

Question 6
Correct
Marked out of

1.00

The sinusoidal input describing function of a static nonlinearity depends on the magnitude of the sinusoidal-input signal.

Select one:

True

The correct answer is 'True'

Information

## (use Matlab/Simulink -- total of following questions: 13 pts)

One considers a double-interator plant  $\ddot{\theta}=u_s$ . The control signal  $u_s$  is delivered by a first-order actuator with a time-constant  $\tau=0.1$  s. A rate-limitation is introduced in this actuator via a standard amplitude saturation placed before the integrator. The limited amplitude is fixed to L=0.5. A proportional derivative control law  $u_c=k_p(\theta_c-\theta)-k_d\dot{\theta}$  is used to stabilize the system. It is assumed that both  $\theta$  and  $\dot{\theta}$  are available for feedback.

In the following, the proportional gain  $k_p$  is fixed to  $k_p = 1$ 

## Question 7 Correct Marked out of

2.00

Compute the smallest value of  $k_d$  with only **one digit after the decimal point** which ensures (without saturation) that the closed-loop system is dominated by a well-damped second-order behaviour with damping  $\xi > 0.75$ .

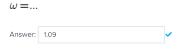
 $k_d = x\,x\,x, x \hbox{\tt [?][?]} o\,r \hbox{\tt [?][?]} x\,x, x \hbox{\tt [?][?]} o\,r \hbox{\tt [?][?]} x, x$ 



The correct answer is: 1.5



What is the corresponding pulsation (rad/s) of the second-order mode that you have placed?



The correct answer is: 1.09

Information

## In the following, the gain is fixed to $k_d = 1.5$ .

Check with time-domain simulations that the system behaves well in the presence of saturation with step input  $\theta_c = 1$ . However, oscillation starts to appear with  $\theta_c \ge 1.5$ . Characterize the amplitude, the pulsation (rad/s) and the nature of this oscillation:





The correct answer is: 11.4

Correct Marked out of 1.00	$\omega_{LC_{SIM}}$ =
	Answer: 0.91
	The correct answer is: 0.92
Question 11 Correct Marked out of	This corresponds to a <b>unstable limit-cycle</b>
1.00	Select one:
	® True ✓
	○ False
	The correct answer is 'True'.
Information	
	Compare the above results with the describing function technique and compute the pulsation and magnitude obtained by this method considering that the equivalent gain of the saturation can be approximated by that of a relay operator.
Question 12 Correct Marked out of 1.00	$x_{LC_{DF}} = \dots$ Answer: 9.5493
	The correct answer is: 9.55
Question 13 Correct Marked out of 1.00	$\omega_{LC_{DF}}$ =
	Answer: 1
	The correct answer is: 1

To improve the behavior of the system, a **dynamic anti-windup** device is introduced. The control law is then modified as follows:

$$u_c = k_p(\theta_c - \theta) - k_d \dot{\theta} - F(s)\epsilon_{aw}$$

with

$$F(s) = \frac{1}{s+1}$$

As usual, the signal  $\epsilon_{aw}$  is obtained as  $\epsilon_{aw} = v - w$  where v and w respectively denote the input and output of the amplitude saturation.

Using simulations, check that the new closed-loop system remains stable for step inputs of increased magnitude  $\theta_c$  and determine experimentally the critical value  $\theta_c^*$  for which a limit-cycle appears. Determine also the characteristics of this limit-cycle. Note that for this particular case, the anti-windup device leads to a reduced size limit-cycle.

Question 14	
Correct	
Marked out of	

$$x_{LC_{SIM}} = \dots$$
Answer: 3.72

Question 15 Correct Marked out of 1.00	$\omega_{LC_{SIM}}$ =  Answer: 0.6327
	The correct answer is: 0.61
Question 16 Correct Marked out of 1.00	The limit-cycle is unstable  Select one:  True   False
	The correct answer is 'True'.
Information	Check the above results with the describing function technique and compute the pulsation and magnitude obtained by this method:
Question 17 Correct Marked out of 1.00	$x_{LC_{DF}}$ =
	The correct answer is: 3.29
Question 18 Correct Marked out of 1.00	$\omega_{LC_{DF}}$ =  Answer: 0.6633
	The correct answer is: 0.66