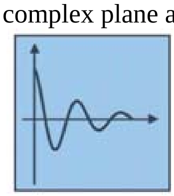
32. Match the transient response shown below to the corresponding letter identifying a pole in the complex plane above.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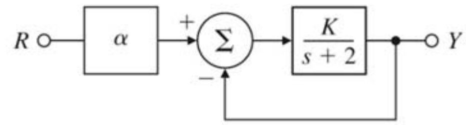


33. In the block diagram shown above, which of the following is the "loop transfer function," G(s), that we use to make a bode plot for assessing the stability margins?

   A. $G(s) = \dfrac{K}{s+2}$
   B. $G(s) = \dfrac{\alpha K}{s+2}$
   C. $G(s) = \dfrac{K}{s+2+K}$
   D. $G(s) = \dfrac{\alpha K}{s+2+K}$

34. Which of the following is LEAST ACCURATE about a compensator with transfer function $G_C(s) = \dfrac{s+1}{s+0.2}$?

   A. It is a lag compensator.
   B. It is typically used to increase the loop gain at low frequency.
   C. It has the side benefit of providing a small increase in the phase margin of most systems.
   D. It can be implemented readily on a digital controller.

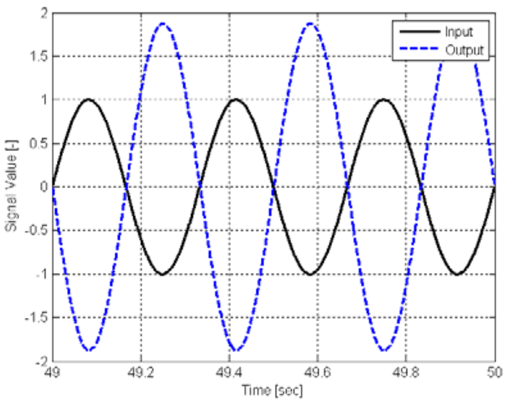
35. Which of the following is LEAST ACCURATE about a compensator with transfer function $G_C(s) = \dfrac{8s+1}{s+1}$?

   A. It is a lead compensator.
   B. It is typically used to improve low-frequency disturbance rejection.
   C. It is equivalent to a PD compensator where the derivative feedback has been passed through a first-order low-pass filter to avoid infinite gain at high frequency.
   D. It can be implemented readily on a digital controller.

36. Which of the following is LEAST ACCURATE about a compensator with transfer function

$$G_C(s) = \frac{s^2 + 3s + 81}{s^2 + 12s + 81}?$$

A. It is a notch filter with notch frequency of 9 rps.
B. The minimum gain of the filter is -4 dB.
C. It is typically used to avoid destabilizing a lightly damped mode in the open-loop plant.
D. It can be implemented readily on a digital controller, but pre-warping is recommended with Tustin's method.



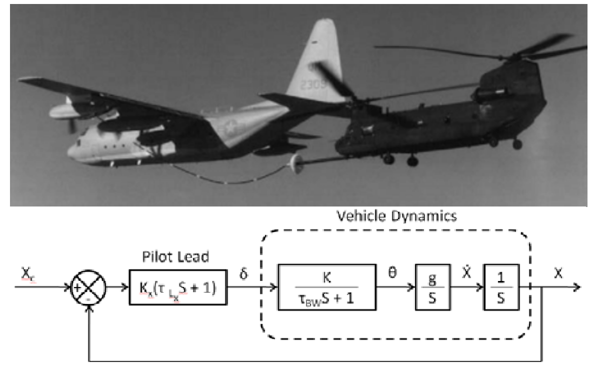
37. To which differential equation does the steady-state response to sinusoidal input shown above correspond?

A. $\frac{dy}{dt} + 10y = 40u(t - 0.11)$

B. $\frac{dy}{dt} = 40u(t)$

C. $\frac{d^2y}{dt^2} - \frac{dy}{dt} = 40u(t)$

D. All of the above.



38. A recent paper[1] presented the block diagram shown above to describe how a pilot controls the position of a helicopter during aerial refueling. The input is desired position, X_c, and the output is the actual position, X. The pilot is directly "measuring" the error, X_c-X, by visually judging the distance between the fueling boom and the supply drogue. The block labeled "pilot lead" is a simple model of a control strategy the pilot might use to track a desired trajectory. Which of following is correct regarding the simple representation of the pilot control strategy shown?

A. It is equivalent to PI control.
B. It is equivalent to PD control.
C. It is equivalent to a notch filter.
D. It is equivalent to full-state feedback with a dynamic estimator.

39. Which of the following conditions *MUST* be true in order for the closed-loop system to be stable?

A. $\tau_{Lx} > \tau_{BW}$

B. $\tau_{Lx} < \tau_{BW}$

C. $K_X < gK$

D. $K_X > gK$

40. Which of the following is LEAST CORRECT concerning "Tustin's Method"?

A. It is a useful way to convert a continuous-time transfer function into a discrete-time transfer function.
B. It preserves the exact discrete-time stability boundary.
C. The resulting discrete-time frequencies *exactly* match the corresponding continuous-time frequencies.
D. It can be derived by considering trapezoidal integration as an approximation to "1/s".

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[1] Kashawlic, *et al.*, "MH-47G DAFCS Helicopter Aerial Refueling Control Laws," *AHS Forum*, 2011.

41. What is the *difference equation* for a digital implementation of a derivative compensator, $u(t) = K_D s e(t)$, if we use Tustin's method, $s \to \dfrac{2}{T}\dfrac{z-1}{z+1}$?

   A. $u[k] = \dfrac{K_D}{T}\left(e[k] - e[k-1]\right)$

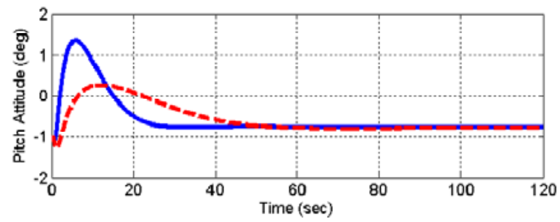
   B. $u[k] = -u[k-1] + \dfrac{2K_D}{T}\left(e[k] - e[k-1]\right)$

   C. $u[k] = u[k-1] - \dfrac{2K_D}{T} e[k]$

   D. None of the above.

42. A very good student runs a digital controller for an inverted pendulum with a sample rate of 16 milliseconds (0.016 sec). She observes 2.5 Hz noise in her sampled measurements of pendulum angle, but the high-speed video of the pendulum motion does not show any movement at this frequency. The most reasonable inference would be…

   A. The extra 16ms of time delay has probably caused her closed-loop system to go unstable.
   B. The noise is aliased 60 Hz electrical noise.
   C. Her system cannot work unless she purchases a much faster microcontroller.
   D. All of the above.



43. A recent paper[2] includes the figure shown above, comparing the responses of original (dashed) and modified (solid) control systems to a step disturbance input. The trim value of pitch attitude is -1 degree. Which of the following is the MOST REASONABLE inference about the changes that were made to the original control system?

   A. The original system did not include integral feedback, which was added to the modified system.
   B. The gain crossover frequency of the modified system is higher than it was on the original system.
   C. The original system did not include a notch filter, which was added to the modified system.
   D. The low-frequency gain of the original system was substantially increased by adding a lag filter to the modified system.

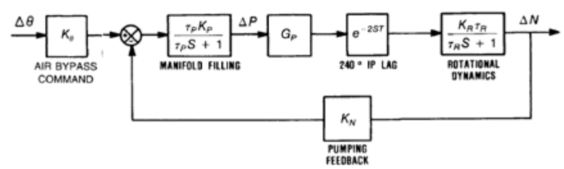


Fig. 2. Block diagram of linearized engine model.

44. The figure above[3] shows a simplified model of an internal combustion engine. Which of the following is MOST ACCURATE about this system?

   A. The closed-loop system will be stable provided the pumping feedback gain is less than or equal to unity.
   B. The block diagram represents a non-linear system because of the e^{-2sT} block describing the "induction power stroke delay."
   C. There is a maximum value of the "delayed pressure torque gain," G_P, for which the system is stable.
   D. All of the above.

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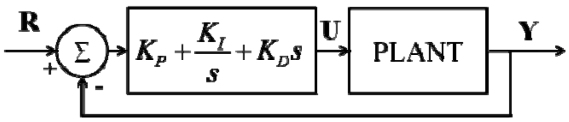
[2] Kashawlic, *et al.*, "MH-47G DAFCS Helicopter Aerial Refueling Control Laws," *AHS Forum*, 2011.
[3] Cook & Powell, "Modeling of an IC Engine for Control Analysis," *IEEE Control Systems Magazine*, 1988.

For all of the problems on this page, the Plant is described by the following differential equation:

$$\frac{d^2y}{dt^2} - \frac{dy}{dt} + 4y = 2u$$



45. Suppose a PID controller is implemented, as shown above. Which of the following is MOST ACCURATE about proportional feedback?

    A. With K_I=0, proportional feedback is required to ensure stability.
    B. With K_I=0, proportional feedback will increase the natural frequency of the closed-loop poles.
    C. With K_I=0, proportional feedback will increase the damping ratio of the closed-loop poles.
    D. All of the above.

46. For the same PID controller discussed in the previous problem, which of the following is MOST ACCURATE about derivative feedback?

    A. With K_I=0, derivative feedback is required to ensure stability.
    B. With K_I=0, derivative feedback will increase the natural frequency of the closed-loop poles.
    C. With K_I=0, derivative feedback will increase the damping ratio of the closed-loop poles.
    D. All of the above.

47. For the same PID controller discussed in the previous 2 problems, which of the following is MOST ACCURATE about integral feedback?

    A. It is required to ensure zero steady-state tracking error.
    B. For fixed values of the other gains, increasing integral feedback gain will decrease the damping ratio of the closed-loop poles.
    C. If there is a possibility of control saturation, it would typically be important to implement some sort of anti-windup protection for the integral feedback.
    D. All of the above.

48. Suppose we decided to drop the PID control of the previous problems and attempt to use modern control. If we wanted to represent the plant using state-space, with $x_1 = \frac{dy}{dt}$ and $x_2 = y$, which of the following system matrices would be correct?

    A. $A = \begin{bmatrix} -4 & 2 \\ 1 & 0 \end{bmatrix}$ & $B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$
    B. $A = \begin{bmatrix} 4 & 1 \\ -1 & 1 \end{bmatrix}$ & $B = \begin{bmatrix} 0 \\ 2 \end{bmatrix}$
    C. $A = \begin{bmatrix} 1 & -4 \\ 1 & 0 \end{bmatrix}$ & $B = \begin{bmatrix} 2 \\ 0 \end{bmatrix}$
    D. None of the above.

49. Which of the following full-state feedback matrices, with $u = -K\underline{x}$, would result in closed-loop poles with damping ratio of 0.5 and natural frequency of 3 rps?

    A. $K = \begin{bmatrix} 0.5 & 3 \end{bmatrix}$
    B. $K = \begin{bmatrix} 2 & 2.5 \end{bmatrix}$
    C. $K = \begin{bmatrix} 0 \\ 2.5 \end{bmatrix}$
    D. None of the above.

50. Instead of choosing the state feedback matrix, K, to place the closed-loop poles at desired locations, as we did in the last problem, we can choose K using LQR design. Which of the following is LEAST ACCURATE concerning LQR design?

    A. "LQR" stands for linear quadratic regulator.
    B. LQR is based on minimizing a weighted scalar combination of state and control activity.
    C. LQR is a simple replacement for just about everything we learned this semester and can be usefully applied by blinding "turning the crank" on a given problem.
    D. LQR has excellent stability robustness properties when the full state is available by direct measurement.