NATIONAL EXAMS

16-Elec-B2 Advanced Control Systems – May 2019

3 hours duration

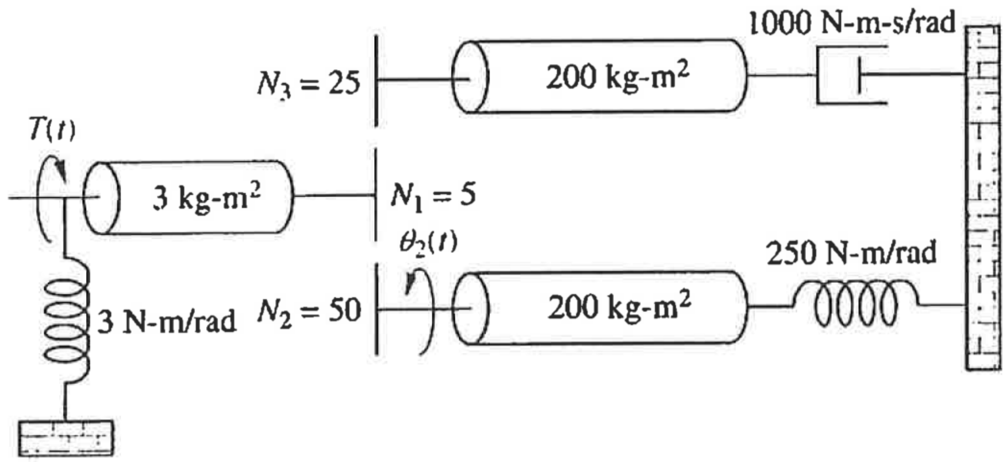
NOTES:

1. This is an open book exam.
2. If a doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
3. This is an Open Book Exam. Any non-communicating calculator is permitted.
4. Any four questions constitute a complete paper. Only the first four questions as they appear in your answer book will be marked.

In the following questions, it is assumed that the control systems are negative feedback with K>0, unless specified otherwise.

Question 1 [25]. Choose the best answer.

1. Find the transfer function, $G(s) = \theta_2(s)/T(s)$, for the rotational mechanical system shown in the following system? **[4]**



(a) $$\frac{10}{1300s^2 + 4000s + 550}$$

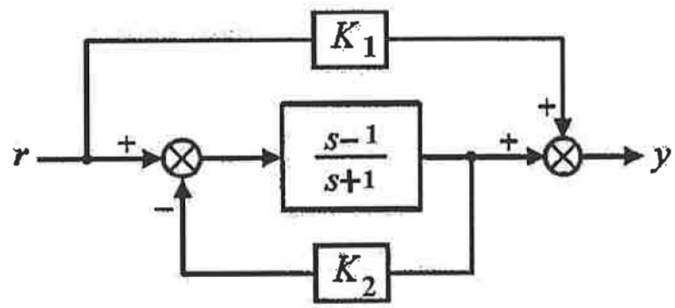
(b) $$\frac{15s}{120s^2 + 4050s + 50}$$

(c) $$\frac{10}{1700s^2 + 4000s + 200}$$

(d) $$\frac{15}{1350s^2 + 250s + 300}$$

(e) None of the above

2. Find K_1 and K_2 values in the way that the following close loop system has a zero at $s = -1$? **[2]**



(a) $K_1 = 1$; $K_2 = -1$ or $K_1 = -1$; $K_2 = 1$

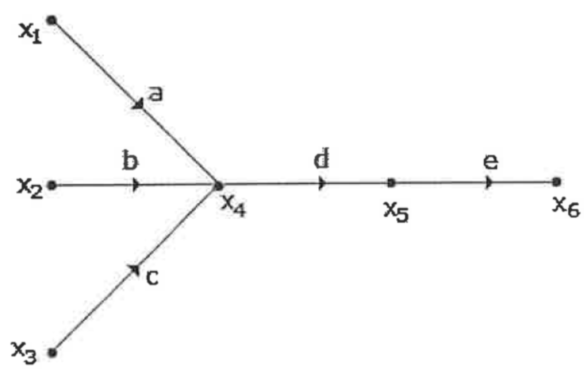
(b) $K_1 = -1$; $K_2 = 0$

(c) $K_1 = 1$; $K_2 = 0$

(d) $K_1 = -1$; $K_2 = -1$ or $K_1 = 1$; $K_2 = 1$

(e) None of the above

3. For the given figure, what is X_6? **[2]**



(a) $de(ax_1 + bx_2 + cx_3)$

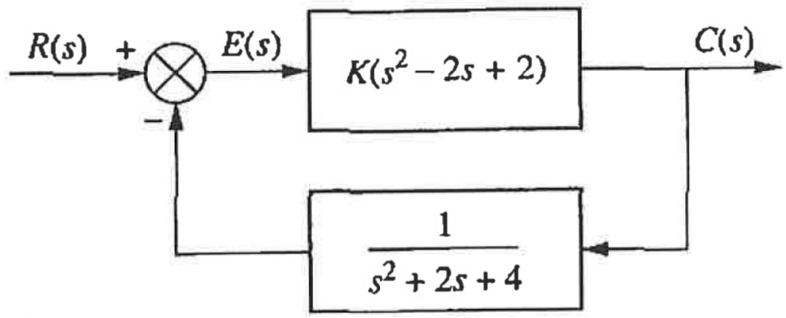
(b) $(a + b + c)(x_1 + x_2 + x_3)(d + e)$

(c) $(ax_1 + bx_2 + cx_3)(d + e)$

(d) $a\,b\,c\,d\,e\,(x_1 + x_2 + x_3)$

(e) None of the above

4. Use the Routh-Hurwitz criterion to find the range of K for which the system of the following figure is stable. [2]



(a) $K > 1$

(b) $K > -1/2$

(c) $-3/2 < K < 0$

(d) $-1/2 < K < 1$

(e) None of the above

5. For a type 1 second-order system and unit step input, the steady state error is? [1]

(a) 0

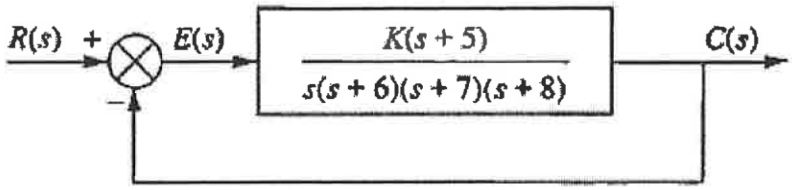
(b) 1

(c) $\frac{1}{1+K_p}$

(d) ∞

(e) None of the above

6. Given the following control system [2]



The value of K so that there is a 20% steady state error for a unit ramp input is:

(a) 620

(b) 560

(c) 672

(d) 336

(e) None of the above

7. Consider a system with transfer function $G(s) = (s+6)/(Ks^2+s+6)$. Its damping ratio will be 0.5 when the value of K is: [2]

(a) 2/6

(b) 3

(c) 1/6

(d) 6

(e) None of the above

8. Consider the loop transfer function G(s)H(s)= $K(s+6)/(s+3)(s+5)$. In the root locus diagram the centroid (intersection of asymptotes with real-axis) will be located at? [1]

(a) -2

(b) -1

(c) -4

(d) -3

(e) None of the above

9. What is the number of the root locus segments which do not terminate on zeroes? **[1]**

- **(a)** The number of poles
- **(b)** The number of zeroes
- **(c)** The difference between the number of poles and zeroes
- **(d)** The sum of the number of poles and the number of the zeroes
- **(e)** None of the above

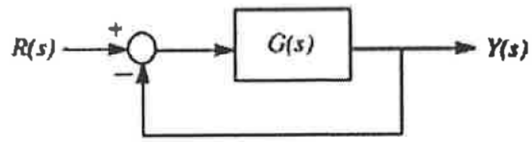
10. The addition of open loop zero pulls the root loci towards? **[2]**

- **(a)** The left and therefore system becomes more stable
- **(b)** The right and therefore system becomes unstable
- **(c)** Imaginary axis and therefore system becomes marginally stable
- **(d)** The left and therefore system becomes unstable
- **(e)** None of the above

11. If any term in the first column of a Routh array becomes zero, then? **[1]**

- **(a)** Routh criterion cannot be used to determine stability
- **(b)** Routh criterion can be used by substituting a small positive number for zero and completing the array
- **(c)** Routh criterion can be used by substituting a big positive number for zero and completing the array
- **(d)** Routh criterion can be used by substituting a small negative number for zero and completing the array
- **(e)** None of the above

12. For the following system, what are the breakaway point on the real axis and the respective gain, *K*. [2]



where

$$G(s) = \frac{K}{s(s+5)(s^2+6s+17.76)}.$$

(a) s =-1.8 K =58.75

(b) s =-2.5 K =4.59

(c) s =1.4 K =58.75

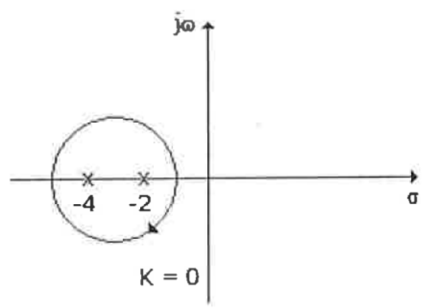
(d) s =1.9 K =80.75

(e) None of the above

13. The given figure shows a root locus plot. Consider the following statements for this plot [1]

1) The open loop system is a second order system
2) The system is overdamped for K > 1
3) The system is stable for all values of K

Which of the above statements are correct?



(a) 1,2,3

(b) 1,3

(c) 2,3

(d) 1,2

(e) None of the above

14. The transfer function G(s) of a PID controller is? **[1]**

(a) $K\left[1 + \frac{1}{T_i s} + T_d s\right]$

(b) $K\,[1 + T_i s + T_d s]$

(c) $K\left[1 + \frac{1}{T_i s} + \frac{1}{T_d s}\right]$

(d) $K\left[1 + T_i s + \frac{1}{T_d s}\right]$

(e) None of the above

15. The amplitude slope for the second order complex poles in a Bode magnitude plot is **[1]**

(a) 0 dB/decade

(b) -6 dB/octave

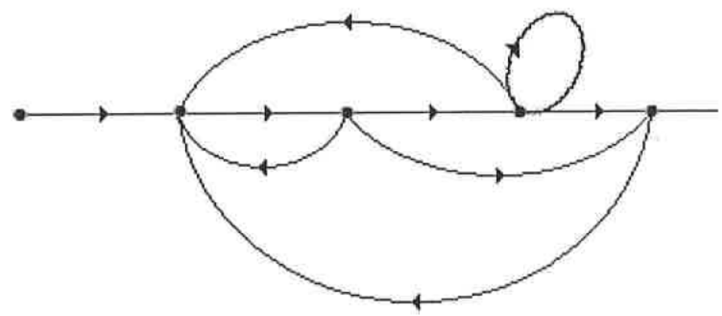
(c) -20 dB/decade

(d) -12 dB/octave

(e) None of the above

Question 2 [25]. Choose the best answer.

1. In the signal flow graph of the given figure, the number of forward paths between the very left input node and very right output node is: **[1]**



(a) 1

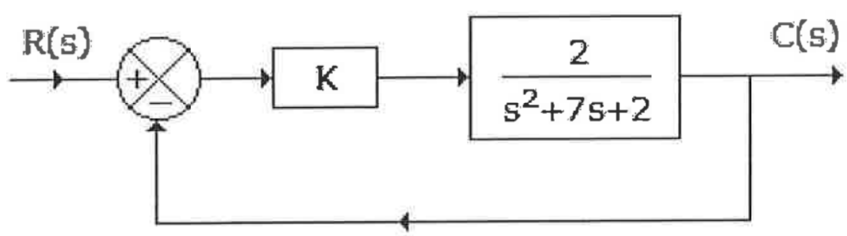
(b) 2

(c) 3

(d) 4

(e) None of the above

2. For the control system in the given figure, the value of K for critical damping is? **[2]**



(a) 1

(b) 5.125

(c) 6.831

(d) 10

(e) None of the above

3. If a system has a closed loop transfer function of

$$T(s) = \frac{24(s-2)}{s^6+4s^5+11s^4-32s^3+40s^2+64s-48}$$, then system is always ? **[2]**

(a) Stable

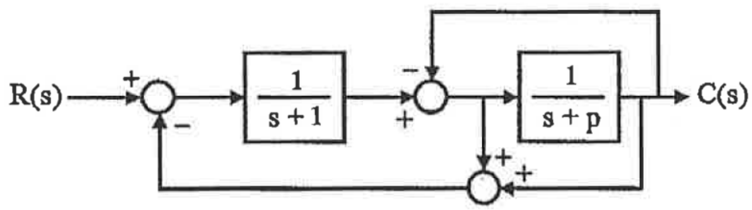
(b) Asymptotically stable

(c) Unstable

(d) Marginally stable

(e) None of the above

4. What should be the range of **p** for having a stable system in the following block diagram? **[2]**



(a) $p > 0$

(b) $p > -1$

(c) $-3 < p < -1$

(d) $-3 < p < 1$

(e) None of the above

5. A system has the following closed loop transfer function. For unit step input, the settling time for 2% tolerance band is? **[2]**

$$\frac{C(s)}{R(s)} = \frac{4}{s^2 + 1.6s + 4}$$

(a) 1.6

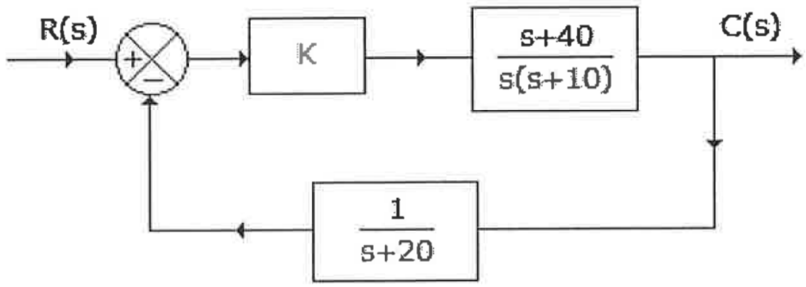
(b) 2.5

(c) 4

(d) 5

(e) None of the above

6. For the system in the given figure $R(s)=\frac{1}{s}$. Then steady state error is? **[2]**



(a) $\frac{1}{1+K}$

(b) K

(c) Zero

(d) 1

(e) None of the above

7. Find the steady state error for a system with closed loop transfer function

$T\ (s)=\frac{4\ (s+1)}{s^3+2s^2+4s+4}$ with respect to input signal $r(t)=\left(3-t+\frac{t^2}{4}\right)u(t)$. **[2]**

(a) 0

(b) $\frac{1}{2}$

(c) $\frac{1}{4}$

(d) $\frac{1}{8}$

(e) None of the above

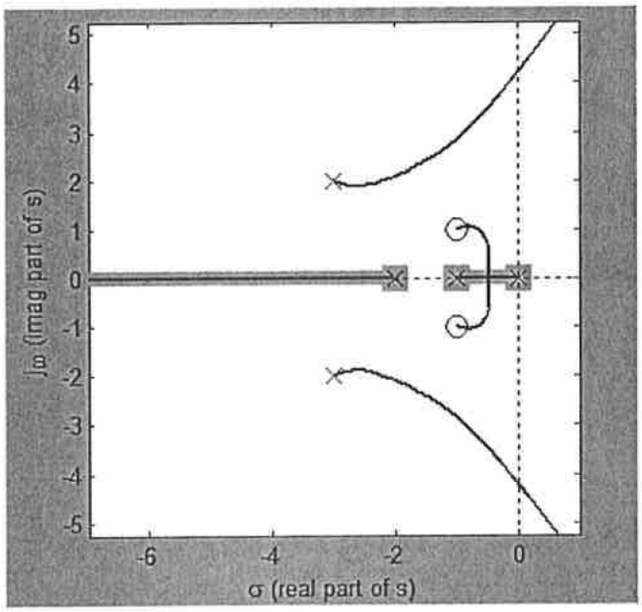
8. Which one of the following is not the property of root locus? **[1]**

- **(a)** They start from the open loop poles and terminate at the open loop zeroes
- **(b)** The root locus is symmetrical about imaginary axis
- **(c)** The breakaway points are determined from dK/ds = 0
- **(d)** Segments of the real axis are the part of the root locus if and only is the total number of real poles and zeroes to their right is odd.
- **(e)** None of the above

9. If the gain of the system is reduced to a zero value, the roots of the system in the s-plane? **[1]**

- **(a)** Coincide with zero
- **(b)** Move away from zero
- **(c)** Move away from poles
- **(d)** Coincide with the poles
- **(e)** None of the above

10. How many closed loop poles does the following graph include? **[2]**



- **(a)** 5
- **(b)** 7
- **(c)** 8
- **(d)** Infinite number
- **(e)** None of the above

11. **Assertion (A):** When the performance of a stable second order system is improved by a PID controller, the system may become unstable.

Reason (R): PID controller increases the order of the system to 3. **[1]**

- **(a)** Both A and R are correct and R is correct explanation of A
- **(b)** Both A and R are correct but R is not correct explanation of A
- **(c)** A is correct but R is wrong
- **(d)** R is correct but A is wrong
- **(e)** None of the above

12. In P-I controller, what does an integral of a function compute? **[1]**

 (a) Density of curve

 (b) Area under the curve

 (c) Volume over the curve

 (d) Circumference of curve

 (e) None of the above

13. Consider the following statements

 1) The effect of feedback is to reduce system error
 2) Feedback increases the system gain at one frequency but reduces the system gain as another frequency
 3) Feedback can cause an originally stable system to become unstable

Which of the above statements are correct? **[1]**

 (a) 1, 2, 3

 (b) 1, 2

 (c) 2, 3

 (d) 1, 3

 (e) None of the above

14. If the phase angle at gain crossover frequency is estimated to be -105°, what will be the value of phase margin of the system? **[1]**

 (a) 23°

 (b) 45°

 (c) 60°

 (d) 75°

 (e) None of the above

15. For an under-damped system, the resonant frequency peak in the Bode magnitude plot **[1]**

- **(a)** Increases by decreasing the damping ratio
- **(b)** Increases by increasing the damping ratio
- **(c)** Is independent of the change in damping ratio
- **(d)** Both a and b
- **(e)** None of the above

16. In frequency response, the resonance frequency is basically a measure of _______ of response. [1]

- **(a)** Speed
- **(b)** Distance
- **(c)** Angle
- **(d)** Curvature
- **(e)** None of the above

17. The open loop transfer function of a unit feedback system is $\frac{K}{s(Js+F)}$. If the frequency at the intersection of - 40 dB/decade line and 0 dB line is ω, then? **[1]**

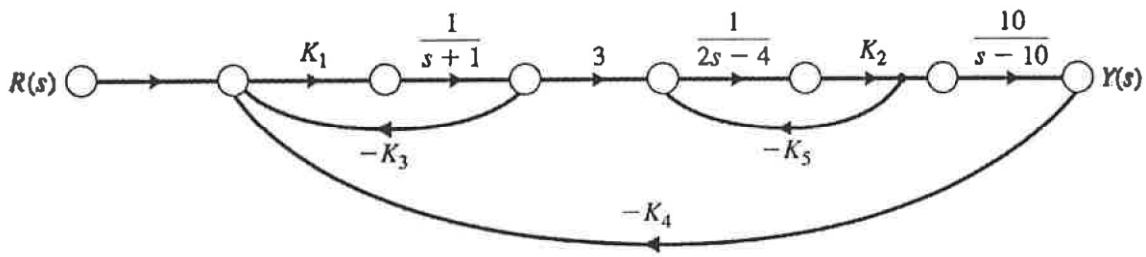
- **(a)** $\omega = \frac{K}{J}$
- **(b)** $\omega^2 = \frac{K}{J}$
- **(c)** $\omega^3 = \frac{K}{J}$
- **(d)** $\omega^4 = \frac{K}{J}$
- **(e)** None of the above

18. The frequency response of a system can be plotted using **[1]**

- **(a)** Bode plot
- **(b)** Nyquist plot
- **(c)** Polar plot
- **(d)** Both a and b
- **(e)** None of the above

Question 3 [25].

1. Consider the following signal flow graph and obtain loop gains, forward path gain(s), Non-touching loops gains, and use Mason's rule to obtain the transfer function Y(s)/R(s). **[5]**



2. A unity feedback system with loop gain $G(s)=\dfrac{10}{s(s+10)(s+20)}$ is to be controlled with a PD controller. The desired poles of the system were calculated to be $s=-12.78\pm j24.94$.

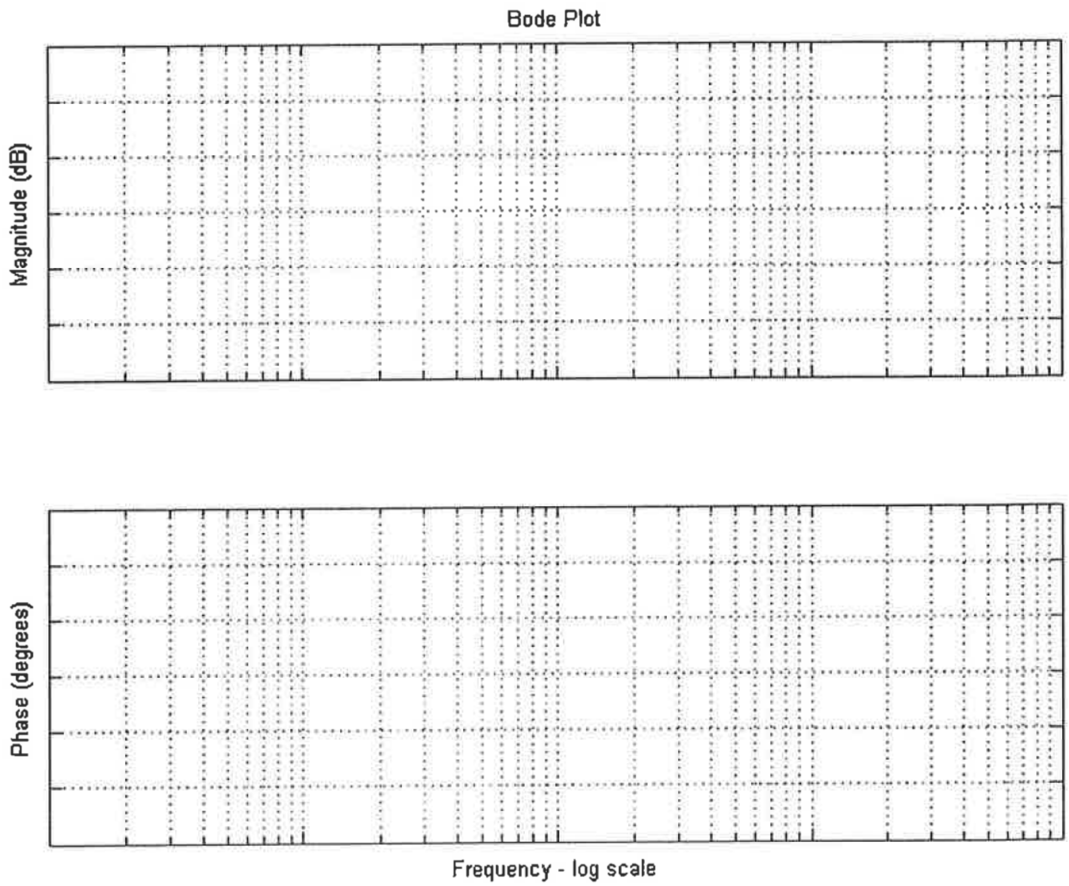
The goal is to find the location of the zero of the PD controller to achieve the desired poles (shown above).

a) Calculate the summation of the angles from the open loop poles to the design point.
b) Calculate the zero angle contribution.
c) Find the location of the zero for PD controller (do not need to calculate *K* value). **[20]**

Question 4 [25].

1. For the system shown with the following TF, $G(s) = \frac{24}{s(s+2)(s+6)}$

(a) Sketch magnitude and phase plots of overall Bode diagram.
(b) What would be the maximum gain (K) to keep the system stable? **[15]**



2. For a system with transfer function of $G(s) = \frac{K(s^2+5)(s^2-3)}{(s^2+6)(s^2-4)}$, plot a possible root locus $K < 0$ **[10]**.

Question 5 [25].

The closed-loop vehicle response in stopping a train depends on the train's dynamics and the driver, who is an integral part of the feedback loop. In the bellow Figure, let the input be $R(s) = v_r$ the reference velocity, and the output $C(s) = v$, the actual vehicle velocity. (Yamazaki, 2008) shows that such dynamics can be modeled by $G(s) = G_d(s)G_t(s)$ where

$$G_d(s) = h\left(1+\frac{K}{s}\right)\frac{s-\frac{L}{2}}{s+\frac{L}{2}}$$

represents the driver dynamics with h, K, and L parameters particular to each individual driver. We assume here that $h = 0.003$ and L = 1. The train dynamics are given by

$$G_t(s) = \frac{k_b f K_p}{M(1+k_e)s(\tau s+1)}$$

where $M = 8000$ kg, the vehicle mass; $k_e = 0.1$ the inertial coefficient; $K_b = 142.5$, the brake gain; $K_p = 47.5$, the pressure gain; $\tau = 1.2$ sec, a time constant; and $f = 0.24$, the normal friction coefficient.

(a) Make a root locus plot of the system as a function of the driver parameter K.
(b) Discuss why this model may not be an accurate description of a real driver-train situation.

Inverse Laplace Transforms	
$F(s)$	$f(t)$
$\dfrac{A}{s+\alpha}$	$Ae^{-\alpha t}$
$\dfrac{C+jD}{s+\alpha+j\beta}+\dfrac{C-jD}{s+\alpha-j\beta}$	$2e^{-\alpha t}\left(C\cos\beta t+D\sin\beta t\right)$
$\dfrac{A}{(s+\alpha)^{n+1}}$	$\dfrac{At^{n}e^{-\alpha t}}{n!}$
$\dfrac{C+jD}{(s+\alpha+j\beta)^{n+1}}+\dfrac{C-jD}{(s+\alpha-j\beta)^{n+1}}$	$\dfrac{2t^{n}e^{-\alpha t}}{n!}\left(C\cos\beta t+D\sin\beta t\right)$

Table of Laplace and z-Transforms (*h* denotes the sample period)		
$f(t)$	$F(s)$	$F(z)$
unit impulse	1	1
unit step	$\frac{1}{s}$	$\frac{hz}{z-1}$
$e^{-\alpha t}$	$\frac{1}{s+\alpha}$	$\frac{z}{z-e^{-\alpha h}}$
t	$\frac{1}{s^2}$	$\frac{hz}{(z-1)^2}$
$\cos \beta t$	$\frac{s}{s^2+\beta^2}$	$\frac{z(z-\cos \beta h)}{z^2-2z\cos \beta h+1}$
$\sin \beta t$	$\frac{\beta}{s^2+\beta^2}$	$\frac{z\sin \beta h}{z^2-2z\cos \beta h+1}$
$e^{-\alpha t}\cos \beta t$	$\frac{s+\alpha}{(s+\alpha)^2+\beta^2}$	$\frac{z(z-e^{-\alpha h}\cos \beta h)}{z^2-2ze^{-\alpha h}\cos \beta h+e^{-2\alpha h}}$
$e^{-\alpha t}\sin \beta t$	$\frac{\beta}{(s+\alpha)^2+\beta^2}$	$\frac{ze^{-\alpha h}\sin \beta h}{z^2-2ze^{-\alpha h}\cos \beta h+e^{-2\alpha h}}$
$t\,f(t)$	$-\frac{dF(s)}{ds}$	$-zh\frac{dF(z)}{dz}$
$e^{-\alpha t}f(t)$	$F(s+\alpha)$	$F(ze^{\alpha h})$